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PREFACE

This book presents the conference proceedings of the International Practical Internet Conference "Challenges of Science" held by the Institute of Metallurgy and Ore Beneficiation JSC, a non-public joint-stock company Satbayev University in Almaty, the Republic of Kazakhstan, on 15 November 2023 for the sixth time.

Researchers exchange their scientific achievements and insights on the challenges of the development of sciences, both from academia and the industry. Results are reflected in the articles published here, allowing a real exchange of ideas and personal views as an expert. Conference materials are indexed by DOI - CrossRef (USA), e-libray.ru (Russia), and a directory of open access to scholarly resources via ISSN 2707-9481 (ROAD, France) and other research digital networks. ROAD, with support from the UNESCO Communications and Information Sector, provides free access licensed under Creative Commons to all conference materials worldwide.

This conference can only succeed as a team effort, so the editors want to thank the international scientific committees, the Organizing committee members and the reviewers for their valuable advice. Especially, Muhammad Noorazlan Abd Azis – Dr., Professor of Sultan Idris Education University (Perak, Malaysia), Dr., Professor El-Sayed Negim (Egypt) and Professor Heri Retnawati from Yogyakarta State University (Universitas Negeri Yogyakarta, Indonesia) made a great effort to research contribution this year. We want to take this opportunity to thank all of our reviewers who provided insightful feedback to select the best articles. We are sure that publications in this book will stimulate both theoretical and practical, basis and will greatly advance our knowledge and capability in future scientific projects.

We hope for further fruitful cooperation. On behalf of the organizing committees, I extend my warmest welcome to all of you to take part in the next issue in 2024. This conference is planned to be held annually and has an open call proposal for developing this scientific project. Short proposals should be sent to conference@kims-imio.kz for more information.

Prof., Dr. **Bagdaulet Kenzhaliyev**
Chief-in editor
On behalf of the organizing Committees
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Guldana A. Begimbetova
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: begimbetovaguldana227@gmail.com
ORCID ID: https://orcid.org/0000-0002-0435-1014

Akmarzhan A. Nogaibayeva
Suleyman Demirel University, Almaty district, Karasay region 040900, Kaskelen city, Abylai khan street, 1/1, Kazakhstan. ORCID ID: https://orcid.org/0000-0001-9121-7595, E-mail: a.nogaibayeva@sdu.edu.kz

Heri Retnawati
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: heri_retnawati@uny.ac.id,
https://orcid.org/0000-0002-1792-5873

Dinara B. Sansyzbayeva
Manash Kozybayev North-Kazakhstan University; Abai Kazakh National Pedagogical University
Kazakhstan. E-mail: dinnar-a@mail.ru
https://orcid.org/0000-0001-5607-6942

Mochamad Bruri Triyono
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: bruritriyono@uny.ac.id
https://orcid.org/0000-0001-5720-9604

Bibliometric Analysis of Research Related to Digital Literacy Using the Scopus Database from 2017-2023

Abstract: This research aimed to carry out a bibliometric analysis of research related to digital literacy using the Scopus-indexed articles database which was published from 2017-2023. To collect data, the author used a document Analysis or documentation instrument, and a sample of collected 665 articles from the Scopus publications was obtained through the application of the saturated sampling technique. The data were analyzed through the R Program Biblioshiny package. The first finding is that a steady rate of publications in the field of digital literacy was observed from 2017 (68 articles) up to 2022 (131 articles). The second finding is that keywords like "e-learning", "digital literacies", and "students" have higher bibliographical coupling indexes of 29, 26, and 23 respectively. For the third finding, the concepts of "e-learning" and "information literacy" are very important terms within their network. Besides, authors whose works had had much attention have included "e-learning", "digital storage," "computer science", "digital environment", "education", "curricula", and "students" in their words. Based on these findings, the main recommendation is for researchers to make further investigations in order to discover why works including the keywords like "e-learning", "digital literacies", and "students" are mostly cited.

Keywords: digital literacy, bibliometric, e-learning, bibliographical coupling, information literacy, students.

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Introduction

The ultimate purpose of research is to discover, develop a tool, and bring in new information or knowledge that eases or develops science, technology, and human coherence (Fatihudin and Holisin, 2011: 4). This explains the common question researchers put to themselves: "how was this topic addressed by others?" There is no common path to bring such novelty though. What is undeniable is how data gathering and related analysis is crucial to the research findings (Medeiros, et al., 2018).

Digital literacy is a topic that was addressed by researchers in different areas. One area of interest for researchers is the impact of digital literacy on education. With the increasing use of technology in the

classroom, digital literacy has become an essential skill for students. A study by Van Deursen and Van Dijk (2014) found that students who were more digitally literate had higher academic performance and were more engaged in their studies. This suggests that digital literacy can be an important factor in academic success. Some researchers tackled the aspect of how digital literacy is going to affect the future of teachers' training (Begimbetova et al., 2022).

Digital literacy is becoming increasingly important in today's society, as technology continues to play a pivotal role in our daily lives (Arlinwibowo et al., 2020; Kassymova, 2018; Sheriyev et al., 2016). According to a study by Hargittai and Hsieh (2013), digital literacy is the ability to access, evaluate, and use digital information effectively. Digital literacy encompasses a wide range of skills, including the ability to navigate digital technologies, critically evaluate digital information, and communicate effectively using digital tools.

One important aspect of digital literacy is the ability to navigate digital technologies. As noted by Hargittai and Hsieh (ibid), individuals with higher levels of digital literacy are better able to navigate digital technologies and use them to their advantage. This includes using search engines to find information, using social media to connect with others, and using productivity tools to improve work efficiency.

Another key aspect of digital literacy is the ability to critically evaluate digital information. As noted by Lankshear and Knobel (2011), individuals with higher levels of digital literacy are better equipped to critically evaluate the quality and reliability of digital information. This includes assessing the credibility of sources, identifying biases and inaccuracies, and distinguishing between fact and opinion.

On top of that, digital literacy also includes the ability to communicate effectively using digital tools. This includes using email, instant messaging, video conferencing, and other digital communication tools to connect with others. As noted by Warschauer (2023), individuals with higher levels of digital literacy are better able to communicate effectively using digital tools and can leverage these tools to expand their social and professional networks.

Another area of interest for researchers is the relationship between digital literacy and social inequality. Some researchers argue that the digital divide, or the gap between those who have access to technology and those who do not, can lead to social inequality. A study by Warschauer and Matuchniak (2010) found that students from lower-income families had less access to technology and were less digitally literate than their wealthier peers. This suggests that digital literacy can play a role in perpetuating social inequality and that efforts should be made to bridge the digital divide.

Digital literacy becomes very interesting as some are doing well by accommodating it while others do not. This creates a digital divide addressed by Pluye, El Sherif, Bartlett, Granikov, Grad, Doray, Lagarde, Loignon, and Bouthillier (2018). This divide is likely to continue given the other factors affecting the mastery of digital literacy. The divide was mostly even during the lockdowns caused by Covid-19, (Azizah et al., 2021); some teachers struggled while others coped well with teaching online (Ndayizeye, 2021).

While researching the effect of digital literacy skills on virtual lectures during covid-19, Sukarno and Widdah (2020) found that digital literacy skills highly correlated with the learning of the "Methods and Strategy on Physic Learning" class. Digital literacy is not going anywhere then, rather researchers project that it will be heightening educational transformation. Recent work in Mexico defended how higher education is going to go through a stream of transformation thanks to a wave of digital literacy mastery among lecturers (Okoye et al., 2022).

Internet use, together with related skills, may have negative effects as distractors of learning. But when parents give support to their children, the student's digital literacy skills are well exploited (Gruchel et al., 2022).

Overall, digital literacy is a complex and multifaceted concept that encompasses a wide range of skills and abilities. As noted by various scholars aforementioned, individuals with higher levels of digital literacy are better equipped to navigate digital technologies, critically evaluate digital information, and communicate effectively using digital tools. As technology continues to play an increasingly important role in our daily lives, digital literacy will become an increasingly important skill set for individuals to possess. The aim of the research

The research questions:

1. What is the current state of research related to digital literacy, based on bibliometric analysis of the Scopus database from 2017-2023?

2. Which fields have shown the greatest interest in research related to digital literacy over the past five years, based on bibliometric analysis of the Scopus database?
3. How can bibliometric analysis, in co-occurrence networks and factorial analysis, provide insights into research related to digital literacy?

Research objectives:

1. To conduct a bibliometric analysis of the Scopus database from 2017-2023 in order to determine the current state of research related to digital literacy;
2. To identify the fields that have shown the greatest interest in research related to digital literacy over the past five years through bibliometric analysis of the Scopus database;
   To investigate how bibliometric analysis techniques, such as co-occurrence networks and factorial analysis, can provide insights into research related to digital literacy.

Research Methods

Research Design: This is an ex-post facto research that uses secondary data from the Scopus-indexed journal article in the area of digital literacy.

Data Source: Scopus-indexed journal articles related to digital literacy.

Data collection instruments: Document Analysis or documentation instrument was used to collect 665 articles from the Scopus publications.

Sampling methods and techniques: In this research, the investigator used the probability sampling method. As far as the sampling technique is concerned, the researcher used the saturated sampling technique (Sugiyono, 2015).

Data Analysis Techniques: The researcher used the R program, especially the "bibliometric" package that she ran in the biblioshiny interface; henceforth the choice of this article's title as a bibliometric analysis.

Research Results

To display the findings in the research, the researcher dimmed it right to show them based on some of the categories or biblioshiny indices. These include the general or main information, free-field plot, and co-occurrence network.

Main information

Based on Figure 1, this study covers the period from 2017 to 2023 and involved 1527 authors conducting research on digital literacy using 2078-related keywords. The research analyzed 665 articles from various sources, including books and journals, selected based on their discussion of digital literacy fields or aspects. Among the 665 articles analyzed, 168 were single-authored works. The study referenced 29976 sources, with an average document age of 3.01 years. The average number of co-authors per article was 2.56, suggesting significant collaboration among researchers. The research achieved an average of 9.633 citations per article, indicating that it was highly regarded by other scholars in the field. The visualization of the information aforementioned can be seen in Figure 1 below:

Figure 1. Main Information

The annual scientific production in areas related to digital literacy can be seen in the Figure 2 below:

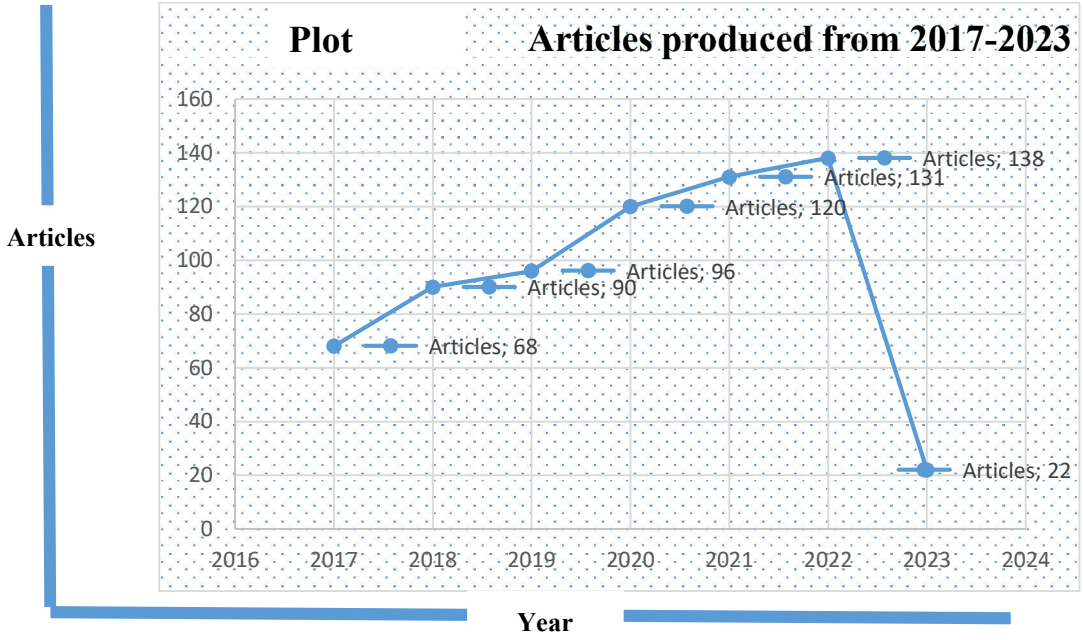

Figure 2. Annual Scientific Production around the "digital literacy" Keyword

Figure 2 describes the number of articles published each year from 2017 to 2023. The number of articles published has increased steadily each year, from 68 articles in 2017 to 138 articles in 2022. The peak is in 2022 whereby the amount climaxed to 138 articles. Even in the year 2023, there are 22 articles published so far.

The increase in the number of articles published over time suggests that the field or discipline related to digital literacy is growing. It may also indicate an increasing interest in the topic among researchers and practitioners.

It is important to note that the number of articles published does not necessarily reflect the quality of the research or the impact of the work. However, it can provide an indication of the level of activity, interest, and collaboration in this field of digital literacy.

Three-field Plot (Sankey diagram): The three-field Plot (Sankey diagram) saves a visualization tool. It shows the flow of research in different countries or regions. As a scatter plot, there are three variables in its display interface: the total number of publications; the citation impact, and the international collaboration rate. In this research, the author tracked the use of the keywords like digital/media literacies, digital literacies, information literacy, new literacies (digital/media) literacies, and media literacy.

Table 1. Keywords and Number of collaborations involved

No	Keyword	Number of international collaboration rate
1	digital/media literacies	13.0
2	digital literacies	9.0
3	information literacy	8.0
4	new literacies (digital/media) literacies	8.0
5	media literacy	1.0

On the other hand, as you can see, Table 1 shows that the keyword "digital/media literacies" has the highest international collaboration rate of 13.0. This indicates that research in this area is often conducted collaboratively across different countries. The keyword "digital literacies" has an international collaboration rate of 9.0, which is also quite high.

On the other hand, the keyword "information literacy" has an international collaboration rate of 8.0. Similarly, "new literacies (digital/media) literacies" also has a collaboration rate of 8.0. The keyword "media literacy" has a relatively low collaboration rate of 1.0. This may be an indication that research in this area is less likely to be conducted collaboratively across different countries.

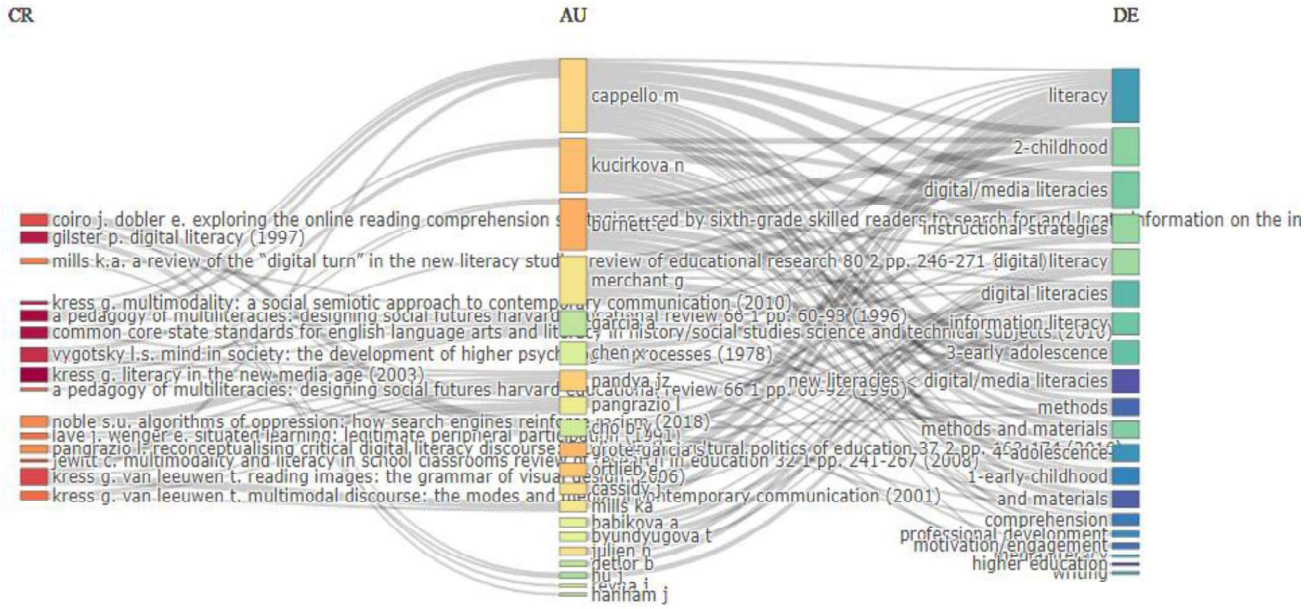

Figure 3. Three-field Plot (Sankey diagram)

Keywords within the body of digital literacy literature from 2017-2023: In this study, we take co-occurrence analysis as a type of network analysis that aims to identify relationships between keywords, terms, or concepts within a body of digital literacy literature from 2017-2023. It involves the action of identifying the frequency with which two or more keywords appear together in a set of articles related to our main keyword "digital literacy." Below is a co-occurrence Network plot:

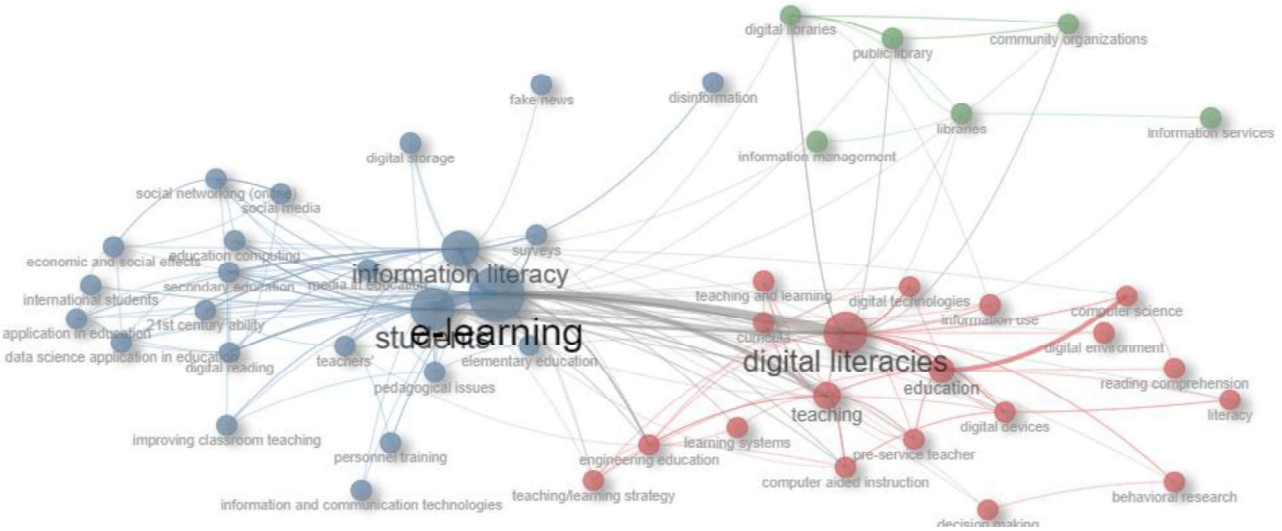

Figure 4. Keywords Co-occurrence Network plot

Table 2 represents the centrality measures of a network composed of different nodes related to digital literacy. Below are four columns and here is the interpretation for each:

Node: the name of the node in the network.

Cluster: the community (or cluster) to which the node belongs.

***Betweenness*:** a measure of how important a node is in connecting other nodes in the network.

Closeness: a measure of how close a node is to other nodes in the network.

Table 2. Centrality measures

Node	Cluster	Betweenness	Closeness	PageRank
digital literacies	1	**194.66**	0.01	0.07
education	1	56.47	0.01	0.04
teaching	1	23.08	0.01	0.04
digital devices	1	7.54	0.01	0.02
computer science	1	7.91	0.01	0.02
information literacy	2	**195.39**	0.01	0.07
e-learning	2	**444.26**	0.02	0.12
media in education	2	3.16	0.01	0.02
education computing	2	0.41	0.01	0.02
digital libraries	3	2.83	0.01	0.02
information management	3	1.87	0.01	0.01
libraries	3	7.94	0.01	0.02
public library	3	1.75	0.01	0.02

***Page Rank*:** a measure of the importance of a node based on the idea that important nodes are linked to other important nodes.

From the table, we can see that nodes in the same cluster tend to have similar centrality measures. Note that centrality refers to the importance of a node (keyword or concept) within the network, Gómez (2019). So, a comment that can be made on the clusters in our bibliometric study is that:

Cluster 1 (digital literacies, education, teaching, digital devices, and computer science) has relatively low centrality scores compared to the other clusters.

Cluster 2 has two nodes with very high centrality scores: e-learning and information literacy. These nodes are important in connecting other nodes in the network and are also important nodes that are linked to other important nodes.

Cluster 3 contains digital libraries, information management, libraries, and public library, which all have low centrality scores. These nodes are less important in connecting other nodes in the network, and they are not linked to other important nodes as frequently.

Bibliographical Coupling: The thematic map below has eight clusters. Considering the author's keywords, niche topics within the realm of digital literacy encompass human-computer interaction, decision-making, fake news, and semi-structured interviews. Currently, there are no noticeable trends indicating emerging or declining themes in this area. However, the fundamental themes can be classified into behavioral research, digital devices, digital technologies, education, computer science, and surveys. Lastly, the motor theme cluster comprises e-learning, digital literacies, and students.

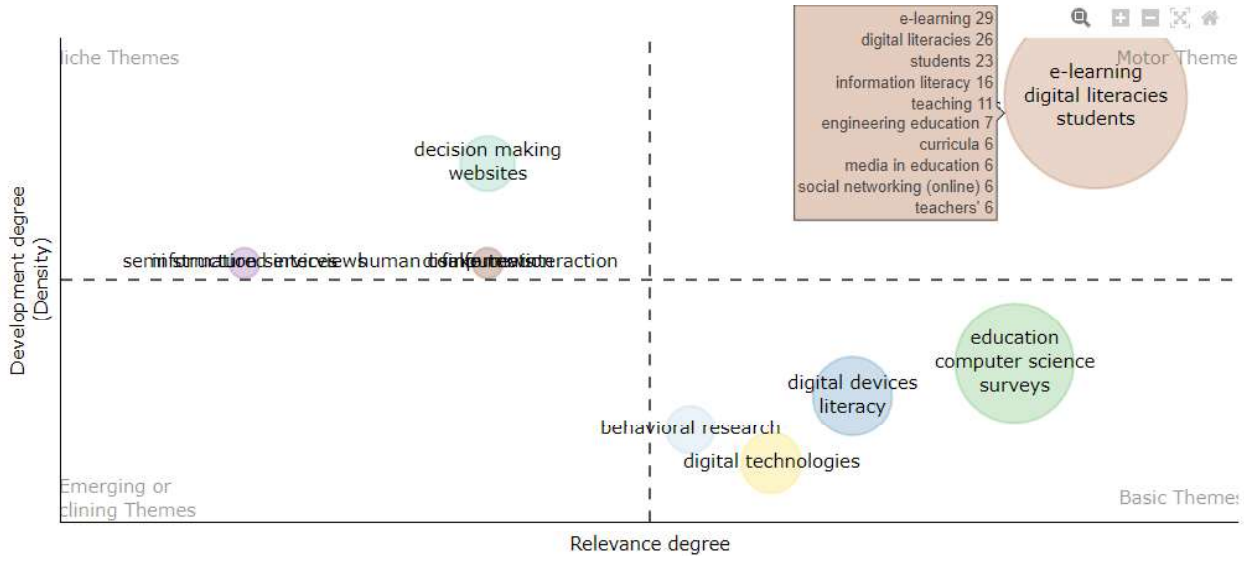

Figure 5. Thematic Map

Something particular about that motor theme cluster is the fact that the bibliographical coupling index amounted to 29, 26, and 23 respectively for e-learning, digital literacies, and student keywords.

Data involving the digital literacy keyword have a large number of variables such as author names, publication titles, keywords, and citation counts. To reduce the complexity of interpreting results, a factorial analysis is worth doing. Note that factorial analysis was used in our bibliometric analysis as a statistical technique to identify patterns and relationships among multiple variables in our digital literacy Scopus-indexed articles dataset.

The following map resulted from the factorial analysis of digital literacy-related keywords: When related parameters were applied to include keywords related to the 'digital literacy' field, there was an automatic clustering and the maximum number of terms was 55. Then the researcher applied factorial analysis as a statistical method to identify a smaller number of underlying variables (Figure 6).

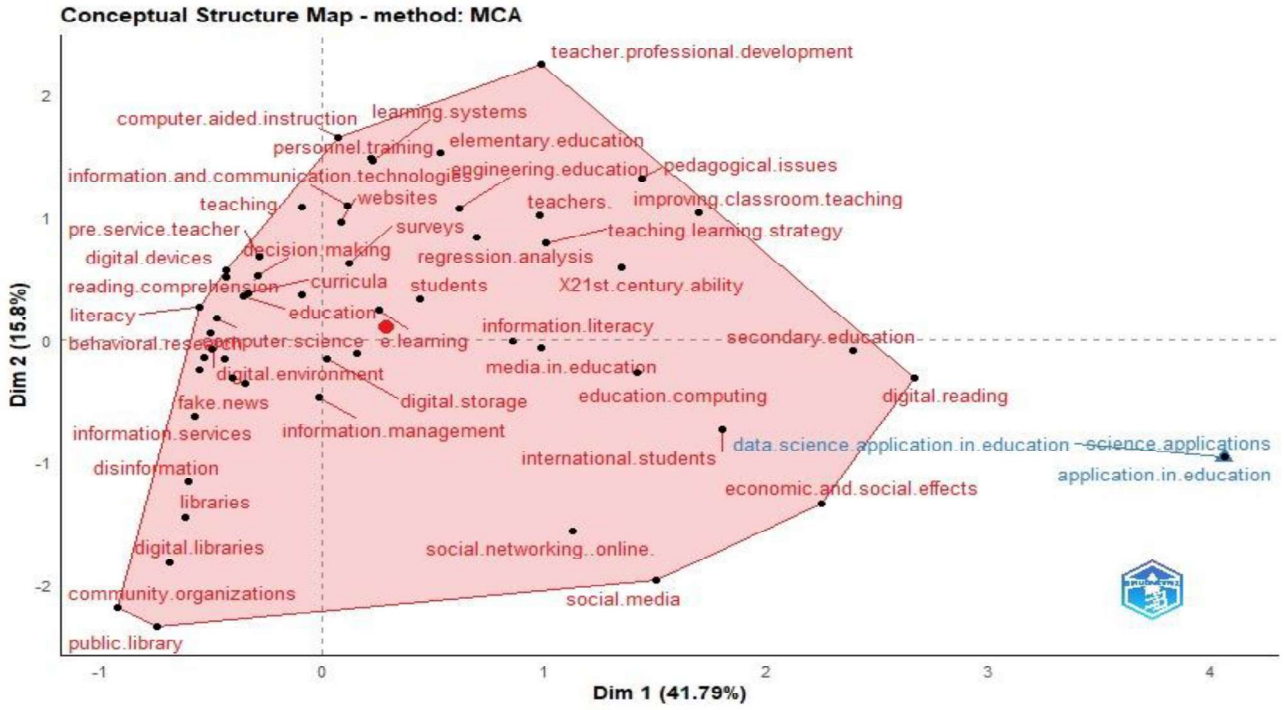

Figure 6. Factorial Analysis

The conceptual structure map that results from such a factorial analysis has two dimensions (Dim.1 and Dim.2), each with positive and lower values:

In dimension 1, keywords located in the positive area (positive values) imply that there is a lot of scholarly output related to them. Keywords that can be listed here are e-learning, information literacy, X21st century ability, teacher professional development, teaching, students, pedagogical issues, and teaching-learning strategies.

Conversely, the lower positive area in dimension 1 signifies that there has been less productivity about keywords in there. Researchers are prolific about these particular keywords. In this study, one can list: digital storage, information management, media in education, international students, digital reading, social networking online, social media, economic, social effects, and data science application in education

In dimension 2, the keywords in the positive areas show the quality (depth) or high impact the scholarly activities have been. Such positive values can also imply a high number of citations these keywords get. High-quality scholarly output has been around keywords like computer science, literacy, education, curricula, digital devices, teaching, and computer-aided instruction.

The lower values in dimension 2 refer to low-quality or low-impact scholarly output gets. Keywords in this area are digital environment, fake news, disinformation, libraries, digital libraries, community organizations, and public libraries. The more a keyword/value approaches the center (for example e-learning our study), the closer the attention it received in recent years (Kassymova et al., 2021**)**.

Discussion of Research Results

Under this section, the researcher positions her findings in the middle of other academics' bibliometric analysis research findings in the field of bibliometric analysis as applied to digital literacy. All is done by keeping track of the research questions in the study.

The first research question reads as:

1. What is the current state of research related to digital literacy, based on bibliometric analysis of the Scopus database from 2017-2023?

The finding is that the number of articles published has increased steadily each year, from 68 articles in 2017 to 138 articles in 2022. The peak is in 2022 whereby the amount climaxed to 138 articles. This simply indicated how increasing research about digital literacy is becoming. This finding resonates with Hicks et al. (2022) findings. In their research, they showed how to leverage information literacy and appropriate it in other disciplinary landscapes. Their findings were that professional fields were leveraging information literacy, including in areas where librarians are.

The results suggest a steady rate of publication in this field, with most of the research published in education and library fields, (Baber et al., 2022).

The researchers applied a systematic literature review method to the dataset. The preliminary findings demonstrated that there is a growing prevalence of digital literacy articles starting from the year 2013-2023, (Tinmaz and Fanea-Ivanovici, 2022).

For the aspect of digital literacy with the greatest interest, the related research finding is:

2. Which fields have shown the greatest interest in research related to digital literacy over the past five years, based on bibliometric analysis of the Scopus database?

To gather insights leading to a related finding, two indexes can illuminate our views:

- the number of articles published around the digital literacy keyword;
- the bibliographical coupling, that is, when two or more authors reference the same work.

The fact that the number of the sampled Scopus-indexed articles related to digital literacy aspects increased steadily, that is, 68 in 2017 and 138 in 2022 means that this discipline is interesting to researchers. This is just a sample in which the researcher applied fixed filters, which means that there are many other articles related to literacy that were not analyzed due to the filters set. Besides, even though the number of articles published does not necessarily reflect the quality of the research or the impact of the work, such a number indicates an increasing interest in digital literacy-related fields or how such literacy is influencing other fields.

What is more, the bibliographical coupling indicates an increase in interest as well. Plot #5 is indicative. It is obvious that if two or more research works both cite one or more documents in common, there is a bibliographical coupling; they have the same interest. The more works are coupled bibliographically, the more their authors have an interest in the topics covered by the documents they cite.

The thematic map analysis indicated these bibliographical coupling and the keywords of interest. Note the motor theme cluster includes: e-learning, digital literacies, and students.

Something particular about that motor theme cluster is the fact that the bibliographical coupling index amounted to 29, 26, and 23 respectively for e-learning, digital literacies, and student keywords.

This finding echoes the one made in Parra, Nuñez, and Vergara (2023). In their work, they found out that terms like "Digital media literacies" and "teachers" were the main topic in the research field and the theme focused on teacher-oriented or teacher-focused digital media literacy.

In terms of co-occurrence networks, that is, identification of relationships between keywords/ terms/ or concepts within a body of digital literacy literature from 2017-2023, the related research question was formulated as follows:

3. How can bibliometric analysis, in co-occurrence networks and factorial analysis, provide insights into research related to digital literacy?

Co-occurrence in the context of this study means the frequency with which two or more keywords appear together in a set of articles related to our main keyword "digital literacy." Scrutiny of Cluster 2

reveals insights into the finding related to this research question: "e-learning" and "information literacy" nodes have the highest centrality scores. This means the two aforementioned nodes are very important keywords or concepts within their network, (see Figure 4). This finding is the opposite of what Aydin & Yildirim, (2022) found out in their research. For these two experts, the co-occurrence analysis indicated rather that concepts like "teachers' digital competence", "higher education studies", teacher training programs", and "ICT in education" were nodes with the highest centrality. This difference may be due to the filter these two studies used.

Surprisingly, the newest nodes found in our study like digital libraries were also a finding in Hicks et al. (2022). These authors observed that professional areas like libraries are leveraging information literacy.

Equally similar results are traceable in Samadbeik et al. (2022). They themselves sampled 241 articles on the digital divide and COVID-19 from the Scopus database between 2020 and 2021. The keywords co-occurrence analysis showed that four main clusters included keywords like: 'telemedicine', 'Internet access and Internet use', 'e-learning', and 'epidemiology'.

As far as factorial analysis is concerned below is the finding. Note that factorial analysis is a bibliometric analysis that uses statistical techniques to identify patterns and relationships among multiple variables in our digital literacy.

Results on factorial analysis reveal that authors whose works had much attention have included the following keywords in their articles: e-learning, digital storage, computer science, digital environment, education, curricula, and students (Begimbetova et al., 2023).

Conclusions and Research Recommendations

On the research question about the state of research related to digital literacy, the results suggest a steady rate of publication in this field, with most of the research published in education and library fields.

Research question 2 is related to the greatest interest in research in the digital literacy research field. The finding was insinuated through the bibliographical coupling indexes like 29, 26, and 23 respectively for e-learning, digital literacies, and students; these suggest a high research interest in digital literacy-related fields.

As far as research question 3 is concerned, keywords like "e-learning" and "information literacy" are very important terms or concepts within their network

What is more, the factorial analysis reveals that authors whose works had much attention have included the following keywords in their articles: e-learning, digital storage, computer science, digital environment, education, curricula, and students.

There is one main recommendation that can be made: further studies should illuminate the reason why the works that included keywords like "e-learning", "digital literacies", and "students" are mostly cited.

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D. Abutalip
Abai Kazakh National Pedagogical University, 050010, Dostyk ave., 13, Almaty, Kazakhstan. Email: abutalip.dnl@gmail.com

F.D. Pertiwi
Mulawarman University,
Jalan Kuaro Kotak Pos 1068, Indonesia
https://orcid.org/0000-0002-4604-3167
email: fdayaningp28@gmail.com

M. Yesbossyn
Suleyman Demirel University, 040900,
Abylai khan street, 1/1, Almaty, Kazakhstan
Email: meiramgul1017@gmail.com

S.B. Suleimen
Abai Kazakh National Pedagogical University
050010, Dostyk ave., 13, Almaty, Kazakhstan
E-mail: samalka___94@mail.ru

G.K. Kassymova
Abai Kazakh National Pedagogical University
050010, Dostyk ave., 13, Almaty, Kazakhstan
E-mail: zhaina.kassym@gmail.com

Career guidance for Generation Z: modern methods of professional orientation in a stress Period

Abstract: This article examines the importance of modern career guidance methods for Generation Z, focusing on the methods and tools used to create effective career guidance. The article examines the unique features of Generation Z and how they differ from previous generations and shows the need for individual approaches to professional orientation. It also discusses the advantages of using the Gallup Professional Orientation Test and the DISC personality test to determine individual professional orientation. Additionally, the authors examine Generation Z from a psychological point and found out that they feel stressed; anxious even in the classroom environment. Recently, many Z generation people are university students that suffer from speaking and sharing their points of view. Therefore, overall grades deteriorate noticeably. As a result, cognitive-behavioral therapy is the best method to cope with stress. Overall, this article contains valuable information for educators, career counselors, and professionals working with Gen Z to improve their professional development and future career prospects.

Keywords: Generation Z, career, test, CBT, stress, anxiety, speaking, students.

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Introduction

Career guidance is an important aspect of a person's life, especially for members of Generation Z. This article discusses the importance of career guidance for Generation Z and how modern career guidance approaches can help them make an informed career choice. This generation will make up a significant percentage of the workforce in the next decade. That is why it is very important to prepare them for the world of work through an effective professional orientation. Today's world is changing rapidly, and the demands of the labor market are changing with it.

Barlas (2018) studied the problems of Generation Z in the system of teacher and student and found out that Generation Z enters universities without professional orientation according to the national test outcomes. It is becoming more and more important to identify their strengths, interests, and abilities

in order to make an informed career choice. The vocational guidance process has also undergone significant changes with the introduction of modern methods. Moreover, language anxiety is one of the problems that is widely spread among Z-generation students and educators. Students who have entered the first year of the university usually feel anxious to answer the questions in the classroom (Kassymova et al., 2018), due to different levels of English. Therefore, speaking is one of the productive skills that hard to achieve fluency.

The purpose of this research *is* to study the formation of professional orientation for Generation Z using modern methods during their stress period.

Research methods

The study discusses the various ways, methods, and types of professional orientation work, the characteristics of Generation Z compared to other generations, as well as the advantages of using the Gallup professional orientation test (https://www.gallup.com/**cliftonstrengths**/en/home.aspx) and the DISC personality test (https://www.123test.com/disc-personality-test/) to determine professional orientation. This study also uses literature from various sources like journals, articles, books, and other documents.

Research results and discussions

Brief information about Generation Z: Table 1 shows different Western Cultural Generations according to Robinson (2023). Asia has its own generational definition based on major cultural, political, and economic influences (Robinson, 2023). Each generation based on history and economics has its own setbacks and difficulties over time. Asia's Gen Zers (2021) born between 1997 and 2012 are going to embrace a quarter of Asia-Pacific's population by 2025; they are expected increasingly make their presence felt in the global workforce (Asia's Gen Z, 2021).

Table 1. Different generations by years

Generation Name	Births Start	Births End
The Lost Generation The Generation of 1914	1890	1915
The Interbellum Generation	1901	1913
The Greatest Generation	1910	1924
The Silent Generation	1925	1945
Baby Boomer Generation	1946	1964
Generation X (Baby Bust)	1965	1979
Xennials	1975	1985
Millennials Generation Y, Gen Next	1980	1994
iGen / Gen Z (Gen Zers) or Zoomers	1995	2012
Gen Alpha	2013	2025

Having been born in the availability of Internet access and information communication technologies, Generation Zers or Zoomers as they are also called, are true digital natives. They spend their spare time much more on the Internet than on TV (Asia's Gen Z, 2021). The latest data from GWI (https://www.gwi.com/) shows that the typical global internet user now spends an average of almost 7 hours per day online (Simon, 2021), which means that humanity may be aware of stressful events in the lives of their friends or family. It may lead to the stress people have in their own lives (Keith Hampton, Lee Rainie, Weixu Lu, Inyoung Shin, and Kristen Purcell, 2015). Another study found that Gen Zers have no

memory of a world without the internet in comparison with the previous generations. Internet is an integral part of their life; almost half of Gen Zers spend 10 hours or more online per day, which means that they do not have time for face-to-face communication (Garnham, 2022).

Characteristic Gen Z based on Hadion Wijoyo, et al (2020): (1) They are the digital generation who are proficient and familiar with information technology and various computer applications. They will access information needed for educational and personal purposes quickly and easily; (2) They love and often communicate with all groups, especially through social networks such as Facebook, Twitter, or other social media platforms. Through this media they are freer to express what they feel and think spontaneously; (3) Tend to be tolerant of cultural differences and are very concerned about the environment; (4) Tend to be tolerant of cultural differences and are very concerned about the environment; (5) Accustomed to various activities at the same time. For example, reading, talking, watching, and listening to music at the same time. This is because they want everything to be fast-paced, and straightforward; (6) Tend to lack verbal communication, tend to be egocentric and individualistic, want instant results, impatience, and do not value the process.

Based on Dill (2015) through forbes.com write about Gen Z in North and South America, Africa, Europe, Asia, and the Middle East with the results that Gen Z is the first real global generation. High-tech in their blood, they have grown up in an uncertain and complex environment that dictates their views on work, learning, and the world. They have different expectations in their workplace, are career-oriented, an ambitious generation of professionals, possessing technical skills and language knowledge at a high level. Therefore, they are an excellent workforce (Arlinwibowo et al., 2020; Kassymova, 2018; Sheriyev et al., 2016; Pratama et al., 2022).

Generation Z needs a little more care of their mental health because they are coming into the workforce at a stressful time. A study of 1,226 Zoomers from Australia, China, Hong Kong, and Singapore shows 73% felt stressed highly due to the COVID-19 pandemic in workplaces; in addition, 57% of them complained about their worsened mental health (Asia's Gen Z, 2021). Research states that Generation Z is the most anxious generation to date. Anxiety is one of the most common mental illnesses worldwide (Facts & Statistics, 2023). The anxiety root cause is not only the pandemic COVID-19 but also unemployment, climate change, technology, online time, finances, current events, etc. among Generation Zers (Garnham, 2022).

The term "anxiety" or "language anxiety" has been described as an "alarming factor causing debilitating effects on foreign language learning process" (Nazeer et al, 2017) and "unease feeling, nervousness or a kind of fear due to individual's perception in learning" (Rajitha, 2019). Moreover, according to Horwitz et al (1986) "the anxious foreign language learner … experience apprehension, worry, even dread. They have difficulty concentrating, become forgetful, sweat, and have palpitations. They exhibit avoidance behavior such as missing class and postponing homework". Many researchers explore speaking anxiety and divide them into two categories: trait anxiety and state anxiety. The most common descriptions from research that has been done in this area were dry mouth, changing voice temper, fear, shaking, and unusual gestures. In contrast, some scholars have done research studies that clearly show a positive effect of language anxiety in the educational process to oblige students to gather their thoughts. Therefore, Suleimenova (2013) claimed that anxiety in speaking a foreign language has a positive effect to lead students with anxiety to give concrete answers.

Another main source of anxiety comes from students' characteristics of speaking in a foreign language such as shyness, personal characteristics, and self-motivation. While studying a new language, anxiety originates from "learners own sense of "self", their self–related cognition … and from the fear of losing self – identify" (Hahsemi, 2011). Therefore, the level of self-confidence has a vital role in speaking a foreign language without any fear (Rajitha, 2020). This position appears to be reasonable, as learners of a foreign language often have self-critique in their education process. Therefore, students usually suffer from internal factors of anxiety. For Suleimenova (2013) anxiety was found to cause problems related to "self-confidence, self-esteem, and risk-taking ability, and ultimately hampers proficiency in a foreign language".

Cognitive-behavioral therapy (CBT) is suggested by psychologists to make changes to thoughts and feelings and improve coping skills such as learning without worries, relaxing, correct breathing, and recognizing and changing unproductive behaviors (Mcleod, 2023; Psychological treatments for anxiety, 2023). CBT identifies our cognition how we think, our emotions how we feel, and our behavior how we act, and all of them are interacted together (see Figure 1).

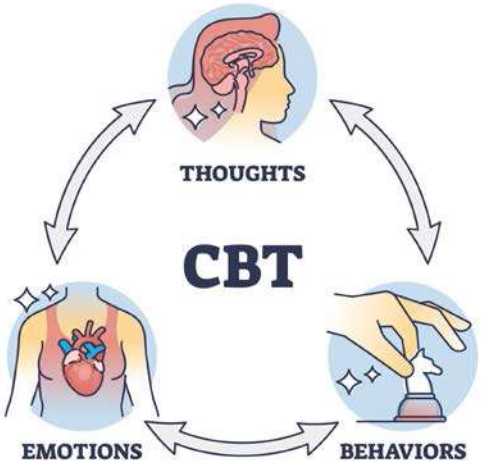

Figure 1. Cognitive-behavioral therapy (CBT)

Methods of creating vocational guidance work

The process of vocational guidance includes identifying one's interests, strengths, and abilities and matching them to the requirements of the labor market. To help individuals determine their professional orientation, modern methods and tools for creating a professional orientation system have been developed. These methods include self-assessment tests, counseling sessions, and performance monitoring.

Self-assessment tests are one of the most common methods used to determine professional orientation. These tests are designed to assess a person's personality, interests, and abilities. Tests usually consist of a series of questions and the results are used to create a profile of a person's strengths and weaknesses (Heppner & Williams, 2017). "Gallup professional test", "16 personalities", "disc test" and many other tests are becoming popular recently.

Counseling is another method used for career guidance. These sessions involve one-on-one interaction between a career counselor and an individual. A counselor assesses a person's interests, strengths, and abilities and makes recommendations about possible career paths. A counselor can also provide information about job requirements, career prospects, and the labor market (Farooq, Pitafi & Akhtar, 2013).

Job shadowing is a technique that allows people to gain experience doing a specific job. This involves spending time with an experienced professional in a particular field to understand the job requirements, day-to-day tasks, and challenges. Job tracking can give people real insight into the job and help them make an informed career choice.

Characteristics of Generation Z compared to other generations

Generation Z refers to people born between the mid-1990s and early 2010s (Heppner & Williams, 2017). Some features of Generation Z compared to other generations:

- *Technology*: Generation Z has grown up in technology and is more comfortable than previous generations. They are digital natives and are accustomed to using smartphones, social media, and other technologies from a young age (Liang & Lenz, 2019).
- *Diversity*: Generation Z is more diverse than previous generations, with a greater mix of races, ethnicities, and cultures. This has led to more open and accepting thinking about diversity and inclusion (Heppner & Williams, 2017).
- *Entrepreneurship*: Generation Z is more adventurous than previous generations. They are interested in starting their own business and being their own boss. This may be due to a lack of job security and a desire for greater independence and flexibility (Heppner & Williams, 2017).

- *Community Consciousness*: Generation Z is more socially conscious than previous generations, focusing on issues such as climate change, social justice, and human rights. They are more likely to get involved politically and act to change the situation for the better (Heppner & Williams, 2017).
- *Work-life balance*: Generation Z values work-life balance more than previous generations. They prioritize their mental health and well-being and seek flexible working arrangements (Heppner & Williams, 2017).

Compared to other generations, Generation Z has grown up with technology as an integral part of their lives. They were born where access to the internet has become a global culture, thus affecting their values and views on life goals. They feel comfortable in digital communication and quickly adapt to new technologies. This generation is also socially aware and values diversity and inclusion. They will prioritize social and environmental issues and be willing to take action to achieve change (Khan & Hashim, 2018).

Advantages of the Gallup Professional Orientation Test

"Gallup" professional orientation test is a valuable tool for determining professional orientation. It measures a person's natural aptitudes, interests, and talents to provide insight into career paths that may be suitable. The test is based on the Clifton Strengths Assessment, which identifies a person's core strengths and how they can be used to achieve career success. The Gallup professional test helps Gen Z make informed career decisions and serves as a starting point for exploring different options. There are several useful points of the test in providing professional orientation in Generation Z:

- *Self-awareness*: Taking the Clifton Strengths Test helps Gen Zers gain a better understanding of their strengths, which helps them better understand themselves and make better decisions about their careers and personal lives (Suzanne M. Savickas & Philip G. DeVol, 2013).
- *Career Development*: Knowing your strengths helps Gen Zers identify potential career paths that match their natural talents and abilities. This can lead to job satisfaction and a fulfilling career (Suzanne M. Savickas & Philip G. DeVol, 2013).
- *Personal Growth*: Understanding their strengths can help Gen Zers thrive in areas that have previously been difficult. For example, if someone is naturally empathetic, they can use this strength to improve their communication skills (Suzanne M. Savickas & Philip G. DeVol, 2013).
- *Improve communication*: The Clifton Strengths test helps Gen Zers understand how their strengths interact with others, which can lead to more effective communication and stronger relationships (Suzanne M. Savickas & Philip G. DeVol, 2013).
- *Confidence*: By understanding their strengths, Gen Zs can be confident in their abilities and willing to take risks and achieve their goals (Suzanne M. Savickas & Philip G. DeVol, 2013).

Overall, the CliftonStrengths test can provide valuable information to help Gen Z better understand themselves, develop their talents, and achieve successful careers and relationships.

The "DISC" personality test

This test can be useful for Gen Z in several ways. Some of the benefits of the "DISC" personality test for Gen Z are:

- *Understanding Personal Strengths and Weaknesses*: Taking a DISC personality test can help Gen Zers understand their personal strengths and weaknesses. This can give you insight into their communication style, how they work in a team, and what motivates them. This knowledge can be useful in making informed decisions about their education, career and personal development (Carlson, Bundick, Dinkmeyer, 2010).
- *Improving Communication Skills*: The "DISC" personality test helps Gen Z people improve their communication skills by giving them insight into their communication style. By understanding their communication style, they can adapt their style to communicate effectively with others, including different types of people (Carlson, Bundick, Dinkmeyer, 2010).
- *Career orientation*: The DISC personality test helps Gen Z people choose a career that fits their personality type. This can give them an idea of the types of jobs they are suitable for and the skills they need to develop to succeed in their chosen career (Carlson, Bundick, Dinkmeyer, 2010).

- *Building Better Relationships*: Understanding the different personality types can help Gen Zers build better relationships with peers, family, and friends. By understanding how others communicate and what motivates them, they can adapt their approach to building stronger and more productive relationships (Carlson, Bundick, Dinkmeyer, 2010).
- *Personality development*: The DISC personality test can be used as a personality development tool. It helps Gen Z people identify areas for improvement and create strategies to overcome challenges and achieve their goals (Carlson, Bundick, Dinkmeyer, 2010).

Overall, the DISC personality test can be a valuable tool for Gen Zers as they navigate their personal and professional lives. It can provide insight into their personality type, communication style, strengths, and weaknesses, helping them make informed decisions and achieve their goals.

Conclusions

To sum up, there are many factors leading to stress. Generation Z is believed to feel more stress than the previous generations. Every student entering the university should have a basic knowledge about personality tests and general phycology. Then, as a result, everyone can conquer the anxiety of speaking and performing in the classroom. Therefore, this research can be beneficial to students who suffer from stress in modern life. Teachers should develop their awareness of all types of anxiety and can produce a suitable education environment and determine the needs of students, especially those who feel anxiety. Cognitive-behavioral therapy is recommended to reduce stress levels. Choosing the right career path is also stressful action. It is the most important decision that can have a significant impact on one's life. With the help of modern methods and tools for creating a career guidance system, Generation Z can make informed decisions about their careers. The Gallup career orientation test and the DISC personality test are two valuable tools to help Gen Z determine their career path. By understanding their natural aptitudes, interests, and talents and aligning them with their personal style and work preferences, Gen Z can create careers that are fulfilling and aligned with their values.

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Zharylkassyn M.B.
Suleyman Demirel University, Kazakhstan
E-mail: 211302033@stu.sdu.edu.kz
ORCID ID 0009-0006-8297-2402

Integrating Continuing professional development with Education system reform in Kazakhstan

Abstract: In the past few decades, the central position of teachers ensuring the quality of education has become increasingly acknowledged internationally. This article considers the reformation of education policy trends regarding teachers' education in Kazakhstan. State policy in the country recognizes education as a priority for social and economic development, with a focus on strengthening the practical training of teachers. It also addresses the challenges faced by state teachers and examines the significant changes to the structure and delivery of teacher education in Kazakhstan since 2011. The paper concludes with a discussion of the author's concerns and recommendations for the future of initial teacher education, with specific reference to the Kazakhstani education system.

Keywords: Continuing Professional Development, professional development, teacher education, education reforms.

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Introduction

The term Continuing professional development (CPD) refers to teachers' learning, support, and activities throughout their careers. Global Monitoring Report on Education for All reports governmental, non-government, and educational organizations worldwide prioritize CPD. "An educational system is only as good as its teachers. It is vital to unlock their potential to make learning more effective. Research indicates that teacher support improves education quality." In all educational establishments, professional development is an important component that enhances teaching and learning quality (Opfer & Pedder, 2011). It is also increasingly recognized that it has a significant impact in promoting and sustaining teacher quality. Thus, the concept of continuous professional development has become an integral part of teacher training, school reform, and academic discourse in recent years (Padwad, 2022). To prepare effective teachers for the 21st century, teacher educators must always be at the top of their game. Only if they can sustain their continuing professional development (CPD) is it conceivable. It entails formal, non-formal, and informal activities that aim to develop the teacher educator's intellectual abilities (cognitive domain), self-confidence, attitude, values, and interest (affective domain), and skills and competencies (psychomotor domain) for personality development and to fulfil the responsibilities of the teaching profession in accordance with the changing times and needs of the prospective teachers and society. Teacher educators typically begin their CPD upon entering the profession and continue it throughout their careers. There are two popular CPD routes for teacher educators: externally planned and mandated programmes and self-initiative. Number of researchers Al Neaimi (2007), Mann (2005), Richard & Farrell (2005), demonstrate that self-initiatives, like external initiatives, play an essential role in the professional development of teacher educators.

There is an extensive body of literature regarding continuing professional development that suggests well-structured, appropriately organized CPD, that can result in significant improvements in teacher practice, institutional improvements, and student outcomes (Bartleton, 2018; Gasanova et al., 2020). Despite these, perceptions, policies, and practices in CPD, especially in Kazakhstan, remain severely

underexplored. For this reason, this paper demonstrates Kazakhstan's education policy, trends, and issues in teacher education reforms by analyzing a few successful practices from high-performing countries and relevant literature.

Research question

The research question that this study follows:

- What CPD policies and practices should be explored in teacher education in Kazakhstan?

Literature Review

As Kennedy (2014) noted, the literature review on CPD has steadily increased in recent years due to the correlation between teachers' quality and learners' outcomes. Some fields, such as engineering, medicine, and law, have maintained pace with the challenges of their practices through a commitment to continuous professional development. Between theory and practice, there is a glaring discrepancy in education and language education, primarily because teachers lack sufficient professional development. There has been considerable discussion about the reasons for this wide gap (Burns, 2016):

1. Policy on teacher education is unclear and vague,
2. Lack of support for CPD management initiatives,
3. Pre-and in-service government programs play an excessively important role in career advancement
4. There is a mismatch between the CPD offered to teachers and the needs of the teachers.
5. Teachers have a heavy workload.
6. Imbalance between work and life for teachers,
7. Teachers are responsible for a variety of administrative and clerical tasks.
8. Teachers do not have enough time and resources.
9. Teachers aren't motivated to take part in CPD.

OECD research conducted in 23 countries revealed that teachers and schools lack both professional and financial resources. Despite such constraints, Wang et al. (2011) research into Continuous Professional Development (CPD) has demonstrated that teachers continue to develop professionally in a variety of ways, both in collaboration with others and individually. CPD providers must provide courses and programs that are relevant and productive. This is undoubtedly the best way to develop professionals through effective CPD. CPD programs could also develop apathy and negativity among participants. A course may be required by their employer or to meet regulatory requirements. CSO (2015) (Cross Stratum Optimization) notes three significant benefits that CPD provides professionals, but not for the development of "reliable and responsible professionals". The whitepaper suggests that "CPD would enhance career prospects" through improved salary packages. Secondly, this would lead to a higher level of commitment from individual employees, which would be beneficial to the employer. In addition, it takes into account the learning styles of employees. As a result, CPD benefits both individuals and employers (Yang et al., 2015).

Finland, Ontario, and Singapore have been able to attract and retain highly effective teachers in part because teaching is a profession that many individuals desire to enter and remain in. In contrast to many other nations, teaching in these three jurisdictions is appealing to academically gifted youth, who remain in the profession rather than seek out more lucrative employment. In Finland, for example, college students surveyed in 2008 ranked teaching as the best profession (Darling-Hammond et al., 2011). This attractiveness is, in some ways, a cultural phenomenon. Leaders in these jurisdictions have frequently emphasised the importance of teachers, thereby elevating the profession's standing. In 1966, when Singapore had just attained independence, the then-Minister of Education, Ong Pang Boon, stated that "the future of each and every one of us in Singapore is determined in large part by what our teachers do in the classroom" (Darlin-Hammond, 2013).

Before entering the profession, a different form of degree is awarded in Finland and Singapore, which is the primary distinction between the two countries' teacher education systems. In Finland, every teacher holds a master's degree. Universities and associated teaching practice institutions provide

research-based, master's-level teacher education. The high levels of critical thinking and research skills possessed by Finnish teachers prepare them to deal with uncertainty (Sarvi, 2022).

A challenge in Finland is the lack of coordination between diverse stakeholders supplying in-service teacher education. Individual teachers are responsible for their own professional development under the Finnish system. On the other hand, such freedom of choice can be instrumental in retaining teachers. Teachers maintain their motivation because they can study more subject areas and explore new teaching pathways. Furthermore, Finnish teachers are free to choose where they desire to teach, and principals are responsible for recruiting teachers. By granting teachers a great deal of autonomy, the Finnish system encourages their ongoing professional development.

Similarly, teachers in Singapore also submit applications individually for in-service education and curriculum-related training. Other forms of professional development are permitted if they are relevant to the subjects they teach. The school staff developer seeks to align a teacher's preferences with the school's strategic objectives for deployment purposes; therefore, teachers' developmental needs are contingent on fulfilling the pragmatic requirements of schools. Research-based teacher education in Finland emphasises personalised professional development for lifelong learning (Sarvi, 2022).

Challenges of Teacher Education in Kazakhstan

In terms of teacher preparation and development, Kazakhstan faces many common challenges. We live in a globalized world where global forces shape health, economics, and social well-being, and social mobility. To keep up with global trends and changes, countries must have highly educated citizens. In terms of responsive trends, there are two general points of view. There is a camp of researchers, educators, and policymakers who think the next step in education reform should focus on curricula standardization, a high-stakes test, and STEM (Science, Technology, Engineering, and Mathematics) initiatives. Therefore, the other groups of educators argue that schools should concentrate on fostering diverse talents, the ability to think creatively, critically, and entrepreneurially. Also, the current curriculum and testing do not reflect right-brain skills or global competencies. The "knowledge society" therefore places a high value on student and teacher performance and emphasizes developing 21st-century skills for all students (Zhao, 2018). In terms of standardization, comparative studies at an international level such as TIMSS and PISA, mostly stimulate and support the first point of view. Every four years, TIMSS (Trends in International Mathematics and Science Study) measures student achievement in mathematics and science. TIMSS aims to improve STEM teaching, but PISA (Program for International Student Assessment) makes a much bolder claim. In accordance with the OECD, which administers PISA, this test assesses students' readiness for the future challenge (OECD, 2010). Today's schools face a wide range of internal diversity issues, such as linguistics, ethnicity, culture, religion, socioeconomic class, gender, race, inclusion, and some other special rights. It is the educator's responsibility to prepare a teaching force capable of producing a diverse range of teaching opportunities. As a result of globalization processes, teachers are under additional pressure to prepare students for a constantly changing world by providing 21st-century skills and helping them develop a lifelong learning mindset. Teacher education programs prepare teachers for teaching in a globalized world. These programs' focus has traditionally been on the local contexts of the schools they serve. Any of this will be possible without broader reforms in the recruitment, selection, and training of teachers (Kulakhmetova, et al., 2015).

CPD at National Education Reforms

It has been reported that over 50% of university graduates and over 64% of secondary specialized education graduates change professions immediately after graduation in some parts of our country. Organizing their professional career is a huge challenge for many young people. Thus, education must be promoted throughout a person's life to ensure its flexibility, diversity, and accessibility. There are concerns regarding quality and efficiency in Kazakhstan as initial teacher education is highly specialized, there are no specific assessments to determine teaching potential, and institutions of teacher education do not have much autonomy in designing their programs. There are only two opportunities for teachers to participate in external professional development training every five years, suggesting that the current framework for

teacher professional development is inadequate. There are substantial opportunities for professional development in Kazakhstan schools, and principals play a more prominent role in instructional leadership than on average in OECD countries.

Kazakhstan's education system was well-developed and centralized under Soviet rule and faced political, economic, and social changes after the Soviet Union's dismissal. Kazakhstan has implemented three stages of education reform since then. The educational reformation process can be divided into three stages: As part of the first phase (1991–2000), international donors called for a reduction in public education expenditures. It is during the second stage of the project (2001-2010) that Kazakhstan's education was integrated into the "international educational space," standards of assessment were established, and the higher education system was restructured so that it could join the European Higher Education Area (Bologna process). High-quality teachers are essential to the success of education reforms. During the first and second stages of reform, teacher education was rarely emphasized, but in recent years its importance has increased. The Kazakhstan education strategy 2011-2020 aims to develop a training system and professional development for Kazakhstan's pedagogical staff (Tastanbekova, 2020).

The "SPED for 2011-2020" program aimed to disseminate best practices from NIS to all secondary schools throughout the country through teacher education reform. Under the auspices of NIS, 14 Centers of Excellence (CoE) were established in May 2011. A program for teacher professional development and trainer accreditation was commissioned by the Kazakh government in August 2011 by Cambridge University Faculty of Education and Cambridge International Examinations. A three-level in-service teacher training program was initiated by the CoE in January 2012. According to the authors, the cascade model was used to reach as many teachers as quickly as possible (Turner et al., 2015). It is estimated that there are over 300,000 school teachers, but 14 CoE were unable to reach all of them. Government Resolution No.232 issued in February 2012 reorganized 17 regional training institutes for in-service teachers into Orleu Centers ("climbing the mountain") for professional development. A two-week professional development course was required every five years for teachers to maintain their qualifications at these 17 regional institutes. There were three stages of teacher development in Kazakhstan, starting in the classroom and working up to senior teachers and middle leaders. During the basic course, teachers learn how to lead classroom learning processes; during the intermediate course, teachers learn how to lead teaching processes within the school system; and in the advanced course, teachers learn how to lead learning processes within school districts. By doing so, Kazakhstan's young people will become global learners in the 21st century. A network of professional development centers will provide leadership throughout Kazakhstan to facilitate the development process (Wilson et al., 2013). As originally planned, 70,000 teachers would go through the program each year, and by the beginning of the 2016–2017 school year, all teachers (325,184 in 2016) would complete both levels. The Ministry of Education and Science, however, reports that only 52,500 teachers have achieved this goal in 5 years from 2012. Even though the program is free, the attending teachers cover all travel and living expenses during the periods of off-site study. Due to the significant gap between urban and rural areas, financial incentives are promised and should be paid from local budgets, but in practice, payments may be delayed or even canceled. Consequently, CPD "Orleu" have started 3-week intensive courses to prepare teachers for the introduction of new educational content since May 2016 due to the inability to achieve the goal of an initial plan (Wilson et al., 2013).

Teachers and Changes in teacher policies in Kazakhstan

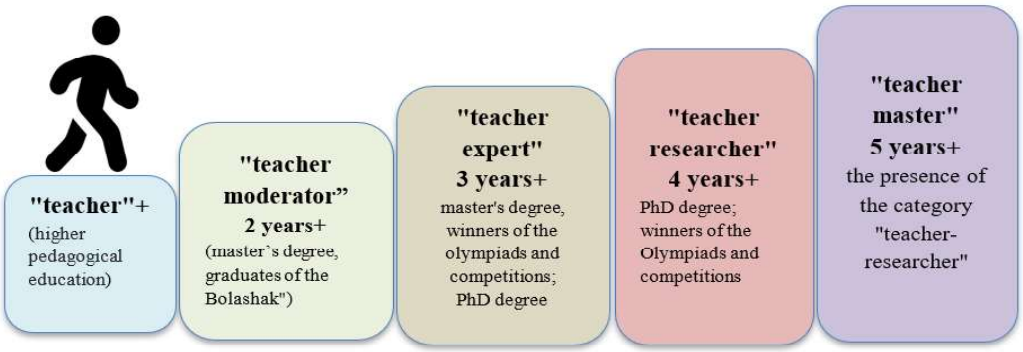
Table 1. Enrolment and graduation in ITE (2018). Source: OECD (2020)

	Number of students newly enrolled in 2018	Total number of students enrolled in 2018	Number of graduated students in 2018	Expected graduation in 2019
Universities	47 057	149 028	38 321	44 113
Colleges	20 346	74 607	20 151	N/A[1]

In Kazakhstan in 2018-2019, more than 90% of teachers had a degree from a college or university (see Table 1). But only 2% of teachers have a master's degree (Ministry of Education and Science, 2018),

and 91% of these degrees are bachelor's degrees. Kazakhstan's teaching job path has had five stages since 2018: teacher, moderator teacher, expert teacher, researcher teacher, and master teacher (Table 2).

Table 2. Teacher certification model. The author's design is based on the official statistics



The new State Programme for the Development of Education and Science aims to enhance teacher working conditions and basic and continuing education. The Ministry of Education and Science (MoES) organized a public debate on the draft law that meets the purpose with teachers, university faculty, public officials, and parents (Government of Kazakhstan, 2019). Changes include:

• Creating alternative paths into teaching for those with discipline degrees (e.g., physics, maths, history) but no teaching credentials.

• Legally recognizing and rewarding mentors.

• New working conditions, including income increases (2020-25) and fewer teaching hours (specified for each level of education).

• Awarding "Best Teacher" and Master's salary increases

Kazakhstan also implemented professional teaching standards in 2017 and a new career system for teachers in 2018. Previously, there were four categories of teachers, but there are now five (see section above), each corresponding to a distinct set of teacher competencies. The new system includes novel teacher evaluation mechanisms. Kazakhstan aims to consolidate its initial teacher education system as part of its efforts to improve the quality of education. Currently, the Committee for Quality Assurance in Education is assigned to devising licensing requirements for ITE institutions. In accordance with the new school curriculum, the World Bank is developing 30 study programmes for the education major (26 at the bachelor's level and four at the master's level). Then, ITE institutions will be able to adjust these to their own requirements and capabilities (World Bank, 2017, as cited in OECD, 2020).

Emerging issues around teacher education

For the Government of Kazakhstan, improving the prestige of the profession of teaching and the quality of education is a national priority. In the secondary education system, several innovations have been introduced, including three-level teacher professional development courses (Kulakhmetova, et al., 2015). Regarding the teacher status and teacher development, the following issues remain:

- Lack of clear professional standards and poor teacher training quality;
- Low status and prestige of Kazakhstan's teaching profession;
- Low-quality candidates are recruited;
- Teacher demand and supply are not properly planned;
- Initially-trained teachers do not meet the government's ambitious plans;
- Special education teachers lack specialist training;
- Newly qualified teachers' mentoring and induction are not related to professional standards;
- Changes are not part of the attestation system;
- Teachers' salaries and schedule systems are fragmented and complicated.

As well as standards for attestation and teacher education, regular teacher evaluations, and the development of formal professional development plans, standards also exist for attestation and teacher education. The lessons learned from around the world:

- In addition to being technicians, teachers should be seen as professionals who exercise judgment;
- Recruiting talented individuals is the first step in getting good teachers;
- Teaching in challenging environments requires strong pedagogical and content training based on research;
- A successful teacher education program emphasizes clinical practice.

Each of the high-performing countries refines its education system continuously. Recently, Singapore has sought to strengthen Professional Learning Communities (PLCs) through which teachers can collaborate to improve classroom practices. For practicing teachers, The Finnish government considers strengthening induction and professional development. The survey of Ontario's teachers found that teacher preparation gaps existed in some areas, including classroom management and teaching special needs students. The province is revamping its induction program. In Pearson's 2012 report, high-performing schools set high standards, and set clear expectations "with a lot of professional responsibility within a collaborative work organization at the front line."

Conclusions and Recommendations

In conclusion, it should be noted that modernization of the educational system demands renewal of the system of improving teachers' qualifications – the main character of the educational process. Teacher preparation and development are an essential part of National education reform. The result of this research has shown that Continuing Professional development is board term and cannot be addressed only to Initial teacher education or pre-service training. The existing relevant literature describes the reasons for the research gap between theory and practice. International studies suggest Kazakhstani policymakers raise the quality of initial teacher education and support early teachers' careers. Furthermore, research highlights the importance of attracting and recruiting highly-qualified specialists in the teaching field. Since 2018, the Ministry of Education and Science requires all teaching staff employed at educational institutions to certify their qualification at Quality Assurance centers every 5 years. In Kazakhstan's system, the attestation and professional development process is mandatory and controlled by the education authority. Comparatively, Singapore and Finland provide autonomy for teachers to pursue their continuing professional development independently. Flowingly, arising issues on teacher education are discussed and lessons from high-performing countries are shown as recommendations. The OECD suggests that states find out what school educators need and set up incentives to meet those needs. This can be done by surveying ITE alumni and teacher trainees in schools, surveying teacher educators and mentors, and making and funding long-term plans for professional development. These projects should put an emphasis on national education goals and build the ability to train people in all of the areas of competence outlined in the standards. It is important to find institutions with the knowledge and skills to develop training in the areas that have been selected, and funds should be required for the development and execution of these courses.

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G.T. Lyskova
Department of Psychology and Pedagogy, Perm State Humanitarian and Pedagogical University, 614000 Perm, st. Sibirskaya 24; Municipal autonomous educational institution "Lyceum 8" of the city of Perm, 62 a, Cosmonaut Leonov str., Perm, 614088, Russian Federation. Email: gusal-s@mail.ru, ORCID ID: https://orcid.org/0000-0002-5276-1202

M.R. Arpentieva
Russian Academy of Natural History, International Academy of Education, Honored Worker of Science and Education of the Russian Academy of Natural Sciences, Center for psychological, pedagogical, medical and social assistance "Assistance", Kaluga, 248000, Dostoevskiy str, 44, Russian Federation. Email: mariam_rav@mail.ru, ORCID ID: https://orcid.org/0000-0003-3249-4941

N.M. Safeek
Department of Educational Psychology, Faculty of Education, University of Colombo, Sri Lanka
Email: safeek@edpsy.cmb.ac.lk

K. Ponniah
Faculty of Languages and Communication, Sultan Idris Education University, Perak, Malaysia
Email: kartheges@fbk.upsi.edu.my

S.V. Koptyaeva
Department of Aesthetic Education and Literature on Art and Local History
STIC KR "Kaluga Regional Children's Library", 74, Lenin str., Kaluga,248001, Russian Federation
Email: assvet18@rambler.ru, ORCID ID: https://orcid.org/0000-0003-4746-2969

Features of the Development of communication skills of younger students in inclusive education

Abstract: A teacher working in an inclusive class needs to build communication in such a way as to ensure the inclusion of children with special educational needs (hereinafter referred to as SEN) in communication with normotypical children by developing their communication skills. The purpose of the article is to analyze research on the problem of the formation of communicative skills of younger students in the framework of the educational process in the context of inclusive education. The scientific novelty and theoretical significance of the study lie in the development of the foundations of an integrative approach to the study and formation of communicative skills of younger students in an inclusive class. The methodological basis of the study is a systematic and competence-activity approach to understanding the problems of the formation of communicative skills. Research methods include theoretical and empirical analysis of the problem and reflection of the results of the ascertaining and formative stages of experimental research. The results of the experiment indicate significant and numerous changes in various aspects of the communicative skills of schoolchildren, the need to introduce joint games and other forms of joint activities of schoolchildren from inclusive classes into the educational program, contributing to the harmonization of relations between them, the development of schoolchildren as individuals, partners, and students, improving performance and satisfaction with educational relationships. The prospect of the study is the further development of an integrative approach, the improvement of the system of means and conditions that contribute to the formation of the development of communicative qualities, communicative actions, and speech skills - the communicative skills of students in general, the development of a system of recommendations that allow future and working teachers to increase their aspirations and skills in the sphere of formation of communicative skills of schoolchildren.

Keywords: primary school student, communication skills, inclusive education, inclusive class, a student with SEN, special educational needs.

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Introduction

One of the priority goals of world education is the availability of quality education, and its compliance with the modern needs of society and every citizen, including in the process and as a result of creating and improving the educational environment that ensures the successful socialization of students with disabilities, providing for the expansion of their learning opportunities and education in non-specialized educational institutions. At the same time, the main goal of teaching children with disabilities today is their most complete socialization, which ensures integration into society: achieving the highest possible level of education and upbringing for each student, involvement in social dialogue and socially significant activity (educational and, later, professional activity). The state educational standards put a special emphasis on preparing children with disabilities for life in different countries and societies, active and parity interaction with it formulates the task of developing their social and subject competencies and identifies requirements for the level of competence formation, including communicative knowledge and skills (Kassymova, 2018; Gasanova et al., 2020).

The concept of modernization of national and world education emphasizes: in order to educate a person who strives for the maximum realization of his abilities, is open to the perception of new experiences, capable of making a conscious and responsible choice in various life situations, it is necessary, first of all, to teach the child to decide what is available to him in different areas and situations of communication, improved in the process of education and upbringing, by language means, various communicative tasks. It is, therefore, about how to form his communicative competence. The same task is served by the competence-based approach that underlies the modern concept of education. This approach is associated with the formation of a system of competencies of key competencies, one of which is communicative competence. Communicative competence acts as a set of complexly structured and interconnected communicative knowledge, skills, and abilities. In particular, communicative competence involves knowledge of the ways of communicative interaction with surrounding people and events and the ability to implement them, the skills to recognize and influence the psycho-emotional state of the interlocutor or interlocutors, the skills and abilities to work in a group, possession of verbal and non-verbal means of communication in the process of performing in collective of various social roles.

One of the main problems of organizing the educational process in the context of inclusive education is the need to take into account the individual needs and characteristics of each student, to ensure and improve the readiness and ability of future and working teachers to work in an inclusive environment, to find and implement ways to increase the effectiveness of this work. Inclusive education in itself requires additional knowledge and skills from teachers, which, when applied, provide high-quality, diverse, individualized support to each student, the general readiness and ability of the teacher to develop work with a variety of children and in various directions, including the formation of children's communication skills, in conditions of inclusion (Stepanova et al., 2006; Stepanova & Demchuk, 2014).

Another problem is the lack of specialists, such as special education teachers, speech therapists, psychologists, and other professionals who can help teachers in teaching children with disabilities and other needs. Another important problem is the need to organize the joint work of teachers and specialists, cooperation and coordination of the efforts of teachers with the efforts and actions of other professionals. To solve these and a number of other problems, targeted work is needed in the field of teacher training and cooperation. Other specialists need specialized training and courses that develop the necessary knowledge and skills in the field of inclusive education, readiness, and ability to work successfully in inclusive education. It is also necessary to correctly focus the efforts of teachers and specialists, ensuring the effectiveness and productivity of their efforts in supporting the development of each student. One of these focuses is the formation of communicative skills in schoolchildren.

The problem of developing the communicative skills of schoolchildren and other groups of people was considered in the works of many domestic and foreign authors. Scientists have revealed the essence of communicative skills, and proposed ways of their formation. However, existing studies practically do not touch upon the problems of the formation of communicative skills in the conditions of inclusive education, specific and general difficulties, and opportunities for building, implementing, and improving children's communication in an inclusive classroom.

Research Methodology

The readiness of future and already working teachers to form the communication skills of students in inclusive classes is ensured by the knowledge of what and how to form in order to achieve the goals of inclusion and the goals of the full development of each individual child. This problem has both practical and theoretical relevance since both teachers and researchers need a structured model that combines the data of existing studies and opens up opportunities for further research, which makes it possible to successfully form the communicative skills of schoolchildren in inclusive and other situations of an integrative model. Such a model should take into account not only general but also specific problems and tasks of the formation of communicative skills of younger students in an inclusive class. The communication skills formed in younger students in an inclusive class are both general and specific: on the one hand, they allow students to interact effectively and productively with other students and people in general, performing universal and particular communicative actions and applying appropriate communication skills, including skills, helping to build, implement, develop and complete contacts in situations of difficult communication, supporting the traditional norms of educational relations, and, on the other hand, they are specific to situations of inclusive contact, in which some of the interacting people have more or less pronounced features of the state of health and are associated with them the specifics of educational needs, which leads to the need for a large-scale transformation of educational relations themselves. In an inclusive situation, the very idea of how and why education and upbringing should be carried out changes, how communication is implemented, which can be called inclusive: aimed at integrating schoolchildren with different educational needs into the educational dialogue. Therefore, in an inclusive class, the teacher needs to be ready to work with both general, universal, and specific tasks for the formation of communicative skills of schoolchildren, including those who are ready and able to cooperate on their own and to form the readiness and ability to cooperate in children of the inclusive class, to overcome the barriers that exist in the communication of children with disabilities and normotypical children.

The aim of the study is to analyze research on the problem of the formation of communicative skills of younger students in the framework of the educational process in the context of inclusive education, to provide future and working teachers with the foundations of a holistic understanding and effective ones. The scientific novelty and theoretical significance of the study lie in the development of the foundations of an integrative approach to the study and formation of communicative skills of younger students in the inclusive class. The methodological basis of the study is a systematic and competence-activity approach to understanding the problems of the formation of communicative skills. Research methods include theoretical and empirical analysis of the problem and reflection of the results of the ascertaining and formative stages of experimental research. The study involved the main (inclusive classes) and control (traditional classes) groups. The study was carried out with the help of the "Chart of Observation of Students' Communication Skills" by the first author, G.T. Lyskova.

The work implements the idea that communicative skills include, firstly, communicative qualities, which include the ability to make contact and address the interlocutor; the ability to listen to the interlocutor; the ability to understand and accept a different opinion, different from one's own; ability to navigate in a situation of communication; the ability to select material and arrange it in speech. Secondly, they include communicative actions that involve intentional, emotional, and expressive shaping of speech utterances; the ability to feel the mood of your interlocutor. Thirdly, they include speech skills associated with having a sufficient vocabulary; mastering the basic lexical signs of the language; assimilation of basic grammatical means; formation of skills of pronunciation of sounds, and syllables.

At the same time, it should be noted that the development of communication skills in educational activities should be carried out in the context of four interrelated situations: communication between a teacher and a student; communication with another student, communication in small groups, communication with class students (Akishina, 2013), using a system of specially selected and developed means that create situations of interaction, including cooperation, of children in the classroom, as well as a system of conditions that encourage schoolchildren to improve communicative skills (development and implementation of communicative actions, manifestation of communicative and communication-promoting qualities and relationships, development and improvement of communication skills, including the most productive and effective models of interaction with other children and adults in the classroom and outside the classroom) in terms of such parameters as inclusion or involvement, activity or subjectivity and

manufacturability or competence. The authors proceeded from the fact that the work on the formation of communication skills should be every day and organically contain all types of activities: learning, play, and work. We agree that the main condition for the socialization of a child with SEN in the future is joint games (Turishcheva & Malykhina, 2019). It is during the game activity with the help of different games that conditions are created for the development of the child's communicative qualities, the formation of communicative actions, and the correction of speech skills.

Results of Theoretical Research

Inclusion is an approach to learning that aims to ensure equal learning opportunities and social integration of all students, including children with different characteristics and needs, including SEN (Stepanova & Demchuk, 2014; Arpentieva et al., 2019a; Arpentieva et al., 2019b). Inclusive education is an important step toward building a just and equal society. It allows children with different needs to be educated together with other children, which contributes to their social integration and development. In addition, inclusive education helps to overcome the stigma and discrimination associated with different characteristics and needs and creates a more tolerant and open society. Inclusive education involves the organization of education in such a way that each student can participate in the educational process and receive the necessary help and support. This involves the use of various methods and technologies of education and upbringing, support and control (assessment), design and reflection of educational processes and results, development of original and adaptation of existing educational materials and equipment (tools), as well as providing additional support to students who need it.

The study of the problems of communicative development of younger schoolchildren is conditioned by the need to timely and successfully form their basic, limiting educational processes, the ability to interact and understand, internalize, and implement ethical norms of social interaction directly in situations of communication with other subjects of the educational process. An analysis of existing studies allows us to assert that communication is a decisive factor in the overall development of the personality of a younger student. Research finds that communication can also help correct the conflicts and difficulties that primary school-age children may have with improper upbringing and training, in particular in conditions of exclusion. Most authors believe that interaction between children is necessary not only for the formation and development of a child as a student (the formation of subject and, further, professional competencies) but also for the formation of his general life (personal and interpersonal) competencies.

Scientists continue to look for ways to ensure the effective organization of the educational process and the provision of quality education to younger students with special educational needs (SEN), taking into account modern world educational trends and existing practical experience. The urgency of the problem is largely due to significant changes in the composition of students in general education and vocational schools, an increase in the number of students and students with special educational needs, who, until recently, were either not included in a specially organized educational and developmental space, or were included, but without any detailed reflection of the problems and results of such inclusion (Taraskina, 2016; Feofanov et al., 2020).

Changes in the understanding of the problems of educational activity of students with special educational needs have occurred due to theoretical research and subsequent changes in the practices, norms, and standards of education, from primary to professional. Thus, the Educational Standards for Primary General Education in different countries focus on the importance of developing key competencies of younger schoolchildren and provide for the development of communication skills in order to successfully socialize a child (Ministry of Education and Science of Russia, 2009). The standard emphasizes that "common to all core competencies are such skills as reading with understanding, the ability to express one's opinion orally and in writing, critical and systematic thinking, creativity, initiative, the ability to logically justify a position, the ability to constructively manage emotions, assess risks, make decisions, solve problems, cooperate with other persons", and it is also noted that "the applicant for education interacts with other persons orally, perceives and uses the information to achieve life goals in various communicative situations" (Ministry of Education and Science of Russia, 2009). The Educational Standards for Primary General Education in different countries are based on a system-activity approach, through which the formation of the student's personality takes place. Such a person must meet the needs of the modern information society, and be an enterprising and competent citizen. The standards also note that

the optimal level of general education for children with special educational needs is ensured by mastering the content of educational sectors in combination with corrective and developmental work.

The introduction of ideas about the importance of communication skills into the standards of general, special, and inclusive education is an extremely important part of solving the problems of formation; however, the scientific study of the problem itself plays a big role, including the integration of existing research and developments. Here, however, we see that not too many scientific publications are devoted to the development of communication skills of younger schoolchildren within the framework of inclusive education, especially of a generalizing, integrative plan (Mikhailovskaya, 2001; Bogush & Gavrish, 2007; Tsepova & Kharchenko, 2008; Sulnichenko, 2009; Sivinsky et al., 2021; Kantor et al., 2023).

Much attention in these works is given to speech. Speech competencies in the life of children of primary school age are the basic skills and abilities necessary for successful communication and social adaptation in society. These skills include the ability to speak and listen, to understand and express thoughts and feelings, and to respond appropriately to communication with peers and adults. The speech also includes the ability to use language to solve practical problems such as shopping, ordering food, communicating with people, giving and receiving help, etc. For the development of speech for life, children of primary school age need to provide appropriate conditions (situations) and support. In addition, it is important to create a psychological atmosphere that will contribute to the development of speech, including taking into account the individual needs and characteristics of each child. To help children develop their speech and social skills, teachers can use a variety of teaching methods, such as cooperative games, various tasks that require the coordination of efforts, and the cooperation of several children. The development of speech for life is an important element of education in elementary school, as it helps children learn, adapt socially, and function successfully in society. It is also a prerequisite for a successful education and career in the future.

In general, "communicative and speech skills" are considered by researchers in different ways. In particular, "communicative and speech skills" are quite often considered as "communicative skills", "speech skills", "speech activity", "communicative and speech competence", and "communicative universal learning skills. Galskova (2015) notes that communication skills determine a person's ability to communicate as a complex multicomponent activity, the nature of which is influenced by various factors. Lutsenko (2002) considers communicative speech skills as "the ability to manage speech activity in the process of solving communicative problems". According to the definition of Mikhailovskaya (2001), communicative and speech skills are "creative skills that include a set of communicative and speech actions aimed at the perception, reproduction, and creation of statements in oral and written speech".

Speech activity is a means of forming a person who is able to express himself correctly and appropriately, communicate freely and effectively; ready for the conditions of life in society. According to Tsepova and Kharchenko (2008), speech activity is a way of realizing social and communicative needs in the process of communication. In this regard, developed speech activity in children appears as a general phenomenon associated with a common property of people, regardless of a particular language. At the same time, this is an individual, unique property inherent in a particular child, developed and appropriated by him, taking into account the conventional requirements for communicative expediency and psychological comfort of speech communication. In Kasatkina's scientific research (2008), communicative universal learning skills are interpreted as the correct distribution of roles within the team, the ability to listen and properly enter into a dialogue, and the ability to build productive interaction with adults and peers. Among all universal teaching skills, communication skills are very important. The level of development of communication skills affects not only the assimilation of knowledge by students but also the development of the personality and the success of its adaptation in society. All skills are formed in the course of her activities, and communication skills are improved through the interaction of students in the classroom and in extracurricular activities.

Communicative and speech development is closely related to the communicative and speech skills of children of primary school age. In particular, Leontiev (2001) points out that "in the process of communicative speech development, skills are formed to adequately select language or speech means, determine the communicative task, realize one's own speech, give it an arbitrary form". Winter (1991) notes that in communicative speech development, there is an interaction of all types of speech activity. In addition, there is an improvement in the ways of forming and formulating opinions and their conscious differentiation in various situations and conditions of communication. Donchenko (2006) came to the

conclusion that the communicative and speech development of children of primary school age should be understood as the development of the ability to fully communicate with the help of language means; formation of communicative and speech competence; development of the main types of speech (listen, read, speak and write) and communicative (the ability to perform speech actions aimed at solving communicative problems) skills. Scientists note that students must master the ability to distinguish between oral and written speech; maintain a dialogue, translate texts; observe the norms of etiquette in communication; compose stories on a specific topic in compliance with grammatical and communicative speech skills, and be able to speak coherently.

In correctional pedagogy and speech therapy, children's speech activity, speech competence, and speech activity (language use) are considered interrelated phenomena. Speech competence is the result of the development of its practical application in speech activity (Galskova, 2003). Researchers believe that communicative competence is the unity of the relevant skills and abilities of the child, reflecting his communicative competence, and his experience of communicative activity (Rose & Gage, 2017; Beukelman & Light, 2020; Cole-Lade & Bailey, 2020; Kantor et al., 2021). However, without effective teacher support for communicative interaction with peers, students with SEN may experience difficulties communicating with peers in the school environment, which affects their motivation, attitude, confidence, and communicative competence (Beck, et al., 2000). Thus, the communicative factor is the limiting success of the educational activity of children with SEN: with its directed and active development with the help of properly selected methodological tools (training and education tools) by the teacher, there is a positive trend in terms of communicative and speech opportunities for teaching and educating children with SEN. The academic results of the educational activity of children in the inclusive classroom and satisfaction with educational relations, processes, and results are improving.

Results of an empirical study

The empirical study included three stages:

- ascertaining;
- forming;
- controlling.

The purpose of the ascertaining stage of the study was to identify the level of communication skills of younger students in the inclusive class. At this stage, in 2019-2022, students from four inclusive classes of the Moscow Autonomous Educational Institution "Lyceum 8" in Perm took part in it. In total, 80 children of the second inclusive classes were diagnosed: 40 people - the main group (inclusive classes in which the formative experiment was carried out) and 40 people - the control group (inclusive classes in which the formative experiment was not carried out). For each student of the inclusive class, the "Map of Observations on the Manifestations of Communication Skills in Primary School Students" developed by the authors was completed. This diagnostic technique allows you to establish the level of development of communicative qualities (skills of the "relationship" group), communicative actions of students (skills of the "appeal" group), and the level of development of their speech skills (skills of the "reflection" group. The technique consists of three parts: observation of the manifestations of the communicative qualities of the individual, observation of communicative actions, and identification of speech skills through observation and conversation.

In the course of the study, three levels of formation of communicative qualities, communicative actions, and speech skills of the subjects were identified: high, medium, and low. The results of an expert assessment of the formation of communicative skills of subjects with SEN indicate that they have a low level of development of speech skills. The communication skills of such children are very limited, and without specially organized training, their skills of children's communicative behavior are very difficult to master. The inability to correctly express one's feelings and correctly understand the emotional state of the interlocutor, and the inconvenience or inadequacy of facial expressions and gestures complicate the communication of students with typical development with students. The results of the ascertaining stage of the study also indicate an insufficient level of formation of communicative skills among other students of inclusive classes. In addition to levels, the leading characteristics of the formation of communicative skills and conditions were identified, the presence of which, according to experts, contributes to their formation: characteristics of involvement and conditions of involvement in an inclusive educational dialogue,

characteristics of activity and conditions of subjectivity, as well as characteristics of competence and conditions for implementation and improvement of competence. It was shown that a holistic understanding of the relationship between different aspects of the formation of communicative skills of schoolchildren by a (future) teacher ensures an increase in his readiness and ability in an inclusive environment, possession of effective means of forming children's communicative competencies.

Analysis of the results of the ascertaining stage of the study made it possible to formulate the goal, objectives, and methodology of the formative experiment on the development of communicative skills of younger schoolchildren in an inclusive class. At the stage of the formative experiment, eight formative-correctional classes were held with students from the inclusive class. All classes were built according to a single structure and included the joint gaming activities of students: the creation of role-playing situations; theatrical games and tasks, board games, construction, and verbal and non-verbal games. Work in the classroom simultaneously took place in three areas: the development of communicative qualities, the development of communicative actions, and the development of speech skills. The content of the classes stimulated children with SEN to communicate with their peers, aroused in them the desire to participate in games with other children, and developed and revealed the potential of students in SEN. At the same time, the individual characteristics of the child (his shyness, peculiarities of speech development) were taken into account. Particular attention was paid to children with SEN with their participation in pair and group forms of work, but the communicative activity of all children in the inclusive class was studied.

During the control stage of the empirical study, the same methodology was used as at the ascertaining stage: "Map of observations of the manifestations of communicative skills in younger students." The calculation of the data of the ascertaining and control experiments demonstrated the presence of significant differences between the main and control groups of children at the end of the study, and differences in the communicative skills of children in the main group at the beginning and end of the study. Let's compare the dynamics of the results in the experimental and control groups for each indicator (Table 1).

Table 1. Dynamics of the indicator "development" of students' communicative skills at the ascertaining and control stages of the study

Stages of development in 2 groups	levels of development of students' speech skills			levels of development of communicative actions			levels of development of communicative qualities		
	high level	medium level	low level	high level	medium level	low level	high level	medium level	low level
Ascertaining stage main group	2	14	4	2	12	6	5	10	5
Control stage main group	3	16	1	3	15	2	7	12	1
Ascertaining stage control group	2	15	3	2	11	5	6	11	3
Control stage control group	3	15	2	3	10	5	6	12	2

According to the first indicator, speech skills (Table 1) results of students in the experimental classes at the ascertaining stage: high level - 2 subjects, average level - 14, low - 4. The results are shown in the control experiment: high level - 3 students, average - 15, low – 2. The most noticeable qualitative change in the group of skills "reflection" of the interlocutor and the situation was that the language of the subjects became more emotionally expressive. Changes in the control group were significantly less noticeable, the communication of children changed minimally.

According to the second indicator, the development of communicative actions (Table 1), the results of the students of the main group (experimental classes) at the ascertaining stage: high level - 2 subjects, average level - 12, low - 6. The results are shown at the control stage: high level - 3 students, medium - 15, low - 2. Qualitative changes in this aspect of skills ("treatment with interlocutors") consisted of the fact that the subjects more often showed leadership qualities in games, in group projects, and demonstrated goodwill and openness. They showed a greater tolerance for a child with a Sensory Processing Disorder. Changes in the control group were significantly less pronounced.

According to the third indicator "development of communicative qualities" (Table 1), a change in the formation of communicative qualities in students of the experimental (main) group was revealed: high level - 5 at the beginning against 7 at the end, average level - 10 at the beginning against 12 at the end, low - 5 at the beginning versus 1 at the end. Qualitative changes in this "relational" aspect of communication skills consisted of the fact that the subjects increased their ability and readiness to maintain communication and to feel the mood of the interlocutor. Students are more likely to show empathy towards other people. The results of the control group at the beginning and end of the study are comparable and less pronounced.

Also, in the main group, differences became noticeable in the attitude and quality of the educational activity of the students of the main and control groups: against the background of less conflict and alienation, the students of the main group were more involved and successful in educational activities, more open to the educational influence of teachers: the changes were multiple and, at the same time, had clear trends: a change in attitude to communication caused changes in perceptions and experiences in communication, as well as the need to master a new model of interaction or correct the old one.

In general, this confirms our assumption about the importance of the systematic use of special means of forming communicative skills, that different skills change in the context of the use of various means of formation in different ways, the "relational" aspect of skills changes most dynamically and fully, the readiness and ability to build contact with different from themselves and other people. The most rigid is the "converting" aspect of skills, instrumental models of building communication, starting with speech patterns and ending with interaction patterns.

Summarize the results of both parts of the study:

1. The most important differences in the formation of different groups of communicative skills of younger students in an inclusive class exist in the degree of inclusion (involvement), technological effectiveness (competence) and intensity (activity) and in the level of skills formation (imitative-imitative, orderly-conventional or reflective-creative).

2. The successful formation of the communicative skills of junior schoolchildren in the inclusive class is associated with the implementation of the requirements of individual and systematic approaches to their formation: taking into account the formation of different groups of communicative skills of schoolchildren in the inclusive class is the basis for the development and implementation of individual educational routes, as well as the subsequent integration of these routes into a single for the entire inclusive class, an educational program that involves the creation of a system of conditions and the use of a set of means for the formation of communicative skills, including specialized teaching aids, methods, and technologies, as well as special types of classes.

3. The process of formation and development of communication skills in the classroom in an inclusive class will be successful if:

- an individualized assessment of the formation of communicative skills is carried out, the design of an individual educational route for the communicative development of a younger student and the integration of these routes into a single program for the formation of communicative skills of all students of the inclusive class in the classroom;
- a motivational environment is formed in the lesson that creates significance and needs for mastering communication skills for primary school students, the need to build relationships of cooperation and mutual assistance of all students of the inclusive class;
- the lesson is organized as a space and time of joint creative and research activities of younger students, contributing to communication between them, the use and improvement of communicative skills, methods, and technologies are applied that are specifically aimed at the formation and development of communicative skills of students;

- the lessons ensure the creation of a reflective educational environment that promotes intensive understanding and improvement of the communicative experience of students, the formation and improvement of their ideas about themselves and communication partners;

- pedagogical cooperation of specialized specialists of the educational organization and the family in the communicative development of primary schoolchildren of inclusive classes is being implemented.

Conclusions

To sum up, firstly, studies by domestic and foreign experts show that inclusive education involves the involvement of people with special educational and other needs in education in educational institutions and the importance of inclusion in the process of their rehabilitation and socialization. Specialists emphasize the importance of creating conditions for the success of inclusion by managing communication and the formation of communicative skills of schoolchildren in classes where there are students with SEN. The formation of such skills in students with special development and in normotypical students of inclusive classes requires purposeful, orderly work of teachers who must be ready for such work: competent and armed with the means and understanding of what conditions are necessary for these means to be effective.

Secondly, students with SEN are characterized by a low level of mastery of communicative means and methods of interaction; the formation of communicative skills is not much higher among normotypical students of inclusive classes. It is difficult for them to coordinate actions to fulfill common tasks and organize mutual control, and mutual assistance. Many children have insufficiently formed language initiative, the ability to argue their position, to convince, to lead a discussion. Students with SEN do not always have a set of options for communicative-linguistic communication strategies, the skill of transmitting information; demonstrating an inability to listen, to maintain a conversation. Schoolchildren of this group experience significant difficulties in choosing adequate language means.

Thirdly, the central component of the diagnostic complex of the study was the "Map of Observations on the Manifestations of Communicative Skills in Primary School Students". This technique allows you to establish and compare the level of development of communicative qualities, communicative skills, and actions of students, as the development of speech skills at the initial (stating) and final (control) stages of the study. The results of the ascertaining experiment testify to the insufficient level and diversity of gaps in the formation of communicative skills among students in inclusive classes.

Fourthly, developed and implemented a cycle of formative-correctional classes aimed at organizing joint play activities of students, with the help of which a child with SEN gradually joins the student team. Work in the classroom simultaneously took place in three areas: the development of communicative qualities, the development of communicative actions, and the development of abilities for dialogue and cooperation with a child with SEN. The development of communicative actions and communicative qualities was the most active, the development of the speech skills of many children with SEN required greater and more specialized efforts of teachers.

Fifthly, normotypical students of the experimental group of the class in the process of playing activities communicated more actively with children with SEN and were more tolerant of them, and less conflicted. Students became more confident in addressing their classmates, they stopped feeling fear that their classmates would not understand them and reject them; in communication with classmates, they began to show interest in what the interlocutor was saying; there was a desire to answer questions addressed to them. At the beginning and end of the study, students with and without SEN of the control group often showed pronounced conflict and aggression, states of misunderstanding, and alienation.

The results obtained allow the authors to state that gaming activity aimed at developing communicative skills contribute to the development of communicative qualities, communicative actions, and speech skills that make up communicative skills, both in ordinary students and in students with SEN. In addition to knowing this fact, due to the consistency and complexity of the formed system of competencies, it is necessary to provide future and working teachers with the foundations of a holistic understanding and effective ones.

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G.A. Stepanova

Laboratory of Innovative Educational Technologies of the Surgut State Pedagogical University, 10/2, 50 let VLKSM str., Surgut, 628417 Khanty-Mansiysk Autonomous Okrug - Yugra, Russian Federation
Email: g_stepanova53@mail.ru
ORCID ID: https://orcid.org/ 0000-0002-3082-6626

M.R. Arpentieva

Russian Academy of Natural History, International Academy of Education, Honored Worker of Science and Education of the Russian Academy of Natural Sciences, Center for psychological, pedagogical, medical and social assistance "Assistance", Kaluga, 248000, Dostoevskiy str., 44, Russian Federation.
Email: mariam_rav@mail.ru, ORCID ID: https://orcid.org/0000-0003-3249-4941

G.K. Kassymova

Abai Kazakh National Pedagogical University; Institute of Metallurgy and Ore Beneficiation, Satbayev University, 29, Shevchenko str., Almaty, 0500010, Republic of Kazakhstan. Email: g.kassymova@satbayev.university, ORCID ID: https://orcid.org/0000-0001-7004-3864

D.B. Kurmanbai

Institute of Pedagogy and Psychology
Abai Kazakh National Pedagogical University, 13, Dostyk ave, Almaty, 0500010, Republic of Kazakhstan
Email: darkhankurmanbai@gmail.com

G.T. Lyskova

Department of Psychology and Pedagogy, Perm State Humanitarian and Pedagogical University
614000 Perm, st. Sibirskaya 24; Municipal autonomous educational institution
"Lyceum 8" of the city of Perm, 62 a, Cosmonaut Leonov str., Perm, 614088, Russian Federation.
Email: gusal-s@mail.ru, ORCID ID: https://orcid.org/0000-0002-5276-1202

Inclusive Health-Saving Education: Ecological Model of Modern Educational Relations

Abstract: An ecological approach to understanding health saving in inclusive educational relationships means that the goal of the teacher and students is to build such relationships and implement such processes and forms of interaction in which "everyone and every one" of the participants wins, a consensus is reached as the point at which they find their best satisfaction. This requires a clear understanding of what is and what is not education and society, what is and what is not a person and society, what is and what is not development and harmony, and what is and what is not transparency and health. The purpose of the study is to analyze the ecological approach to understanding health saving in inclusive educational relations. The research method is a theoretical analysis of the ecological approach to understanding health saving in inclusive educational relations. Inclusive health-saving education is discussed as a part of the ecological model of modern educational relations. Inclusive health-saving education is a part of the ecological model of modern educational relations. Within the framework of exclusive school education, ignoring the tasks of health protection and development, there is a high chance of negative impact, mathetogenesis, and pediogenesis, it is difficult for an individual to become a student, to realize the existence of different strategies, forms, and types of learning activity and learning relationships. Thanks to inclusion, people can experience themselves and the world as different, in different situations. Inclusion allows minimizing (prevention), overcoming (correction and development, or rethinking many problems of an individual or group).

Keywords: inclusiveness, educational relations, health saving, ecological approach to understanding health saving, inclusive educational relations.

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Introduction

Inclusive health-saving education is a part of the ecological model of modern educational relations. Inclusion is a deeply ecological option for building educational and other social relations. One of the leading focuses, in this case, is the problem of health saving of the subjects of the inclusive process. An ecological approach to understanding health saving in inclusive educational relations means that health is recognized as the central criterion and goal for the success of inclusive educational relations: teaching and educating a person as a fully functioning integrity suggests that his life is the life of a spiritually, psychophysiologically and socially healthy being, self-actualizing and self-realizing, harmonious and transparent. In other cases, a person one way or another slides into ill health, illness, including various kinds of addictions, drug addictions, etc.

An ecological approach to understanding health saving in inclusive educational relationships means that the goal of the teacher and students is to build such relationships, implement such processes and forms of interaction in which "everyone and every one" of the participants wins, a consensus is reached as the point at which they find their best satisfaction. Multidirectional social trends cause a wide variety of individual and social problems that require, to varying degrees, urgent solutions deployed in time and space, conscious, multiple, and purposeful transformations. Among a number of ideas that both the researcher and practitioners rely on to overcome these problems and choose the vector of directions for transforming difficult and crisis situations, the idea of environmental friendliness is often used (Arpentyeva, 2017; Borovskaya et al., 2020; Panichkina et al., 2022; Podberezniy et al., 2022; Kassymova et al., 2023a; Kassymova et al., 2023b). The ecological imperative as the imperative of caring about the essence of things, about the correspondence of actions and efforts to the goals and possibilities of change, is now a system of requirements and guidelines for human concern for the harmony and transparency of the relationship of the individual and the group with the surrounding worlds of nature and culture, with oneself and one's inner self world (Arpentieva, 2021; Arpentieva et al., 2019; Kassymova et al., 2018; Kassymova et al., 2019; Kassymova et al., 2023a; Kassymova et al., 2023b). The idea or the imperative of sustainability is applicable to various areas of the life of society, organizations, and individuals. It is responsible for creating ever-new and important approaches, concepts, and technologies in modern science and practice. In education, the environmental imperative is associated with the implementation of the concepts and theories of "lifelong education" or lifelong education, competence-based training and upbringing, and the "surviving", "adventure" model of training and upbringing (Arpentyeva, 2017; Borovskaya et al., 2020; Panichkina and et al., 2022; Podberezniy V. et al., 2022; Podberezniy, Arpentieva, Panichkina, 2023; Kassymova G. et al., 2023a; Kassymova G. et al., 2023b). It is also associated with the ideas of individualized and special education focused on the individuality of students and teachers, as well as with the ideas of health-saving and inclusive education (M. Afshar Ali, Kh. Alam, A. Magyar, S. Schwab, F. Stanford, B. Taylor, Sh. Rafiq, M. Venetz, C. Zurbriggen). Each of these and other areas of the implementation of the environmental imperative is the scope of numerous developments and scientific works, however, there are few studies devoted to their understanding as environmental, and there are practically no works related to the study of health-saving as an environmental category, including in the context of inclusion. At the same time, the heuristic potential of the ecological approach to understanding health saving in inclusive educational relations is very significant. In addition, it has significant practical significance and value: the environmental imperative helps to identify and implement the most effective and productive ways of transforming and overcoming existing problems and barriers to their solution, without sacrificing either the tasks of developing and moving forward or the tasks of preserving the existing one (Arpentyeva, 2017; Borovskaya et al., 2020; Panichkina et al., 2022; Podberezniy et al., 2022; Kassymova et al., 2023a; Kassymova et al., 2023b).

However, in modern science and practice, environmental ideas often come down to anti-ecological, pseudo-practical, and pseudo-scientific ideas of "sustainable development", emphasizing the importance of some mythical "stability" that does not exist in the world and fear of changes in the BANI and VUCA worlds. However, both in culture and in nature, stability is realized in two main variants: as stagnation ("stagnation") and a stage on the way to collapse (destruction) and as a "plateau" insignificant in size and time of existence on the way to development, a delay which is fraught with destruction and death. The goal of inclusive education, even if we take into account its function of health preservation, the function of preserving and transmitting culture, is precisely the development and support of the development of the

individual as a whole: educational programs (contents), methods (forms, technologies) of an inclusive school at all its levels must be constantly updated and change (Malygina, Antoshina, 2020). This flawed model is generally associated with the "marketing" model of inclusion. According to this model, people with special needs (disabled people) are primarily interested in it, and normotypical individuals act only as a means of satisfying these needs (Genta et al, 2020; Matsiori, 2020; Olalla, Merino, 2020; Podberezniy, Arpentyeva, Panichkina, 2023; Podberezniy et al., 2023), which, of course, causes rejection among the latter, as well as rent expectations and consumer attitudes among the former. This significantly violates the requirement to include a schoolchild or student with disabilities or other characteristics (abnormal, queer) in the school or university educational environment and the team of peers and teachers without infringing on the rights and needs of healthy (normally typical) students. Inclusion should therefore not be reduced to the creation of an adaptive environment that acts as a "melting pot", even when it comes to health protection. For health conservation as an idea, it is important to abandon repressive diversity management practices: to suppress diversity and individuality for the sake of orderliness and stability.

However, the focus on adaptation and assimilation (both on the part of people with disabilities and other inclusive groups and on the part of the social majority groups that accept them), on the essentialist division of "right" and "wrong" values and attitudes, patterns of behavior/interaction, identities, and traditions, to "correct" the "wrong" ones and assimilate the "correct" ones, is fundamentally ineffective. It is ineffective both within the framework of the changes of modernity and the challenges of life associated with them, and the general, traditional goals of general, special, and inclusive education (Grillo, 2003; Lie, 1995; Podberezniy et al., 2023). Stability and enforcement are the source of "differentialist racism" (Balibar, Wallerstein 2004), which proclaims "noble" goals (preservation of diversity, tolerance, security, inclusion) in order to strengthen and rigidly fix the boundaries between people and groups, creating a caste, highly stratified and rigid community. Accordingly, "stability" as an idea of education practically destroys the very possibility of inclusion, proclaimed as the ideal of modern education at its various levels. Only the rejection of "leveling" and assimilation helps to overcome the anti-ecological aspects of "stability" and understand the essence of "instability" as an important, but not the only part of life: both revolutions and involutions and periods of accumulation of changes and periods of gradual changes are important in the life of a person, an organization and society (Tully 2008). At the same time, different subjects are forced, with interest or out of habit, but are included in a direct discussion (Kozlova, Mikheev, 2020). Dialogue as an ecological option for integration is a guarantee of development and change, and a guarantee of protecting individual and social harmony and freedom, preventing and overcoming exclusion and injustice, and equalizing the status of different subjects (Kozlova, Mikheev, 2020). The concept of exclusion or social exclusion by R. Lenoir (1974) is associated with the fixation on rejected groups: socially unprotected, rejected (stigmatized and subjected to bullying and alienation, going through discrimination and deprivation) minority groups (Makeeva, 2020). Exclusion, including for the sake of stability, is a manifestation and process of experiencing total social disadvantage, limited or lack of access to necessary and sufficient resources, exclusion of a person or group from society, shifting him to the "social bottom", to marginal "borderline" zones, etc.

This happens, among other things, as a result of a "chain reaction" and the breakdown of several or all social systems and relationships (Atkinson, 2000; Gore, 1995; Paugam, 1996). Overcoming the "exchange" model of "sustainable development", which manifests the agony of the bourgeois system, is associated with the chance to go beyond pragmatism and consumerism, understanding inclusion as "education for the disabled". Connecting the ideas of "empathy of society", it reflects the importance of the ecological culture of the subjects of education, and the dialogical, development-oriented nature of the relationship of these subjects to other subjects. Like the ecological imperative, the education imperative, its central task, is connected precisely with development (Arpentyeva et al., 2019; Arpentyeva et al., 2020; Podberezniy et al., 2023).

Research Methodology

The purpose of the study is to analyze the ecological approach to understanding health saving in inclusive educational relations. The research method is a theoretical analysis of the ecological approach to understanding health saving in inclusive educational relations. The ecological approach is aimed at changing the priorities of education (Karopa, 2012; Niyazova, 2020; Oleinikov, & Podlesny, 2013;

Podberezniy, Arpentyeva, Panichkina, 2023). Considerable attention is paid to the problem of the ecological approach. However, most foreign and domestic research is not devoted to the problems of teacher education, but to certain issues of general and environmental psychology (U. Bronfenbrenner, J. Gibson, K. Levin, R. Barker, J. Sallies, J. Kerr, R. Cervero, R. Lickliter, Yu.I. Alexandrov, V.I. Panov, etc.). In fact, there are no special studies of theoretical and methodological foundations and the development of technologies and conditions for an ecological approach to organizing and improving the educational environment in the professional training of a teacher/teacher. The ecological approach is created by S. Barab and U.-M. Roth, proposes taking into account the "network of opportunities", "sets of efficiencies" and "life worlds" as the main elements of personality development in education. Opportunity networks characterize the opportunities that provide the subject with the possession of new knowledge and its application. Efficiency sets represent the skills and abilities necessary for the effective and productive use of knowledge. Life-worlds involve inscribing new knowledge into the subject's worldview (Barab S.A., Roth W.-M., 2006). The central term of the ecological approach is "affordance" (affordance), proposed by J. Gibson. "Affordance" is a concept that unites the organism and the environment.

According to J. Gibson, affordance is the opportunities that the surrounding world (environment) provides to the individual, that is, the "complementarity" of the individual and the environment. Learning is the process of forming new affordances based on previously acquired individual experience. In the context of this understanding, the environment is divided (differentiated) in one way or another in accordance with the experience of the individual's behavioral acts throughout the history of his individual development. In affordances, the individual reflects not the external physical world (as such), but the history of his relationship with the ecological world. In the theory of the ecological approach, an individual's understanding of the environment is based on assessments of its relationship with objects and goals/results of behavior. The environment of the bottom of the individual is the result of realized (both externally and internally) behavioral (activity) acts. In recent years, the concept of a "learning ecosystem" (Learning Ecosystem) has gained popularity (Oleynikov, & Podlesny, 2013; Brodo, 2006; Guetl & Chang, 2008; Pirie, 2004:), it is sometimes argued that the future of E-learning (Electronic Learning is the Learning ecosystem (Uden, Wangsa, Damiani, 2007; Dong et al., 2009; Sheriyev et al., 2016; Arlinwibowo et al., 2020; Pratama et al., 2022).

Research Results and Discussions

The term "ecology" was introduced by E. Haeckel (1866), who considered the connection between living beings and the environment to be the subject of ecology research. The ecology of education is a system of knowledge, skills and abilities, value orientations of a teacher, and special measures and activities that help the teaching staff of an educational institution make the educational process healthier, develop a strategy for ensuring a healthy lifestyle for all participants in the educational process, healthy learning and education in the classroom and in the course of socially useful activities. The ecology of education covers the mode of the educational process in the course of active interaction with other children and teachers. It also includes various areas and methods of bio- and psychodiagnostics and correction. The concept of the "ecological approach" was first introduced into the subject area of environmental psychology by the American Psychologist J. Gibson (1966). The term "learning ecology" was proposed by J.S. Brown when studying the issues of changing teaching strategies, and V.P. Maykova, A. Richardson, and R.D. Crick identified the principles of green learning and identified the factors that influence its effectiveness (Brown Richardson, 2002 and others). At present, the ecological approach is aimed at the formation and development of ecological consciousness, including the ecological responsibility of a person to society. Ecology has gone beyond the boundaries defined by E. Haeckel (1866), now social pedagogy and educational psychology are areas of widespread use of the "ecological approach" (Deryabo, 1999; Sokolova, 2014). The ecological approach provides for a revision of the usual methods of teaching and education from the standpoint of the ecology of man and society, and the development of new educational technologies that are more natural and culturally appropriate. Over time, the goal of environmental education becomes not so much the formation of individual environmental competencies, but the development of environmental culture and an ecological approach to understanding a person and his life, including education (Moiseeva L.V., Fayrushina S.M., 2017). Education, as a subsystem of an evolving society, changes in parallel with this society, the external and internal conditions for the formation of a

person change, while one of the highest social goals is precisely education, corresponding (according to V.I. Vernadskiy) to an educational society (Tyumaseva Z.I., 2006). Taking into account the variety of interdependent factors influencing the educational environment, as well as the "global scale" of the ongoing content and structural changes, from the methodological positions of modern pedagogy, education is considered a living, dynamically developing system, which brings it closer to ecology ("habitat of organisms") and requires its rethinking from the standpoint of the concept of "ecology of learning" (an ecology of learning), which can be understood as "natural learning" or "natural learning". The need for a new, environmentally friendly approach to education is due to the fact that the usual models of learning (traditional classroom learning, learning based on ICT technologies, blended learning) are poorly oriented to the needs of modern society. Scientists note the need to create a learning system focused on understanding the systems and environments in which a person exists, as well as on the reflection of lived situations (Banathy, 1991; Blewitt, 2006; Crick, 2007; Hill, Wilson, Watson, 2004; Korochistova, Nagel, 2022; Maykova, 2013; Sadovskaya and Padporyn, 2018).

An environmentally friendly educational environment is characterized by a wide range of focuses: focus on the learning context; integrity and ease; person-centered approach; orientation to the application of knowledge in real life; "learning throughout life"; development of critical thinking and non-standard problem solving; team interaction in solving educational problems; research skills; active use of digital resources and wide access to multimodal visual materials. In the framework of this study, we will dwell in more detail on the last two aspects, namely, the "redundancy" of digital and multimedia tools in teaching to influence all channels of perception in order to select the most appropriate learning style (Korochistova, Nagel, 2022).

According to the theory of U. Bronfenbrenner, the various environments in which people participate directly influence their transformations, including development. Humans are born with a range of genetic attributes that develop depending on the person's contact with the environment. Systems related to the environment of people play different roles, in proportion to their properties: at the same time, each of the large systems contains smaller ones: microsystem, mesosystem, exosystem, macrosystem, and chronosystem.

Relationships established in microsystems are characterized by the greatest influence on human development. The microsystem is the level closest to man. This includes the behaviors, roles, and attitudes that are characteristic of the day-to-day environment in which the person operates. The environments in which people spend most of the day are usually stable, not very diverse. However, at certain times they can be changed and directly affect a person.

The mesosystem includes the relationship between two or more environments in which a person actively participates. Thus, the mesosystem is understood as a system of microsystems that are formed or expanded when a person enters a new environment (the relationship between family and work or social life and school). Fluctuations in communications developed in each of the connected microsystems will determine the relationship between them and human development in each of them. This element is associated with the expansion or narrowing of the rights and possibilities of behavior. The mesosystem determines the degree of social support that a person has. Depending on the interconnection and addition of microsystems, a person will see or not see the satisfaction of his need for support.

The exosystem includes environments in which a person does not directly participate, but in which events occur that affect the functioning of his environment. The individual is not directly involved in these contexts (although in some cases he may be), but the changes made in this environment usually affect the individual in one way or another. The relations and opinions established in the exosystem (acquaintances, relatives, etc.) concern a person not directly, but indirectly. Relationships between third parties indirectly affect human development.

The macrosystem includes all factors related to culture and the historical and cultural moment in which a person. Usually, the structure and essence of micro, meso and exosystems are similar, built on the same model: the enormous influence of the macrosystem on its substructures is manifested. A significant part of personal development is limited by the norms and laws established at the government levels of the region in which the person lives. In addition to laws, there are other rules that determine social ratings, and the position of a person in society. Sociocultural norms determine the functioning of people, the socialization and coexistence of people, and establish operational standards that ensure mutual understanding.

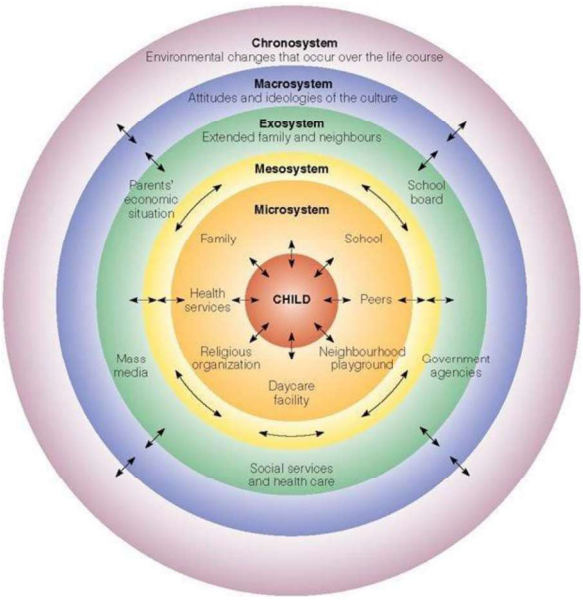
The fifth level is the chronosystem, it consists of all environmental changes that occur during life and affect development, including major life transitions and historical events. At the same time, development occurs in the process of increasingly complex interactions between an active, developing integral biopsychological individual and other people, situations, objects, and their symbolic reflections in his external environment. In order to understand the impact of these immediate processes on development, we must focus on the person, context, and outcomes of development, as these processes differ and affect people in different ways (Bronfenbrenner & Evans, 2000).

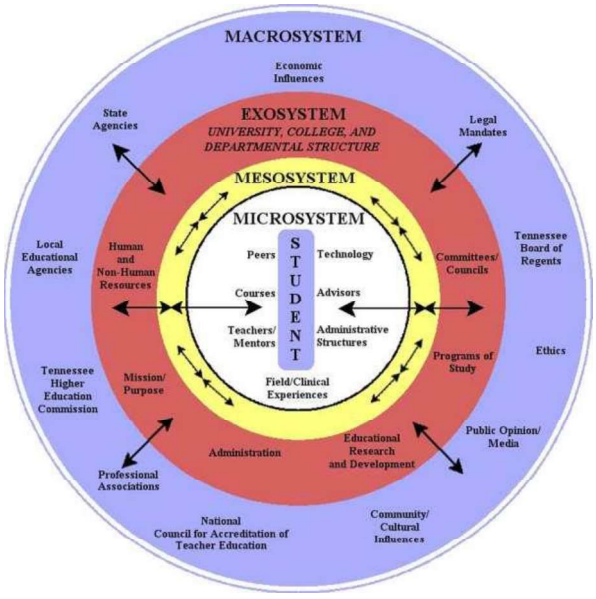
The experience of children with certain special educational needs is largely determined by their cultural differences; differences in the systems in which they are included. Understanding the ecology of these children can help strengthen the provision of social work services for these children (Paat, 2013). Research on youth mental health recovery suggests that the components of a child or young person's mental health recovery are embedded in the "environmental context of powerful relationships", consistent with U. Bronfenbrenner's theory that a person's ecological systems, such as peers, family, and school, contribute to mental health (Kelly, & Coughlan? 2019). Wilson et al. (2002) found that creating a positive school environment through a school spirit that values diversity has a positive effect on student attitudes at school. Langford, et al. (2014) found that whole-school approaches to health care can positively impact student achievement and well-being.

U. Bronfenbrenner defined the ecological approach as the scientific study of progressive mutual adjustment throughout the life of an active, developing human being and the changing properties of the immediate environment in which a person lives; he believes that this process is influenced by relationships within a given environment, as well as from the wider context in which this environment is included. "It should be noted that the subject is understood as a person actively shaping his own development. Between the subject and the social environment, there are relations of reversibility - the environment affects the subject and itself changes in the course of interaction with him. Society is presented not as a fixed, limited given, but as a complex dynamic system. The ecological approach shows that without taking into account the influence of social factors, it is impossible to adequately understand the formation of a human (Pictures 1 and 2).

According to U. Bronfenbrenner's model, human development is a dynamic process that goes in two directions. The first is the impact of various elements of the environment, the second is the activity of the person himself to restructure the multilevel living environment. U. Bronfenbrenner relied on K. Lewin's field theory. If K. Levin proceeded from the formula B=f (PE) (behavior is a function of personality and environment), then Bronfenbrenner used this formula a little differently: D=f (PE) – development is a function of personality and environment. Here, in contrast to the formulation of K. Levin, the time parameter appears: the characteristics of the subject at a given moment in time are directly due to the specifics of his characteristics and environment throughout his life up to this moment. In this sense, D is not so much a process of development as its result. Therefore, for example, the definition of a person's characteristics without taking into account the environment in which they were formed and applied is impossible from the standpoint of environmental psychology. It is known that different cultures require the development of different abilities depending on the cultural goals. In this context, inclusion is the successful inclusion of a person in all systems, a full-fledged dialogue with the outside world at all four levels.

Inclusion in education is a way to implement the ecological imperative of a person to a person, a group to a group, etc. (Afshar et al., 2020; Lyskova et al., 2023; Magyar et al., 2020; Schwab et al., 2020; Stanford, 2020; Stroebel, 1996; Posypanova et al., 2021; Podberezniy et al., 2023; Stepanova et al., 2021). It is such a way and way of organizing education, which allows children, adolescents, youths, and adults of different subcultures to interact with each other, satisfying the needs for mutual assistance and cooperation, service and care, self-improvement and mutual improvement, exchange and management of knowledge and skills (competencies). In foreign countries, such education has been developing for a long time and is legally enshrined. The essence of inclusive education is a system of views that do not allow any discrimination against children and also helps to realize in the educational environment the necessary conditions that people need. Inclusive education is based on an ideology that excludes any discrimination against children, ensures equal treatment of all people, and creates special conditions for children with special educational needs. We are talking about children with special needs, with disabilities, with disabilities.





Pictures 1 and 2. Human development systems according to U. Bronfenbrenner (Evans, 2023 and others)

The ecological approach confirmed that developmental deviations do not completely determine the present and future life of the child; the life trajectory is also a derivative of favorable/unfavorable external conditions. System-ecological (or ecosystem), real-procedural, cooperative-activity, and medical-philosophical concepts in the 21st century inherits the views of the previous period and consider the child in relation to the surrounding world and the conditions that are created / should be created for his / her development (Feuser, 2001; Haeberlin, 2000; Reiser, 2006). New studies have confirmed the qualities of inclusive education as an environment in which the development of children with disabilities proceeds according to a positive scenario and ensures inclusion in society. In continuation of research on the influence and interaction of a child with disabilities with the environment within the framework of the system-ecological concept, A. Sander developed a psychodiagnostic study scheme "Child - environment - analysis" (Heimlich, 2022; Sander, 2002).

The child's psyche is considered from two aspects: not only the state of his mental sphere is fixed, but also the features of the external space, in particular the influence of reference persons, which forms the inner circle of people and his exceptional situation inherent in his life. The appearance of this methodology confirms the latest approach in special education: when organizing psychological and pedagogical assistance and its area - the forms and concept of education - environmental factors that determine the nature of communication and the course of the child's further development cannot be ignored at the beginning of the XXI century. The psychological and pedagogical theory is replenished with arguments "for" in favor of joint education and its priority over separation. G. Reiser and G. Voiser consider inclusive education to be conditions that improve the quality of life of children with disabilities through social acceptance and diverse contacts. The earliest studies of the patterns of development of children with disabilities, the merits and ways of integrating them into a mass school date back to the first third of the 20th century, L.S. Vygotsky called the driving forces for ensuring the mental development of the child - from internal, biological sources (anatomical and physiological prerequisites for the transformation of the psyche) and external, which form the cultural and historical conditions and the social situation of development in the form of certain relationships with other people. This classification made it possible to distinguish between primary and secondary (biological and social) disorders. Anomalies of the body L.S. Vygotsky described as primary disorders that provoke the appearance of secondary, derivative defects (due to an unfavorable situation in the microsociety and society) and the formation of the child's personality in a depleted space. To the variety of unfavorable situations, L.S. Vygotsky attributed the education of children with disabilities in a special school, to depriving them of contact with healthy children. The situation of isolation contributes to the excessive concentration of the child on their own defects and disabilities. In the future, these personality traits form significant barriers to contact and vigorous activity among healthy people who are not included in the inner circle. In general, the theoretical and applied areas of inclusion in

Russia and abroad are developing according to similar ideas. According to modern researchers, inclusive education is a long-term educational strategy that involves great patience and tolerance (acceptance and respect), systematic and interdisciplinarity of efforts, consistency, and continuity of activity aimed at building a dialogue between subjects of education. Inclusion involves the involvement in the learning process of each object of the educational process (a pupil of a preschool institution, a pupil, a student) with the help of an educational program that matches his abilities, as well as the satisfaction of individual educational needs, the provision of special conditions (Lesher, Demenina 2015). Inclusive education is essentially a multi-stage system that includes different groups of subjects and stakeholders with social, functional, and other differences. It is aimed at (re)habilitation, (re)socialization in the process of education and upbringing, at school - in the context of preparation for life in general, in college, vocational school, or university - in the context of professionalization (Boiko et al., 2020; Lyskova et al., 2023; Podberezniy et al., 2023).

The general principles of an environmentally friendly health-saving inclusive educational environment include 1) the principle of the earliest possible inclusion of a person with disabilities in an inclusive environment, which creates conditions for the optimal early and full formation and development of social interaction abilities; 2) the principle of active cooperation, mutual assistance and consensus of the efforts of parents and an interdisciplinary team of specialists, the polysubjectivity of the educational space-time, which ensures the success (efficiency) of accompanying the processes of upbringing and education of a schoolchild or student with disabilities; 3) the principle of individual orientation of education, in particular, individual educational trajectories for students with disabilities; 4) the principle of development of the educational environment, including the model of an educational institution (kindergarten, school, university), 5) the principle of the priority of education (socialization): the formation and development of social competencies and experience, including partnership; 6) socio-psychologically safe, barrier-free environment; 7) development of competence and enrichment of the palette of vectors of professional development of specialists and other subjects of education, 8) the principle of caring for health as a holistic and developing phenomenon (Nazarova, Bogdanova, 2019; Bayramov, Gerasimov, 2019; Booth, Ainscow, 2020; Kassymova et al., 2023a; Kassymova et al., 2023b; Podberezniy et al., 2023; Podberezniy, Arpent'eva, Panichkina, 2023; Silver, 2012).

Health-saving inclusive practice is necessary for society, parents, and educators to accurately and timely prevent, identify and correct blockades and barriers to harmonious and transparent social interaction, accepting and collaborating relationships, mutual assistance and service, creativity, and participation (Bishop & Noguera, 2019; Suchkov, 2020; Pandit, 2017; Spratt and Florian, 2013; Robo, 2014; Posypanova et al., 2021; Stepanova et al., 2021). Inclusion as a doctrine is associated with a certain stage of psychosocial maturity, and culture of individuals, groups, and societies. It involves carefully built, reflective, and corrected structures of interaction between the student's family and society and with other families, school/university, and other social institutions (Volkova, Henchel, 2020; Imms et al., 2016; Podberezniy et al., 2023). At each stage of inclusive educational relations, health-saving inclusive practice acts as an environmental imperative. It involves certain semantic aspects and technological solutions in educational environments as environments for supporting human development as a fully functioning, psychologically, physically, socially, and spiritually healthy entity (Arpentyeva, 2017; Borovskaya et al., 2020; Panichkina et al., 2022; Podberezniy et al., 2023; Kassymova et al., 2023a; Kassymova et al., 2023b; Lyskova et al., 2023).

Individualization of the educational environment of an educational institution is possible and productive, provided that it will be transformed in accordance with the subtle and precise differentiation of the educational and other needs and opportunities of the child, and his health (Kuzmicheva, Afonkina, 2020), as well as with a focus on "human-like" education in general (Khutorskoy, 2020). The mechanism of individualization of a health-saving inclusive educational environment is creativity and changes in health-saving inclusive environmental complexes, which involves a reflexive analysis of the components of the educational environment and activities, interdisciplinary interaction of specialists supporting children, adolescents and young men with disabilities, etc. (Kassymova et al., 2023a; Kassymova et al., 2023b; Shemanov and Makaeva, 2016; Posypanova et al; 2021; Podberezniy, Arpentieva, Panichkina, 2023; Stepanova et al., 2021; Zakirova, Nikitina, 2016; Zollers, et al., 2010).

The basis of inclusive education is an ideology that pays attention to the importance of special conditions for students with special educational and other needs (Ushakova, 2020), it is not a discovery of our time and has existed for many decades (A. Blanchet, S. Geinik, I. G. Pestalozzi, and, further - M.

Montessori, N. Benk, B. Nirie, B. Person, F. Galton, J. Pereira, J. Itard, E. Seguin, G. Hanselman). An essentially ecological understanding of the education of people with disabilities was proposed by I.P. Pavlov: "... nothing remains motionless, unyielding, and everything can always be achieved, change for the better, if only the appropriate conditions are met" (Pavlov, 1949, p. 188), L.S. Vygotsky and A.S. Makarenko also wrote about the same. About this is the idea of "occupational therapy" in its broadest sense and the ideas of the theory of ecological systems of U. Bronfenbrenner.

In the context of exclusive school education, which, as a rule, simply ignores the tasks of health protection and development, there are high chances of a negative impact of the educational process on human development, the risks of mathetogenesis and pediogenesis, schoolchildren among students and professional developments for teachers, it is difficult for an individual to become a student, to realize the existence of different strategies, forms and types of learning activity and learning relationships (Arpentyeva, 2017; Borovskaya et al., 2020; Panichkina et al., 2022; Podberezniy et al., 2023; Kassymova et al., 2023a; Kassymova et al., 2023b; Lyskova et al., 2023). Thanks to inclusive education models, people with and without disabilities can experience themselves and the world as different, in different situations (Kendall, 2017), and understand their own and other people's capabilities and limitations. Inclusion allows you to minimize (prevent), overcome (correct and develop) or rethink (positive behavior) many problems of an individual, group, and society, combine individualization and socialization, adaptation and creativity (Boiko et al., 2020; Maltseva, 2018; Podberezniy, Arpentieva, Panichkina, 2023; Podberezniy et al., 2023; Posypanova et al.; 2021; Scott et al., 2007; Stepanova et al., 2021).

At the same time, it is important to note that full, "total", inclusion is not applicable in all situations. It is necessary to involve other forms of education and upbringing in order to ensure the development of all children, adolescents, youths, and young people without exception, other researchers of the problems of the ecological potential of inclusion also speak about it (Volkova, Henchel, 2020; Ivanov 2021; Kozlova, Mikheev, 2020; Pavlov, 1949 and others). Thus, one of the leading principles of correction, including in special and inclusive education, assumes that educational progress arises under the condition of focusing on the potential capabilities of individuals, and not on their limitations, "diseases", on development, and not on compensation, on overcoming and creativity, rather than just adaptation and "sustainability". Scholars believe that inclusion makes people feel valued/important, successful/powerful, and included/needed (Horn, 2018; Mitchell, 2011; Lyskova et al., 2023; Shulekina and Novikova, 2020). Therefore, in particular, I. A. Erina and colleagues (20002) introduce the concept of "reverse inclusion": normotypical children, adolescents, and young men come to certain lessons/classes in correctional classes, where they study and are brought up together with students with disabilities. In general, the practice of joint education and upbringing of people with different characteristics has existed for a long time and, in addition to shortcomings and difficulties, has a number of advantages (Arpentyeva, 2017; Borovskaya et al., 2020; 2022; Kassymova G. et al., 2023a; Kassymova et al., 2023b). Therefore, building an inclusive environment should start at the earliest possible stage of life or education (Ivanov, 2021; Lyskova et al., 2023; Posypanova et al; 2021; Stepanova et al., 2021).

An environmentally friendly educational environment is characterized by a wide range of focuses: focus on the learning context; integrity and ease; person-centered approach; orientation to the application of knowledge in real life; "learning throughout life"; development of critical thinking and non-standard problem solving; team interaction in solving educational problems; research skills; active use of digital resources and wide access to multimodal visual materials. In the framework of this study, we will dwell in more detail on the last two aspects, namely, the "redundancy" of digital and multimedia tools in teaching to influence all channels of perception in order to select the most appropriate learning style (Korochistova, Nagel, 2022). An ecological approach to understanding health saving in inclusive educational relations is an important line of modern research (Arpentyeva, 2017; Borovskaya et al., 2020; Panichkina et al., 2022; Podberezniy et al., 2022; Kassymova et al., 2023a; Kassymova et al.., 2023b; Lyskova et al., 2023; Takahashi 2004).

Conclusions

The ecology of education is an integrative system of knowledge, skills and abilities, value orientations of a teacher, and special measures and activities that help the teaching staff of an educational institution to make the educational process healthy, to develop a strategy for ensuring a healthy lifestyle

for all participants in the educational process, healthy learning and upbringing in the classroom and in the course of community service. The ecology of education covers the mode of the educational process in the course of active interaction with other children and teachers. It also includes various areas and methods of bio- and psychodiagnostics and correction. At present, the ecological approach is aimed at the formation and development of ecological consciousness, including the ecological responsibility of a person to society. Ecology has gone beyond the boundaries defined by E. Haeckel (1866), now social pedagogy and educational psychology are areas of widespread use of the "ecological approach". The ecological approach suggests taking into account the "network of opportunities", "sets of efficiencies" and "life worlds" as the main elements of personality development in education. Opportunity networks characterize the opportunities that provide the subject with the possession of new knowledge and its application. Efficiency sets represent the skills and abilities necessary for the effective and productive use of knowledge. The ecological approach provides for a revision of the usual methods of teaching and education from the standpoint of the ecology of man and society, and the development of new educational technologies that are more natural and culturally appropriate. Over time, the goal of environmental education becomes not so much the formation of individual environmental competencies, but the development of environmental culture and an ecological approach to understanding a person and his life, including education. Education, as a subsystem of an evolving society, changes in parallel with this society, the external and internal conditions for the formation of a person change, while one of the highest social goals is precisely education that corresponds to an educational society.

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Saltanat Bekmurzayeva
Abai Kazakh National Pedagogical University
050010, Dostyk ave., 13, Almaty, Kazakhstan
ORCID ID: 0009-0005-1356-4619
E-mail: bekmurzaevasaltanat30@gmail.com

Fang Yuqi
Dalian University of Foreign Studies, Liaoning, China
ORCID ID: 0000-0002-6806-4129
E-mail: fangyuqi2022@126.com

Guldana A. Begimbetova
Yogyakarta State University, Jl. Colombo No. 1,
Indonesia. ORCID ID: 0000-0002-0435-1014
E-mail: begimbetovaguldana227@gmail.com

Mustafa Tevfik Hebebci
Necmettin Erbakan University, Konya, Türkiye
ORCID ID: 0000-0002-2337-5345
E-mail: mhebebci@gmail.com

Lazzat Karibayeva
Suleyman Demirel University
040900, 1/1 Ablayhan st., Kaskelen, Kazakhstan
https://orcid.org/0009-0004-9826-8503
Email: lyazzat110@gmail.com

Leong Tack Khang
International Transnational Education Association, Malaysia
E-mail: benjamin@icccm.net

Improving students' cognitive processes to enhance the quality of education

Abstract: This article discusses the problem of improving the quality of students' knowledge by improving their cognitive processes in the educational environment. The purpose and content of the modern educational paradigm are to focus on the free and comprehensive development of future generations, self-education, competitiveness, successful life as a business person, the education of students, their quality of education, and the education of a responsible, humane citizen. Much research is being carried out in this direction. However, the problems of improving students' cognitive processes and improving their knowledge quality require particular study. There are contradictions between the definition of pedagogical conditions for the development of cognitive processes of students and the need to determine their effective ways. The authors found that the concept of cognitive has different meanings. Improving students' cognitive processes at an early age can significantly improve the quality of knowledge. Various research methods were used, including a theoretical analysis of literature, an express questionnaire, and a question-and-answer questionnaire "designed to improve the cognitive processes of students." The studied questions in this article will be helpful for those who are engaged in the education and upbringing of students, including parents and teachers, as well as psychologists and sociologists.

Keywords: Cognition, education, student, learning theory, cognitive processes.

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Introduction

The methodical basis of the theory of education was the theory of knowledge, i.e., the theory of the comprehensive and harmonic formation of the pupil's character. According to this theory, education and teaching are considered specially organized activities. One educational theory's main requirement in teaching students is cognitive activity and awareness (Amirova, 2014; Gasanova et al., 2020). Fulfillment of this requirement is reflected in the student trying to understand the teaching content, connect the past with the new, determine the main and supplementary, use the acquired knowledge through experience, and base his opinion on it. Conscious mastery of knowledge is impossible without mastering one's mental work methods, allowing one to acquire new knowledge independently (Borisova, 2013; Kassymova, 2018). Existing studies

often contrast the cognitive processes of input and output. They examine their respective roles in language acquisition. There is no opposition between inputting and outputting (Qiyi, 2009). Input is the key and prerequisite of learning, and output is the guarantee. They are inseparable and complementary. However, the input cannot be spontaneously transformed into the output, and the learners must go through a series of cognitive processes from the input to the output.

Today, individuals must have skills and abilities appropriate for their age (Hebebci, 2023; Hebebci & Usta, 2022). One of the most critical skills is cognitive. Developing cognitive skills is essential for lifelong learning and survival in any emergency; it is crucial to open up the full cognitive potential of every learner, as each person is unique (Casanova et al., 2021; Tiffany, 2022). Human cognition consists of several processes (Samuel et al., 2017; Tiffany, 2022), such as perception, attention, memory, working memory, pattern recognition, real-life problem-solving abilities, and academic achievement. In order to process learning and achieve an educational goal, in addition to the learning process, there are several factors such as good sleep, diet, various vitamins (iodine, iron, folate, zinc, vitamin B12, and omega-3 polyunsaturated fatty acids), physical exercise, etc., which have a positive impact on healthy cognitive development since childhood (Tiffany, 2022).

Digitally supported learning opportunities have proliferated in educational contexts, and many students rely on the Internet to continue their education for self-development and school contexts (Duman, 2023; Hebebci et al., 2020). Research results show that newly developed online programs are built on modern digital tools but require more focused content and a different focus than traditional learning scenarios (Rohdeet al., 2023). Digital education is conducive to tapping students' implicit cognitive potential and promoting students' ability to proactively, persistently, and quickly solve problems (Chunming, 2020). The interest in students' cognitive activity is developed based on the need to understand the social meaning of education and increase the service rate to society. The most effective manifestation of activity is the student's ability to use the acquired knowledge in life and practice effectively. This arises from the requirement to form a cognitive process in the student's activity during education. If we analyze the pedagogical and psychological literature, the term "cognitive" is based on the concept of activity. Cognitive action is a very active mental action of the learner toward knowledge (Tlegenova, 2012). Cognition is an integral part of a person's mental activity and part of a research study of philosophy, sociology, pedagogy, and psychology. There are components of cognitive activity and levels of its development (Korobova et al., 2018). It consists of cognitive needs, logic, goals, and action methods. Cognition is also seen as an essential characteristic of culture (The newest philosophical dictionary, 1999). The cognitive process is a concept that a single symbol cannot represent and has many multifaceted characteristics. Korobova et al. (2018) found that cognitive activity is an intensive learning process that meets the life needs of an individual; his/her professional career is determined by cognitive activity at different levels of the training period. For example, through the cognitive activity of "coordinate" problem-solving, students can experience the cognitive process of the holistic characteristics of graphics and cultivate their mathematical literacy (Liu, 2022).

Cognition is defined as a characteristic of an individual that reflects a person's attitude to action by being ready to act independently, striving to achieve set goals, and being able to choose optimal ways. Thus, activity in education is not only the condition of the learners but also the quality of education. We mean the personality expression of the learner determined by his attitude to the content and nature of the activity, his efforts, and his desire to achieve spiritual and free cognitive goals.

Integrating cognitive processes and educational practices holds significant promise for enhancing the quality of education. Cognitive load theory, for example, emphasizes the importance of reducing the cognitive burden on learners to facilitate higher cognition processes and improve the quality of online discussions (Cook, 2006). Educators can provide students with practical strategies to improve higher cognitive processing by incorporating collaborative problem-solving and cognitive tools into online discussion environments. Some Chinese scholars put forward the three-cycle teaching model of "cognition-practice-cognition," which recognized the critical position of cognition and practice in teaching activities (Jin, 2005). Furthermore, by modeling experts' cognitive processes, educators can help students transfer problem-solving skills to new situations (Mayer, 1998). These approaches highlight the potential of integrating cognitive processes into educational settings to maximize learning outcomes and foster the development of critical cognitive skills among students.

In the Kazakhstani educational evaluation system, there is a growing emphasis on Criteria-based assessment, which encompasses both formative and summative assessments (Begimbetova et al., 2023). Formative assessment involves providing ongoing feedback and monitoring students' progress to support their

learning and development. The summative assessment evaluates students' achievement and proficiency at the end of a unit and module. "Evaluation" of the cognitive process includes checking and judging two small cognitive processes. Verification means that learners determine whether there is a problem with the internal consistency of an operation or scheme based on standards or guidelines. Evaluation means that learners determine whether an operation or program meets the requirements of external consistency based on external standards or guidelines (You, 2016). To ensure the effectiveness of these assessments, it is essential to create tasks that primarily target cognitive skills, aligning with Bloom's taxonomy.

Bloom's taxonomy (Table 1) provides a hierarchical structure for organizing cognitive processes into distinct levels. The taxonomy includes various levels, such as remembering, understanding, applying, analyzing, evaluating, and creating (Krathwohl, 2002). Each level represents a progressively higher order of cognitive engagement. By utilizing measurable verbs associated with these levels, educators can establish clear expectations for students and facilitate the practical assessment of their learning outcomes. This approach enhances instructional design by emphasizing specific actions that students must demonstrate, ultimately leading to a more focused and comprehensive educational experience.

Table 1. Bloom's taxonomy measurable verbs associated with each level

Level	Description	Measurable Verbs
Remembering	Recalling or retrieving information	List, Define, Identify, Recall, Recognize
Understanding	Interpreting and comprehending information	Explain, Summarize, Paraphrase, Classify, Compare, Contrast
Applying	Applying knowledge or skills in a new context	Solve, Demonstrate, Use, Apply, Illustrate
Analyzing	Breaking down information and identifying patterns or relationships	Analyze, Compare, Contrast, Differentiate, Organize, Deconstruct
Evaluating	Assessing or making judgments about information or concepts	Evaluate, Critique, Justify, Assess, Determine
Creating	Generating new ideas or products	Create, Design, Invent, Compose, Construct, Develop

Research problems in this study aimed to study the concept of cognition and improve the quality of education by developing students' cognitive processes.

The research goal of this study is to determine the level of formation of students' cognitive processes in the current educational environment.

Method

Research Design

This study uses research design types for both qualitative and quantitative research. Methods such as theoretical analysis of the literature on the research topic and questionnaires were used. Materials, views of teachers, and various scientists on "cognitive activity" were considered and studied. The authors also created questionnaires for identifying what factors influence the cognitive development of school students and how to enhance education quality.

Participants

This research includes secondary school students in Chemistry subject. They were randomly chosen to collect data. The participants consisted of 12 female and 9 male students.

Data collection tools

According to this research, different sources were reviewed to identify a research gap and to create a questionnaire. Ten survey questions and two open proposal questions "for improving students' cognitive processes" were compiled by the authors, and participants responded via online Google form.

Data analysis

Descriptive analysis methods were used to analyze the data obtained. In this direction, values such as frequency and percentage were used. In addition, some of the data obtained from the participants were transferred as they were.

Results and Discussions

Ancient philosophers such as Aristotle, Socrates, Democritus, Abu Nasir al-Farabi, Yusip Balasagun, etc., deeply learned about knowledge; they studied the First Cause of existence (Freeman, 1983; Baird, 2010). In many works, one can find opinions about the importance of the development of cognitive processes for human life (Bekbolganov, 2007).

Piaget proposed a four-staged level of cognition development starting from birth to the end of adolescence. He studied a sequence of thinking patterns with four key features, such as stages always happening in the same order; each is a significant transformation of the stage before it (Cognitive Development: The Theory of Jean Piaget, 2023). Siegler (1976) studied developmental differences in children's cognition as three aspects of cognitive development. Problem-solving skills by existing knowledge and information perception are underlying developmental changes as a third aspect of cognitive development. R.G. Lemberg, N.D., studied various aspects of cognitive development. Ivanova, A.E. Abylkasymova, G.K. Akhmetova, T.S. Sadykov, Sh.Sh. Karbaeva, N. D. Khmel, M.N. Skatkin, K. Zharykbaev, etc., in many pedagogical and psychological scientific works. While reviewing the scientific research, it is possible to single out the recognized innovative pedagogical direction. Yu.K. Babansky proposed a system for optimizing education. At the same time, M.A. Danilov and B.P. Esipov made a didactic classification of teaching methods that form the cognitive process in solving the students' cognitive tasks (Belyaeva, 2003).

Later, several works by Aristova (1968), Lerner (1974), Shamova (1977), etc., tried to distinguish between these concepts. B.P. Yesipov, V.A. Krutetssky, and others considered the concept of cognition to be a broader concept (Ormanova, 2009). I.Ya. Lerner held the opposite opinion about the relationship between the concepts of cognitive activity and cognitive curiosity. He said, "You cannot be inquisitive without being active," and thus attributed activity to inquisitiveness (Mustoyapova, 2003; Tuyakov, 2009). A recent book chapter stated that such four main links are complex and dynamic:

- Curiosity, which is a children's active exploration by asking questions;
- Wonder, which is emphasized affective response, reflection, and pursuit of further knowledge;
- Creativity, which discusses capacities such as generating ideas, original transformations, and novel combinations;
- Relationship between curiosity, wonder, and creativity.

Bazhydai Westermann (2020) suggested future research to understand their interrelations as they unfold developmentally.

Students' achievement in good learning results stimulates their cognitive activity (Deryabina & Sergeichik, 2020). It is primarily a need for new information and ideas about the world. The activity reflects a certain degree of inquisitiveness in the student's mind (Ezhov et al., 2013). Cognitive activity is a desire to master new skills correctly (Abukhanova, 2007; Abuova, 2007). It is also a mental action of the learner toward new knowledge (Asaubaeva, 2010). Cognitive activity activates all higher cognitive processes of a learner from the level of their development, leading to constant search as a result of the person's attempt to reconstruct reality (Amirova, 2014). Communicative tasks are essential; teachers control students' learning development (Nazarova, 2021). Table 2 provides different definitions in detail and analyzes the concept of "cognitive activity" by various scientists.

Table 2. Content analysis of "cognitive activity."

Definitions	Sources by
The teacher's responsibility is to advise students in personal development and motivate them since the joy of achieving good results stimulates their cognitive activity.	Deryabina & Sergeichik (2020).
The cognitive need is primarily a need for new information. However, new information can appear in different forms: new knowledge about a	Ezhov, Bologova, Nebolyubova (2013)

thing, new knowledge about something new, motivation for something new, and a system of new ideas about the world.	
The activity reflects a certain degree of inquisitiveness in the student's mind.	Abukhanova (2007)
Cognitive activity is not attributed to simply mobilizing the student's mind and physical strength; it is valued as the quality of the individual's actions. This quality is the content and attitude of the student's actions and the desire to master knowledge correctly. It is reflected in the mobilization of behavior.	Abuova (2007).
Cognitive action is a very active mental action of the learner towards knowledge. It consists of cognitive needs, logic, goals, and action methods.	Asaubaeva (2010)
The relationship of cognitive activity with a particular field of science, cognitive activity, participation in them, and cognitive relationship with participants are becoming essential. At the same time, cognitive activity to activate all higher cognitive processes of a person from the level of their development leads to constant search due to the person's attempt to reconstruct reality.	Amirova (2014)
One possible way to activate students' cognitive activity is to set communicative tasks in the learning process, which must be carried out with the teacher's prompting, guidance, and control and contribute to the speedy and successful achievement of the planned learning outcome.	Nazarova (2021)

The following questionnaire for improving students' cognitive processes was conducted among school learners in grade 9; the subject is chemistry. It contains five answers and two open questions where learners can suggest their ideas for effective learning styles. The results obtained based on the questionnaire for improving students' cognitive processes were as follows:

1. To understand the new material that the teacher is lecturing, is it necessary to listen attentively, read books, and conduct experiments in a laboratory on one's own to expand the given knowledge?

47.4% of the respondents indicated that self-searching is very necessary, 36.8% indicated that it is only partially necessary, and a small number of respondents answered yes, it is necessary.

2. How do you study, and what sources do you often use to improve your knowledge?

The vast majority (52.6%) answered that they use the Internet. The remaining 36.8% said they use books, while a small percentage said they look at additional literature and find it difficult to answer.

3. So that the lesson does not become an empty lesson in the life of students, it should be interesting.

89.5% of the respondents indicated that they believed the lesson should be interesting; the remaining few said they had difficulty answering and disagreed.

4. Is every lesson exciting and essential to you?

47.4% of students think it is exciting, 26.3% say it is only partially interesting, 15.8% say they do not know, and 10.5% say yes.

5. Do you find it challenging to solve tasks given in class?

47.4% said no, it is not difficult at all, 31.6% said it is more complicated, others said it is challenging to answer, and yes.

6. Can you solve simple problems with different tasks?

42.1% said they could ejaculate quickly, 47.4% indicated that they could ejaculate only partially, and the remaining few answered no.

7. Do you want to do research work in the future?

31.6% said that they would like to do it, 31.6% said that they are not very interested, 15.8% said that they are only partially interested, and the remaining few answered that they are not interested at all; I do not know, it is difficult to answer.

8. Will it help to improve the student's cognitive processes by organizing extracurricular, individual work, scientific works, and additional literature?

57.9% said it helps very well, 26.3% said it partially helps, and the rest had difficulty answering.

9. The number of tasks given to each student should be adjusted to his level so that the student has his level. Do you agree with this?

68.4% agreed with the question, 15.8% partially agreed, and the remaining few disagreed.

10. Is it necessary to improve cognitive activity in class?

73.7% said yes, it is essential, and the rest of the respondents gave critical answers: partially necessary; I do not know, yes, definitely, yes necessary.

11. What is needed to increase knowledge in education to raise the quality of education? Make your suggestions, please.

- *Students left the following suggestions and thoughts on the question:*
- *Reading books, memorizing notes;*
- *It is better to shorten the lesson with many quiz games;*
- *It is necessary to use the Internet and books;*
- *In my opinion, necessary videos and slides should be shown to improve the lesson, or it is necessary to show cartoons about exciting facts. For example, the cartoon "Smeshariki" is full of information about biochemistry;*
- *You should listen carefully to the teacher;*
- *I think it is necessary to read a book;*
- *I think an excursion or a subject-related laboratory is needed;*
- *Changing the way of conducting classes;*
- *Adding additional materials, etc.*

12. What is needed to improve the quality of education in order to increase awareness? Make your suggestions, please.

- *Respondents left the following answers:*
- *Reading books, writing notes, and memorizing;*
- *To improve the quality of education, it is necessary to understand the lesson well and be proactive;*
- *Read many books, read extra information besides the textbook;*
- *Making the lesson enjoyable;*
- *Be interested in new information and strive for knowledge;*
- *Open special classrooms and conduct various engaging lessons, etc.*

Through the results of this questionnaire, we can find out their open thoughts about the modern teaching technologies used to increase the cognitive activity of students. The questionnaire results allow us to conduct a pedagogical experiment to improve students' cognitive skills in teaching. According to the questionnaire results obtained while improving students' cognitive processes in this study, most students showed the need for independent research on "Mastering new material." According to "improving knowledge," students' most frequently used sources are Internet sources and books in the second place. Regarding how important it is to make the lesson enjoyable, the students said it should be exciting.

"What is needed to raise awareness and raise the quality of education?" - Various excursions, additional materials, quiz questions, games, etc., gave many exciting ideas. "Making simple calculations" was easy for a few respondents and difficult for most respondents. "Doing scientific work in the future" is attractive to a small part of the respondents, while the majority said that they are not very interested.

"Literature helps to improve the student's cognitive processes" - most indicated that it helps very well. "What is needed to increase knowledge in education, to improve the quality of education?" - said that it is essential to make the lesson enjoyable, to open special classrooms, to conduct various exciting lessons, and to increase the necessary information. In the "Determining the student's level" question, most said that assigning tasks to each student at their level was correct, while a small number disagreed. "Cognitive activity" - to the question of how much improvement is necessary, the majority said it is essential. In contrast, a few respondents said they do not know or that it is partially necessary.

Conclusions

To sum up, cognitive development depends on education and several external factors such as healthy nutrition, physical activities, sleeping, etc., starting from childbirth. Integrating cognitive processes into educational practice and aligning assessments with Bloom's taxonomy suggests a prospective way to maximize learning outcomes, develop critical thinking skills, and create an enriched learning environment for students. This integration can significantly contribute to improving the quality of education and student learning outcomes.

For students' cognitive development, questionnaire results showed that academic tasks should be assigned according to a student's abilities and skills. Solving cognitive problems increases the ability to think and develops students' intellectual skills. The development of cognitive processes depends on the activity of students. This task is critical to correctly forming active behavior in the future. Cognitive problem-solving is a cognitively active process. These tasks contribute to the formation of cognitive motives of students; that is, they use their existing knowledge and achieve insufficient information through creative search.

Recommendations and limitations

Over the past several decades, research in education psychology has provided many principles for developing instructions to mediate human cognitive processes (Clark & Harrelson, 2002). This study is limited to a literature review and an online survey, so the authors recommend that teachers use teaching methods without stress in the classroom that generate human learning processes, including attention, perception, emotional management, and short-term and long-term memories.

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Kenzhegali M. Smailov
"Institute of Metallurgy and Ore Beneficiation" JSC a subsidiary of Satbayev University, Kazakhstan
E-mail: k.smailov@satbayev.university
ORCID ID 0000-0002-9277-5254

Yeldar Nuruly
Al-Farabi Kazakh National University
71 al-Farabi Ave., Almaty, 050040, Kazakhstan
E-mail: yeldar.nuruly@kaznu.edu.kz
ORCID ID 0000-0002-9321-2285

Complex Ni and Co Extraction from Leached Nontronitized Serpentinite via Hydrometallurgical Process at Atmospheric Pressure

Abstract: The growing significance of mineral processing processes in the contemporary mining and processing industry lies in their aim to augment the concentration of valuable constituents within processed natural raw materials. Predominantly, these processes encompass pyrometallurgy, hydrometallurgy, and electrometallurgy. Each method can extract nickel; however, the high energy demand of pyrometallurgy necessitates a shift toward refining the efficiency of hydrometallurgical procedures. Consequently, optimizing nickel-containing ore processing technologies to yield high-purity nickel and its compounds is a current research concern. This paper investigates the hydrometallurgical processing of nickel and cobalt via leaching, specifically targeting oxidized nickel-cobalt ore. Analytical studies reveal a promising potential for complex extraction of nickel and cobalt, achieving impressive yields of 98.4% and 90.7%, respectively. Our analysis further demonstrates that implementation of this method can notably elevate the extraction degree of targeted metals. Significant energy resource conservation is made possible by conducting extraction at a moderate temperature of 353K and at atmospheric pressure. Importantly, this approach facilitates the extraction of valuable components even from ores containing negligible concentrations. This scientific endeavor enhances our understanding of efficient, sustainable practices in the field of mineral processing, demonstrating the potential of hydrometallurgical methods for nickel and cobalt extraction.

Keywords: hydrometallurgy, nickel and cobalt extraction, leaching process, energy efficiency, mineral processing.

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Introduction

Nickel, also called the "green" metal, has a large commercial demand that is growing (Tsai & Chan, 2013; Torabi & Ahmadi, 2020; Shukla et al., 2001) because of many appealing properties, including ductility, corrosion resistance, resistance, magnetism (Morcali et al., 2017; Abikak et al., 2023), and high-temperature resistance (Li et al., 2017; Zhapbasbayev et al., 2021). Cobalt is also an equally strategic metal used in many commercial, industrial, and military applications.

Kazakhstan ranks 7th in the world regarding the total cobalt reserves. The state balance sheet records 55 deposits of cobalt[1]. The most significant reserves are held by such companies as KAZNICKEL LLP, Kyzyl Kain Mamyt LLP, and Sokolov-Sarybai Mining Production Association (SSGPO) JSC[2]. The Republic of Kazakhstan has a number of large nickel deposits: Gornostayev (173 thousand tons/nickel) in the Abay region, Shevchenko (1 million tons), Kundybay, Podolsk, Zhitikara, Akkarga, Milyutin, and Ekibastuz-Shiderti (262 thousand tons) in the Pavlodar region and others[3]. The deposits belong to the formation of iron-manganese-cobalt-nickel ores

[1] Order of the Minister of Investment and Development of the Republic of Kazakhstan from June 28, 2018 № 478 "On approval of the Program of state subsoil fund management". URL: https://online.zakon.kz/Document/?doc_id=33233470&show_di=1&pos=5;-106#pos=5;-106 (date of reference: 02.05.2023).
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[3] Production of nickel-cobalt products in the Republic of Kazakhstan: market research. URL: https://damu.kz/upload/iblock/51c/MarketingovoeIssledovanie_ProizvodstvoNikel_kobaltovovoyProduktsiiVKazakhstane.docx (date of reference: 20.06.2023).

and are represented by three types of ore minerals: asbolane-hydrohematites, kerolite-nontronite-ochras, and nickel-cobalt-melanites. The content in the rocks: Fe 13-33 %, Ni 0.1-0.66 % and Co 0.06-0.35 %. Developed and presented for extraction nickel-containing ores contain mainly metal oxides in the form of Fe_2O_3, NiO, and CoO. Today, about 73 % of nickel use is for the production of stainless steels, which are of high quality and long life, and nickel is also used to fabricate batteries for electric cars and other electrical applications (Olafsdottir & Sverdrup, 2021). The cobalt that accompanies nickel is also a very important component in the production of nickel-containing lithium-ion batteries; it improves their quality and service life (Li & Lu, 2020; Yukun et al., 2021; Miryuk, 2024). Oxidized (lateritic) nickel ores contain about 70 % of the world's geological reserves of nickel and cobalt. The ferronickel production stage is energy-intensive and is mainly used for oxidized ores that are transported to metallurgical plants (Selivanov & Sergeeva, 2019). Processing one ton of ore produces 1.5-2.5 kilograms of nickel, requiring the burning of coal and generating slag waste that needs to be disposed of. Currently, it is very important to develop an affordable technology for processing oxidized nickel ores that would result in minimal environmental impact.

This study (Ivanov et al., 2022) is devoted to solving this problem. The paper presents a study of the agglomeration, roasting, and leaching of oxidized nickel ores with the choice of optimal parameters, which include the addition of various reagents, varying the temperature, duration, and program of roasting, and creating the necessary atmosphere in the roasting furnace. Analysis shows that only a small fraction of ferrous minerals forms ferrous sulfate when sulfated with sulfuric acid, even at elevated temperatures. The loss of nickel bound to oxygen by iron compounds can be reduced after roasting at temperatures no higher than 6500C, during which the iron oxides recrystallize to form α-Fe2O3 while nickel is released, which can be leached. The sintering and roasting process can achieve higher recoveries of nickel and cobalt, which are components of the various ore minerals that are available for extraction at different stages of ore processing.

About 60 % of nickel is extracted from sulfide-nickel ores, which are depleted due to over-exploitation, and hard-to-process poor ores have now become the main raw material for nickel mining (Chen et al., 2017; Guo et al., 2009; He et al., 2013). When the ore is processed by the traditional pyrometallurgical smelting process, that is, primary ore (flotation) → nickel concentrate (high-temperature smelting) → low-grade nickel matte (converter smelting) → high-grade nickel matte (milling and flotation separation or sulfuric acid leaching or high-pressure ammonia leaching process) → nickel and copper products (Park et al., 2006), the high concentration of waste rock in the flotation process produces large amounts of sludge, making difficult the separation of the metallic minerals (Fu et al., 2010; Lu et al., 2000). Conversion of low-grade nickel matte into high-grade nickel matte results in low recovery of valuable metals and low economic benefits throughout the process (Li et al., 2017; Mu et al., 2018).

Recent research on the recovery of valuable metals from low-grade nickel matte has been conducted mainly in hydrometallurgy, namely atmospheric pressure leaching (Xiao et al., 2020), high-pressure leaching (Sinisalo et al., 2021), oxygen pressure leaching (Behnamfard et al., 2013), acidic iron chloride leaching (Cui et al., 2018) and oxidation-ammonia leaching (Chen et al., 2014). Atmospheric leaching has the advantage that the leaching of valuable metals can be significantly lower and is improved by adjusting certain process parameters such as temperature and particle size.

The hydrometallurgical process, as compared to pyrometallurgy, significantly improves the recovery of some metals, reduces energy consumption, is more environmentally friendly, and easily provides continuity and automation of equipment, but the overall recovery of valuable metals is low (Chen et al., 2017; Li et al., 2018). Sulfuric acid firing is considered to be a promising process because of its low reaction temperature, high reactivity and efficiency, and proven exhaust gas recovery technology.

There is a way of complex processing of nickel-cobalt raw materials (Nesterov et al., 2010), where autoclave leaching of raw materials is carried out by nitric acid solution (HNO2) with concentration 100-150 g/l, at temperature 200-2500C, pressure 4.0-6.0 MPa, ratio T:L = 1: (2-4) and within 1.5-2.0 hours. The extraction of cobalt and nickel from raw materials is 96.6 % and 90.3 %, respectively. Despite the high degree of extraction of target metals, this method has a number of drawbacks: (1) significant power consumption due to maintaining high temperatures during extraction; (2) the need for complex hardware design due to the use of autoclave leaching.

The method of hydrometallurgical processing of oxidized nickel-cobalt ores (Duisebayev et al., 2014), based on ore leaching with sulfuric acid with a concentration of 200 g/dm3 at 900C±50C and the use of gaseous sulfur dioxide in an amount of 1.4-3.0 vol. % of the pulp volume is also used. Treatment of ore with sulfur dioxide makes up 5-7 % of the leaching time, and the process of ore leaching takes 60 minutes. The

disadvantages of the method include extremely low cobalt extraction of 58.5 % and significant energy costs due to the high-temperature maintenance on a constant basis.

Analyzing literature sources describing methods of nickel and cobalt extraction from ores, we conclude that the existing technologies have a number of serious drawbacks. In addition, there is a need to find suitable solutions related to the development of new as well as optimization and improvement of nickel-containing ore processing technologies.

The purpose of this paper is to develop an effective, simplified, and accelerated method of complex extraction of nickel, cobalt, and associated metals from refractory oxidized ore that excludes high-temperature, autoclave, energy-intensive processes requiring a complex hardware design. The goal of this research is to achieve a high degree of extraction of target metals at 353 K by using available, less toxic, and efficient local reagents.

Methods

In this study, our focus was on the leached nontronitized serpentinite ore, specifically extracted from the Gornostayev deposit situated in the Abay region. The ore was subjected to meticulous preparation before the experimental procedures commenced. The primary step in the sample preparation process involved the reduction of the ore to a manageable size. This was accomplished by crushing the ore to a fraction range of 45 to 0.6 microns. The equipment utilized for this purpose was a planetary mono-mill Fritsch Pulverisette 6, originating from Germany, known for its precision and consistency in reducing the sample size while minimizing contamination.

Following the size reduction process, we subjected the samples to a detailed structural analysis by X-ray diffraction (XRD). The XRD imaging was executed with the assistance of a D8 Advance (Bruker) equipped with an α-Cu radiation source operating at a tube voltage of 40 kV and current of 40 mA. This instrument was selected for its unrivaled accuracy and superior resolution capabilities. The obtained diffractograms were analyzed, and the interplanar distances were computed with the help of EVA software, a highly regarded tool in the realm of XRD data analysis. Further steps included the generation of sample transcripts and the conduction of phase searches. For these procedures, we used the Search/match feature in combination with the comprehensive PDF-2 powder diffractometric database, ensuring a thorough examination of the structural components of the samples.

For a more nuanced understanding of the crushed ore, we also obtained high-resolution images using a Quanta 200i 3D scanning electron microscope (SEM) from FEI Company, USA. The SEM provided in-depth morphological details of the crushed ore particles, allowing us to observe the physical characteristics at a microscopic level. Moreover, the material composition of the ore was investigated via a Leica DM2500 P optical microscope. This powerful tool offered detailed insights into the mineralogical composition of the sample, paving the way for a deeper understanding of the leaching behavior.

The last stage of the analysis focused on the measurement of nickel and cobalt content in the hydrochloric acid solution post-leaching. An 8300 DV inductively coupled plasma emission spectrometer, a product of PerkinElmer Inc., was employed for this purpose. This instrument is well-recognized for its sensitivity, robustness, and high precision in trace elemental analysis, making it ideal for determining the content of nickel and cobalt in the solution.

Research experiment

The subject of our investigation was an oxidized nickel-cobalt-containing ore from the Gornostayev deposit. Amongst the variety of potential ore samples, this specific sample was selected for its challenging processing attributes by existing industrial techniques, which thereby exemplifies the pressing need for novel methodologies.

When planning efficacious solvents for the extraction of nickel and cobalt from such ores, an understanding of the compounds' forms in both the ore and their processed products is crucial. This is due to the varying reactivity of different chemical states of nickel and cobalt, which thereby affect the efficiency of their extraction. Therefore, to advance a new technology for the effective extraction of nickel and cobalt from nickel-cobalt-containing ore, a comprehensive knowledge of the phase composition of the studied material is imperative.

An X-ray diffraction (XRD) analysis was conducted to elucidate the mineralogical composition of the ore. The diffractogram of the sample, as demonstrated in Fig. 1, provides a visualization of the material's crystalline phases. Our X-ray phase analysis unveiled that the oxidized ore sample predominantly contains maghemite (77.5%), followed by hematite (12.8%), and kaolinite (9.7%), as outlined in Table 1.

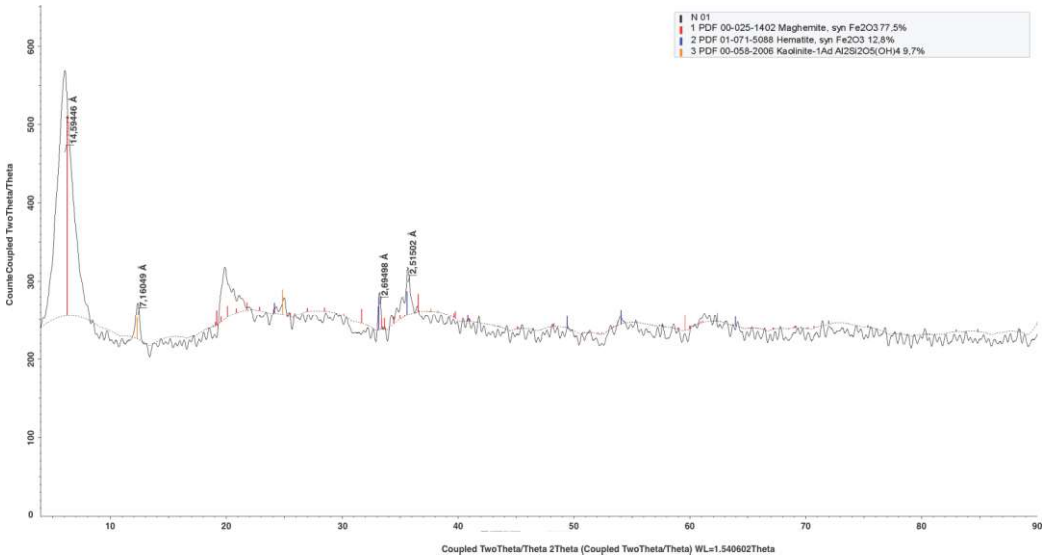

Fig. 1. Diffractogram of oxidized nickel-cobalt ore before leaching

Table 1. Phase composition of oxidized nickel-cobalt ore "before" leaching, determined on the basis of X-ray phase analysis

Sample	Name of compounds	Formula	Percentage content, %
Ore No. 1	Maghemite	Fe_2O_3	77.5
	Hematite	Fe_2O_3	12.8
	Kaolinite	$Al_2Si_2O_5(OH)_4$	9.7

Post-leaching, it was observed that the crystalline structure of the nontronite mineral, initially identified as kaolinite, was eradicated. This destruction implies that the encapsulated nickel and cobalt ions were successfully released from the solid phase and migrated to the solution, as visually represented in Fig. 2. The respective contents of maghemite and hematite post-leaching are elucidated in Table 2. The transitions of these mineral phases provide significant insights into the leaching process's effectiveness, advancing our understanding of the leaching dynamics of nickel and cobalt from such ores.

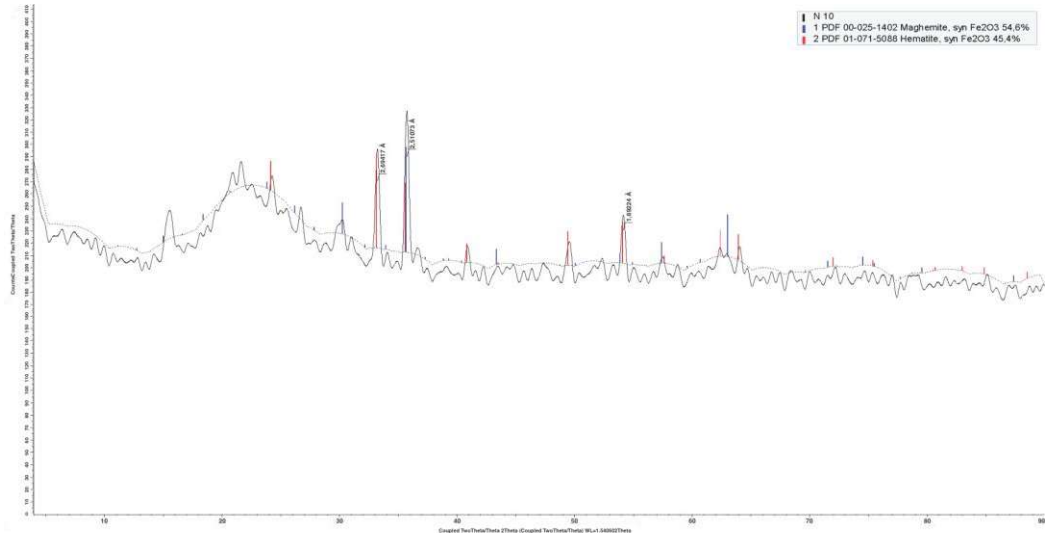

Fig. 2. Diffractogram of oxidized nickel-cobalt ore after leaching

Table 2. Phase composition of oxidized nickel-cobalt ore "after" leaching, determined from the X-ray phase analysis

Sample	Name of compounds	Formula	Percentage content, %
Ore No. 1	Maghemite	Fe_2O_3	54.6
	Hematite	Fe_2O_3	45.4

Chemical analysis of the ore showed that the refractory oxidized ore contains 0.98 % Ni and 0.05 % Co, which are bound in the oxidized ore in the form of the main mineral – kaolinite ($Al_2Si_2O_5(OH)_4$). The chemical composition of the ore is shown in Table 2. It should be noted that the above minerals in HCl are relatively difficult to dissolve with the formation of gelatinous silica. As can be seen from the analysis, nickel and cobalt are associated with hardly soluble silicates. The elemental composition of the oxidized nickel-cobalt ore is shown in Table 3.

Table 3. Elemental composition of oxidized nickel-cobalt ore

Component	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**K**	**Y**	**Ca**
Content, %	0.49	8.45	1.45	19.50	0.02	0.05	0.04	0.004	0.65
Component	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Sr**	**Zn**
Content, %	0.01	0.02	0.58	0.20	13.14	0.05	0.98	0.01	0.01

The material composition was determined by a Leica DM2500 P microscope. The sample was studied in immersion liquids with different refractive indices. Liquids with refractive indices characteristic of nontronite (kaolinite) from N=1.550 to N=1.600 were selected. The refractive index of nontronite (kaolinite) is about 1560. The content of nontronite, defined as kaolinite, according to X-ray diffraction analysis is 9.7 %. Kaolinite containing Fe belongs to the nontronite group.

Nontronite is a clayey material, a sheet silicate of the montmorillonite group (smectite group), with the formula $(Fe,Al)_2[Si_4O_{10}][OH]_2 \times nH_2O$. Usually contains significant amounts of Al_2O_3 (up to 14 %) and Mg (up to 8 %), also CaO (up to 2 %), in small amounts of K_2O, Na_2O, sometimes NiO, Cr_2O_3. Cobalt and nickel in this ore are isomorphically related to the mineral badellite $Al_2[Si_4O_{10}][OH]*nH_2O$. The mineral has a brownish-green color. The presence of iron oxides gives it a brownish hue. In the immersion preparation, the product has a leafy form (see Fig. 3).

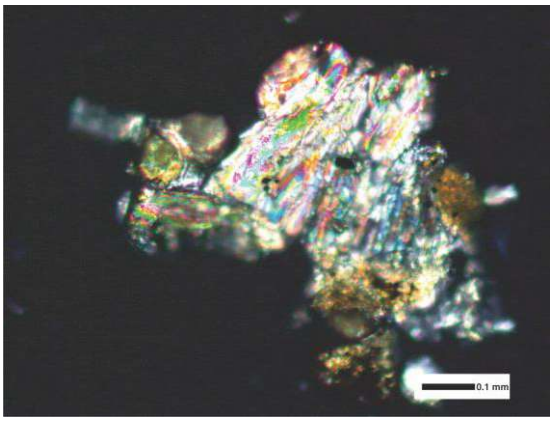

Fig. 3. Nontronite in the immersion preparation. Magnification 100, Nicoli +

Serpentine forms nests in nontronite rock. Serpentine as a radiating aggregate of grains, nontronite is present as a cryptocrystalline aggregate.

According to the refractive index, serpentine belongs to group IV, so the relief and shagreen surface are weak. In thin sections the mineral is colorless or yellowish-greenish, but in colored varieties the pleochroism is absent or hardly noticeable.

Serpentine is similar to chlorite in optical properties, and differs from it in mineral association. Serpentine develops mainly from olivine, rhombic pyroxene, and chlorite by monoclinic pyroxene, hornblende, biotite (see Fig. 4).

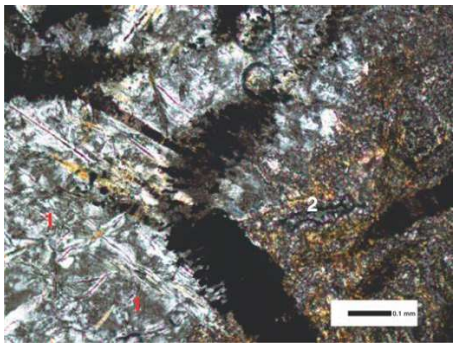

Fig. 4. Serpentine (1)-nontronite rock (2). Transparent thin section, magnification 100, Nicoli +

Scanning Electron microscope images at different scales of crushed particles of oxidized nickel-cobalt ore are shown in Figure 5. As can be seen from Figure 5, the size of most of the particles is not bigger than 45 microns and are mostly aggregates of ultrafine particles, but there are also smaller particles with an average diameter in the range of 100 to 620 nm.

As shown by the chemical analysis of the studied ore, the silicate content in the ore is quite high (19.5%, Table 2), which in turn complicates the dissolution process. Therefore, a cheap but effective reagent - ammonium fluoride (NH_4F) – was chosen for the effective destruction of silicate groups.

It should be noted that in order to achieve optimal extraction of the target metals it is necessary to consider the optimal parameters affecting the dissolution process, such as the concentration of dissolving reagents, solid-to-liquid ratio, stirring rate, and leaching duration, and temperature (Ospanov et al., 2020; Ospanov et al., 2021). In addition, orthogonal scheduling of the experiment of the second order with a "star shoulder" ($\alpha = \pm 1.215$), where it is necessary to change only one particular factor while keeping the others strictly constant, was used to select the optimal conditions for the complex extraction of nickel and cobalt from the oxidized ore (Smailov et al., 2022).

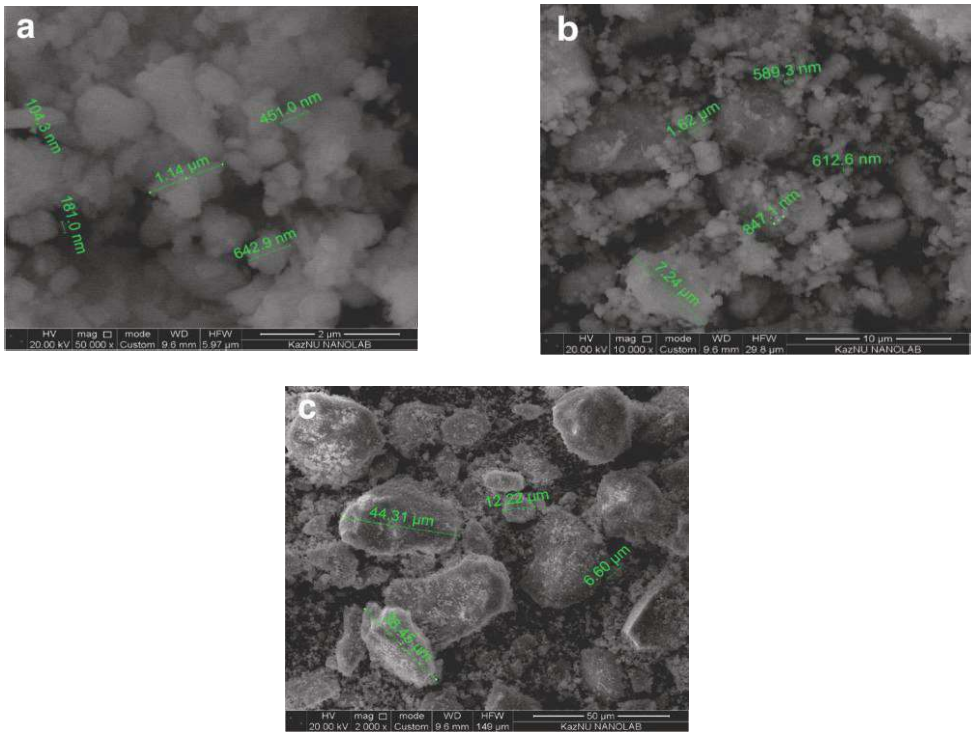

Fig. 5. Scanning electron microscope images of oxidized nickel-cobalt ore at magnifications of (a) 2 µm, (b) 10 µm, (c) 50 µm.

During the experiment, a sample (5.0 g) of oxidized nickel-cobalt ore was placed in a sealed reaction vessel of 250 cm^3, then added 100 cm^3 of aqueous solution containing 15 cm^3 of concentrated hydrochloric acid. After every 60 minutes, 1 g of ammonium fluoride was added under constant stirring at 250 rpm with a

T:L ratio of 1:20 for 300 minutes. The temperature was gradually raised from 273 K to 353 K and maintained at this temperature until the end of the dissolution process. The resulting hydrochloric acid solution was filtered through a medium-density filter and the precipitate was washed 5-6 times with 1 mol/dm^3 hydrochloric acid, and the filter with the cake was discarded. Then, the filtrate was analyzed to determine the content of valuable components by using a PerkinElmer Inc. 8300 DV inductively coupled plasma emission spectrometer.

This experiment was conducted in 4 parallels and their error was less than ±5%. Table 4 below shows the results of the search for optimal conditions of nickel and cobalt extraction, taking into account the various parameters mentioned above.

Table 4. Degree of Ni and Co extraction depending on various factors

NH_4F concentration, %	Ni extraction rate, %	Co extraction rate, %
2.0	84.2	82.7
3.0	87.7	84.2
4.0	91.5	87.6
5.0	**98.4**	**90.7**
6.0	96.2	91.5
Temperature, K		
298	58.2	52.7
323	71.7	64.2
343	84.5	83.6
353	**98.4**	**90.7**
363	96.5	91.8
HCl concentration, %		
5	51.4	47.5
10	71.1	63.3
15	**98.4**	**90.7**
Duration of the experiment, min		
120	49.0	46.3
180	68.5	54.2
240	88.2	82.7
300	**98.4**	**90.7**
360	96.4	91.5
Ratio of solid to liquid (S:L)		
1:10	64.6	54.0
1:15	83.2	77.4
1:20	**98.4**	**90.7**
1:25	96.7	91.5
Stirring speed, rpm		
200	88.7	83.5
250	**98.4**	**90.7**
300	96.6	91.4

Research Results and Discussion

From the results tabulated in Table 4, it is deducible that optimal conditions for the recovery of nickel and cobalt have been determined. These include the following parameters:

- a concentration of 5% and 15% for the dissolving reagents NH_4F and HCl respectively;
- an experimental duration of 300 minutes;
- a solid-to-liquid ratio (S: L) set at 1:20;
- a stirring speed maintained at 250 rpm.

Under these stringent yet necessary conditions, the extraction efficacy of nickel was observed to be 98.4% while that of cobalt reached 90.7%. It is worth mentioning that deviations below these critical values resulted in diminished extraction efficiency for both target metals.

These findings underscore several salient advantages of the proposed method over existing approaches. Firstly, the method utilizes cost-effective and readily available reagents of less toxicity that are

sourced locally. Secondly, the technique significantly enhances the extraction efficiency of nickel and cobalt from refractory oxidized ores. Thirdly, the incorporation of NH_4F in HCl enables extraction to be undertaken at 353K under normal atmospheric pressure, thus accommodating ores of diverse compositions. Additionally, this method not only achieves extraction of nickel and cobalt but also facilitates the recovery of other valuable associated metals in a comprehensive manner.

Based on the results obtained, a novel scheme of hydrometallurgical processing of oxidized nickel ores has been proposed. This includes the following steps: the ores are first crushed and ground from 45 microns down to 0.6 microns, then subjected to flotation for enrichment. Subsequently, the ore undergoes leaching at 353K with an NH_4F-based composition in HCl. The dissolved ore is then filtered before precipitation of nickel, cobalt, and associated metals occurs. The filtrate is then cycled back to the start of the process. The final steps encompass the decontamination and neutralization of filtrate, and the resultant cake is either disposed of securely or repurposed within the construction industry. Figure 6 provides a graphical illustration of this proposed technological scheme of complex extraction of nickel and cobalt from oxidized nickel-cobalt-containing raw materials.

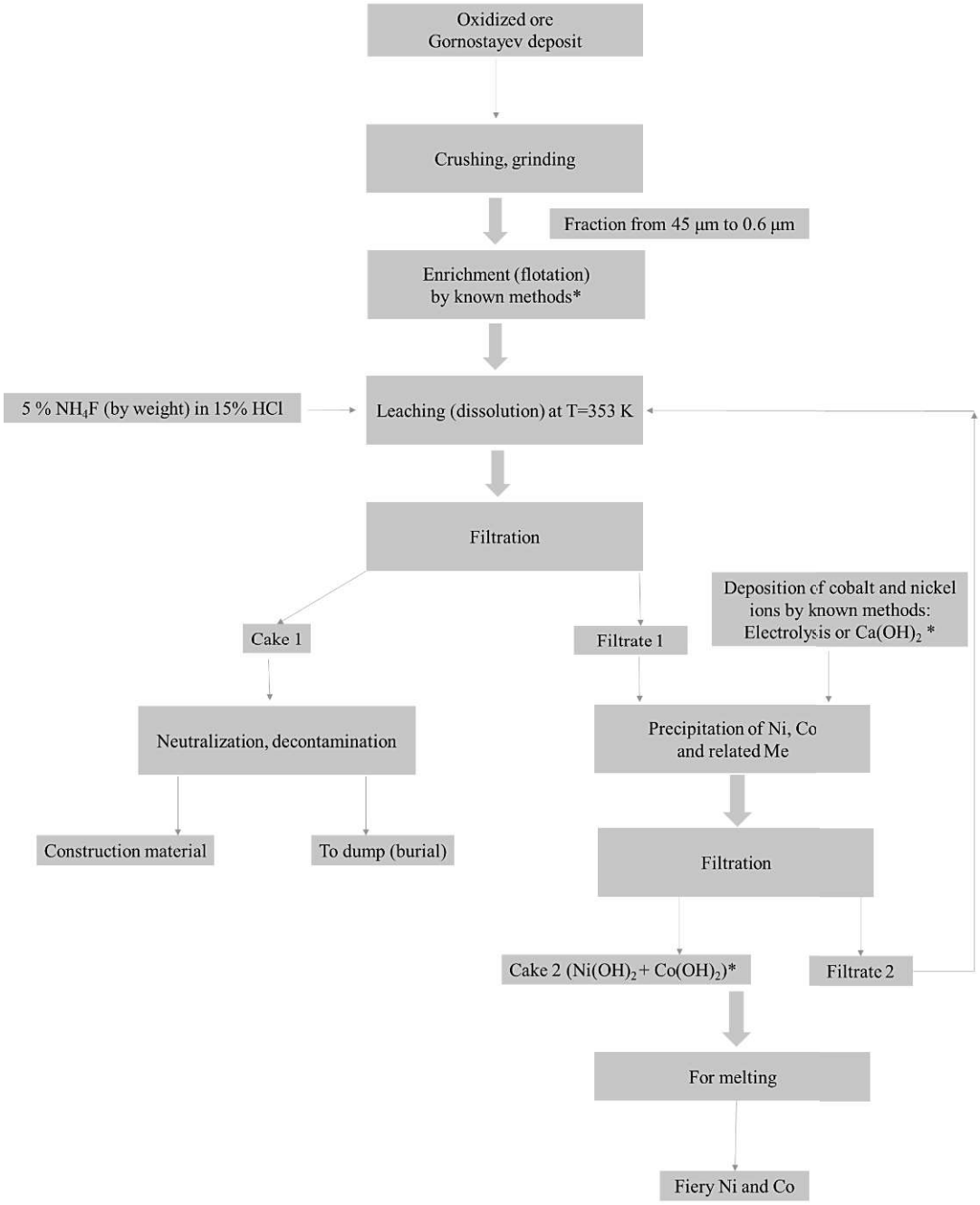

Fig. 6. Basic technological scheme of complex extraction of nickel and cobalt from oxidized ore of Gornostayev deposit

In summary, this research paper proffers an innovative, environmentally friendly, and cost-effective scheme for the comprehensive extraction of nickel and cobalt from oxidized nickel-cobalt-containing ores, using local reagents of less toxicity. The optimal conditions for the dissolution of nickel and cobalt-bearing minerals have also been precisely determined.

Conclusions

In the contemporary economic climate, characterized by acute oscillations in global market prices of nickel and cobalt, an exigent issue arises regarding the economically viable processing of low-grade oxidized nickel ores indigenous to Kazakhstan. In an endeavor to address this, we proposed a novel and more promising hydrometallurgical methodology as a feasible alternative to the extant ore processing techniques being implemented within the nation.

The novelty of our technology revolves around the comprehensive extraction of nickel and cobalt from oxidized nickel-cobalt-bearing resources. This innovative approach is distinctive in its obviation of the high-temperature process. Conventionally, this process is notorious for the emission of noxious gases and has a proclivity for energy profligacy. Our method, thus, not only minimizes environmental hazards but also underscores energy conservation - features that are instrumental in driving the transition towards sustainable mining practices.

Upon meticulous analysis of the experimental data gleaned from our research, we ascertain that our groundbreaking technology facilitates enhanced extraction efficacy of nickel and cobalt from refractory oxidized ores. We therefore postulate that the deployment of this technology in industrial-scale operations can potentially revolutionize the nickel and cobalt mining landscape by augmenting metal recovery rates, thereby maximizing resource utilization and industrial efficiency.

In summary, our work is not only responsive to the immediate challenges posed by fluctuating commodity prices, but it also sets a benchmark for future endeavors in the field, thus pushing the frontier of sustainable mining practices. Further research will be instrumental in understanding the scalability of this innovative technology and its broader implications for the industry.

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Yulinda Erma Suryani
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: yulindaerma.2021@student.uny.ac.id
https://orcid.org/0000-0002-6953-9595

Heri Retnawati
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: heri_retnawati@uny.ac.id
https://orcid.org/0000-0002-1792-5873

Nur Hidayanto Pancoro Setyo Putro
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: nur_hidayanto@uny.ac.id
https://orcid.org/0000-0002-3019-8498

Zhanerke Khamit
Abai Kazakh National Pedagogical University
050010, Dostyk ave., 13, Almaty, Kazakhstan
E-mail: janerkehamit49@gmail.com
https://orcid.org/0000-0001-5731-5466

Cognitive Abilities of Senior High School Students

Abstract: The Scholastic Assessment Test is a test used to measure cognitive abilities. The Scholastic Assessment Test predicts prospective students who are able to complete their studies in college well and on time. This study aims to (1) describe the cognitive abilities of high school students through the scores of the Scholastic Assessment Test on Computer-Based Written Examination in 2021; (2) find out the subtest that has the most influence on the Scholastic Assessment Test score. This study uses secondary data, namely the mean score of the SMA/MA Scholastic Assessment Test in the province of Yogyakarta Special Area which is included in the Top 1000 results of the 2021 Computer-Based Written Examination. In the Province of Yogyakarta Special Area, there are 83 schools that fall into the Top 1000 category with details: 28 Senior High Schools in Yogya City, 23 schools in Sleman Regency, 18 schools in Bantul Regency, 7 schools in Gunung Kidul Regency, and 7 schools in Kulon Progo Regency. The data analysis methods used in this study were descriptive statistics and multiple regression analysis. The results of data analysis show that the highest average of students' cognitive ability in the low group is reading comprehension and writing ability, in the medium group the highest average is reasoning ability, and in the high group, the highest average is quantitative ability. Based on the results of the regression analysis, it can be seen that the reasoning ability subtest has the greatest contribution to the Scholastic Assessment Test scores of high school students in the Special Area of Yogyakarta.

Keywords: Cognitive ability, Computer-Based Written Examination, Scholastic Assessment Test.

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Introduction

Cognitive ability shows the intellectual capacity or function of human thinking. Intellectual capacity is an individual's basic capital to develop to achieve optimal performance. The potency test is designed to predict the chances of future success by uncovering relevant basic abilities. The assessment test prioritizes the predictive function rather than the description function. Because of this predictive function, the potency tests are very useful in the selection process. The general ability test used to measure cognitive abilities is known as the Academic Assessment Test. The Academic Assessment Test serves to reveal general assessments related to academic tasks and is used as a predictor of learning success in college (Azwar, 2016; Arlinwibowo et al., 2020; Sheriyev et al., 2016).

The Academic Assessment Test has been used to measure the cognitive abilities of prospective students in the selection of new students for a long time. There are several tests that have been developed abroad for the purpose of selecting new students, including the SAT (Scholastic Aptitude Test), GMAT (Graduate Management Admission Test), or LSAT (Law School Admission Test). When students are given the

opportunity to complete their studies, these tests are proven to be able to predict student performance well (Young et al., 2014).

Since 2019, the Joint Selection for State University Entrance has used the Computer-Based Written Examination (CBWE). The Higher Education Entrance Test Institute (LTMPT) is an institution that organizes standardized higher education tests in Indonesia that organizes CBWE. The implementation of the CBWE test by LTMPT has advantages including: credible, standardized test results, the implementation of the test can be followed by many participants at once in a short time, and test results are given individually (Sulaiman & Khaerudin, 2021). CBWE predicts prospective students who are able to complete their studies in higher education well and on time. Therefore, the selection of admission to universities uses the Scholastic Assessment Test (Lyren, 2008). There are three components of the test material in CBWE, namely the Scholastic Assessment Test (SAT), English, and Academic Competency Test (Permen Ristek Dikti, 2018). The CBWE of the Scholastic Assessment Test is the same as other tests used in the selection of new student admissions which aim to predict individual performance in the future (Kolbrin et al., 2008). The assessment test uses constructs related to student assessment, trying to predict students' understanding and use of information from various types of sources to support their goals (Cook, 2009).

Until 2021 the CBWE has been carried out 3 times, but studies on the results of CBWE, especially the Scholastic Assessment Test, have not been found. Based on the data from the Scholastic Assessment Test, what is the cognitive ability of senior high school students in Yogyakarta? Among the four sub-tests of the Scholastic Assessment, which sub-test has the highest correlation with the score of the Scholastic Assessment Test results? This research was conducted using data from the 2021 CBWE results, in particular the results of the Scholastic Assessment Test scores. The data of score results were analyzed using descriptive statistics to obtain an overview of the cognitive abilities of high school students in Yogyakarta Special Area.

The SAT tested in the CBWE consists of four subtests, namely General Reasoning Ability, Quantitative Ability, General Knowledge and Comprehension, and Ability of Reading comprehension and Writing. Quantitative abilities include knowledge and mastery of basic mathematics. The results of these four subtests build students' cognitive abilities which are one of the indicators in the selection of new student admissions at State Universities. Among the four SAT subtests, which subtest has the most influence on the Scholastic Assessment Test score? Therefore, in this study, researchers conducted a study of the results of this SAT score in order to provide an overview to researchers in developing instruments that measure students' cognitive abilities.

The description of the cognitive abilities of senior high school/Islamic senior high school students in the Special Area of Yogyakarta can be used as input for researchers in conducting studies on the cognitive abilities of senior high school students, what things must be prepared so that students are able to face the challenges they will face in higher education. The results of this study provide an initial overview for researchers to develop an instrument to measure the cognitive abilities of senior high school students, which will later be used to help prepare senior high school students to face college entrance selection.

Research Methods

In accordance with the research objectives, to describe the cognitive abilities of senior high school students in Yogyakarta Special Area (DIY), this type of research used descriptive research. The source of the data used in this study was the result score of the Computer-Based Written Examination (CBWE) on Scholastic Assessment Test (SAT) in the Province of Yogyakarta Special area in 2021. There are 83 schools in Yogyakarta Special Area that are included in the Top 1000 schools (www.ltmtp.ac.id), with the following details: there are 28 schools in Yogya City, 23 schools in Sleman Regency, 18 schools in Bantul Regency, 7 schools in Gunung Kidul Regency, and 7 schools in Kulon Progo Regency. The data used were the mean scores of SAT, quantitative ability, ability to understand reading and writing, reasoning ability, and general knowledge and comprehension. The data analysis technique used in this research was descriptive statistics, using the SPSS.21 program and multiple linear regression analysis using the Lisrel.850 program.

Data Analysis Results

The Computer-Based Written Examination (CBWE) in 2021 was followed by 23,110 schools in Indonesia. The number of participants who took part in the CBWE was 777,858 participants. The Higher Education Entrance Test Institute (LTMPT) as the organizer performed a ranking (Top 1000 schools) using the total score calculated based on the CBWE score consisting of 60% SAT (Scholastic Assessment Test) + 40% ACT

(Academic Competency Test) from participants in each school. The schools included in this ranking are schools with more than 40 participants taking the CBWE in 2021. The number of schools that meet these criteria is 4,432 schools. In the Province of DIY there are 83 schools that are included in the Top 1000. Descriptive statistics on cognitive abilities of students in DIY can be seen in the table 1.

Table 1. Descriptive Statistical Results of Cognitive Ability of SMA/MA Students in DIY

Regency/City	Mean Score	Standard Deviation	Highest Score	Lowest Score
Quantitative	545,22	48,347	670,713	521,029
Reading	560,57	31,777	643,812	532,208
Reasoning	560,41	31,534	641,560	530,547
Knowledge	557,47	33,188	647,595	527,218
Scholastic Assessment Test	542,85	25,704	616,584	512,411

Based on the SAT scores from the eighty-three schools, the schools were grouped into three levels, namely: High SAT score group, Medium SAT score group, and Low SAT score group. The results of the grouping can be seen in the table 2.

Table 2. Results of Grouping Cognitive Ability of SMA/MA Students in DIY

Region	High Group	Medium Group	Low Group	Amount
Yogya City	7 Schools (8,433 %)	7 Schools (8,433 %)	14 Schools (16,87%)	26 Schools (33,734%)
Bantul Regency	1 School (1,204%)	5 Schools (6,024%)	12 Schools (14,457%)	17 Schools (21,686%)
Sleman Regency	2 Schools (2, 409 %)	5 Schools (6,024%)	16 Schools (19,277%)	23 Schools (27,710%)
Gunung Kidul Regency	1 Schools (1,204%)	1 School (1,204%)	5 Schools (6,024%)	7 Schools (8,433 %)
Kulon Progo Regency	0 School	2 Schools (2, 409 %)	5 Schools (6,024%)	7 Schools (8,433 %)
Total	11 Schools	20 Schools	52 Schools	83 Schools

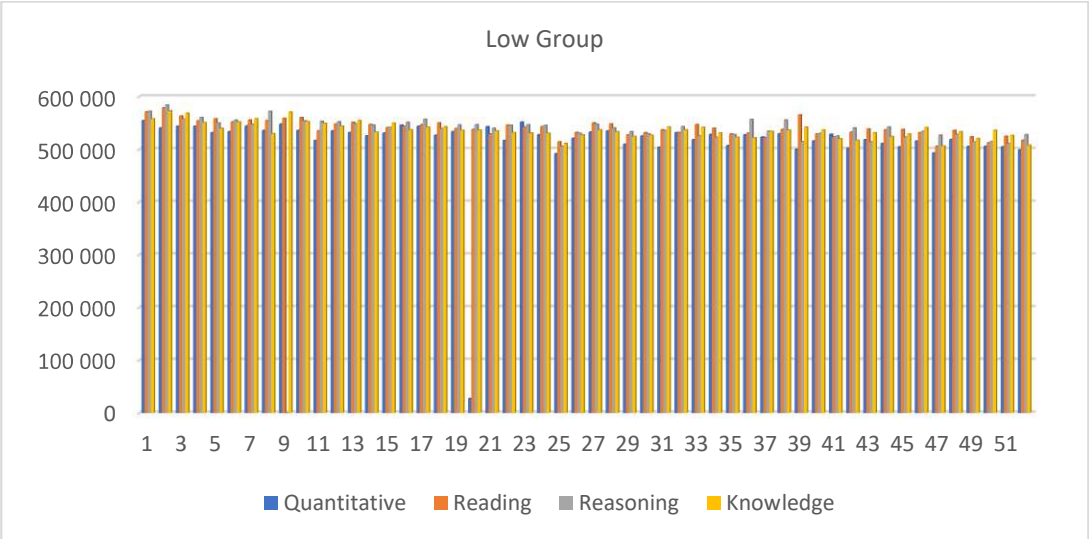

Chart 1. The Low Cognitive Ability Group

There are 26 schools in the city of Yogya that are included in the Top 1000, in Bantul Regency with 17 schools, in Sleman Regency with 23 schools, in Gunung Kidul Regency with 7 schools and in Kulon Progo Regency with 7 schools. Based on the grouping, there are 11 schools in the high cognitive ability group, 20 schools in the medium cognitive ability group and 52 schools in the low cognitive ability group. The high and medium groups are dominated by schools in Yogya City, there are 7 schools belonging to the high group and 7 schools belonging to the medium group. While in the low group the most are schools in Sleman Regency, as many as 16 schools are included in the high group, 7 schools are in the medium group and 12 schools are in the low group.

In the low group (Chart 1), the mean score of students' cognitive ability is 516,171. The mean score of students' quantitative ability is 515,057; the mean score of reading comprehension and writing ability is 540.509; the mean score of general reasoning ability is 540,229 and the mean score of general knowledge and comprehension is 536,674.

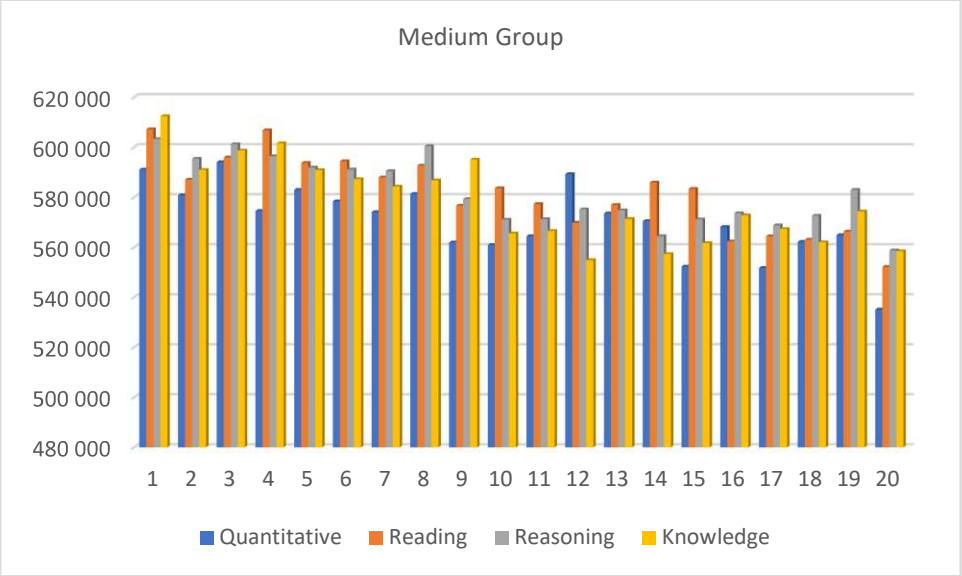

Chart 2. The Medium Cognitive Ability Group

In the medium group (Chart 2), the mean score of students' cognitive ability is 559,696. The mean score of students' quantitative ability is 570,622; the mean score of reading comprehension and writing ability is 581.393; the mean score of general reasoning ability is 581,731 and the mean score of general knowledge and comprehension score is 578.018.

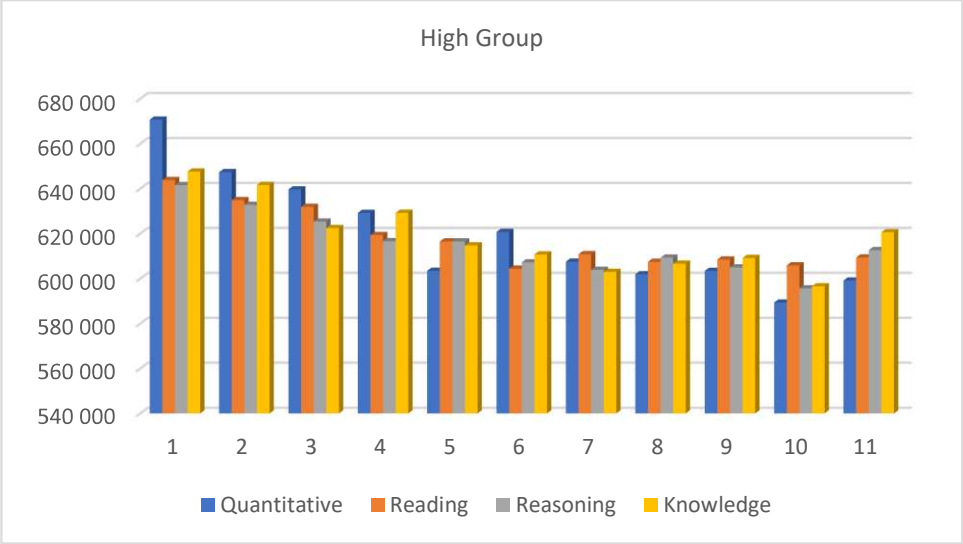

Chart 3. The High Cognitive Ability Group

In the high group (Chart 3), the mean score of students' cognitive ability is 535,820. The mean score of students' quantitative ability is 619,302; the mean score of reading comprehension and writing ability is 617,529; the mean score of general reasoning ability is 615,128 and the mean score of general knowledge and comprehension is 618,384. In the high group, among the four SAT subtests quantitative ability has the highest mean score among the other three subtests.

The Scholastic Assessment Test consists of four subtests, to find out which of the four subtests has the greatest contribution to students' cognitive abilities, the data analysis was carried out using Structural Equation Modeling. Data processing and analysis used Lisrel version 8.51, the estimation results and the model formed are shown below.

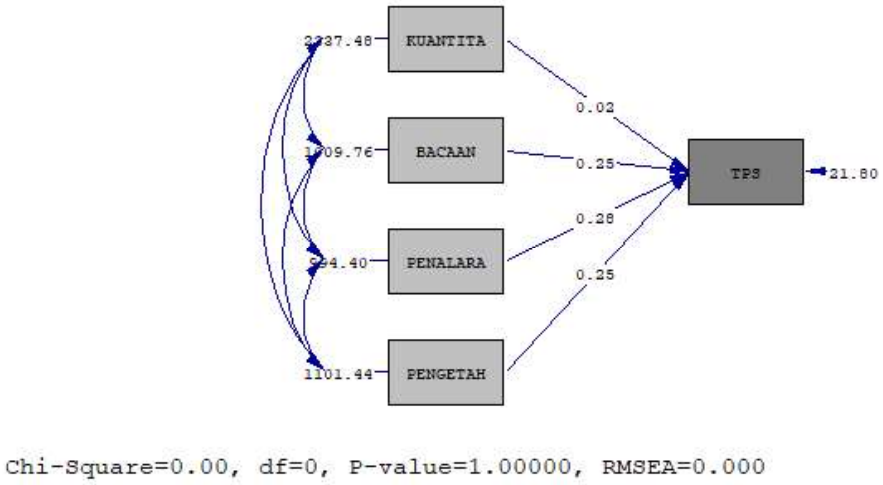

Figure 1. SEM Results of Scholastic Assessment Test

In the picture above, it can be seen the effect of each subtest on the score of the Scholastic Assessment Test (Figure 1). The correlation coefficient of quantitative ability to the Scholastic Assessment Test is 0.02. The correlation coefficient of reading comprehension and writing ability on the Scholastic Assessment Test is 0.25. The correlation coefficient of reasoning ability to the Scholastic Assessment Test is 0.28. The correlation coefficient of general knowledge and comprehension of the Scholastic Assessment Test is 0.25. Based on the correlation coefficient value of each subtest, it can be seen that the reasoning ability has the highest correlation coefficient value, thus it can be concluded that the subtest that has the largest contribution to the Scholastic Posttension Test is reasoning ability. This can also be seen in the results of Structural Equations.

```
LISREL Estimates (Maximum Likelihood)

        Structural Equations


     TPS = 97.03 + 0.022*KUANTITA + 0.25*BACAAN + 0.28*PENALARA + 0.25*PENGETAH, Errorvar.= 21.80, Rý = 0.97
         (9.84)  (0.018)          (0.063)       (0.053)         (0.058)                    (3.49)
          9.86    1.24             3.88          5.38            4.22                       6.24
```

Figure 2. Results of the Regression Equation of the Scholastic Assessment Test

In the Structural Equation figure 2, it can be seen that the correlation coefficient value of the quantitative ability subtest is 0.22 with an error of 0.018 and a t-statistic value of 1.24. The correlation coefficient value of the reading and writing comprehension subtest is 0.25, with an error of 0.063 and a t-statistic value of 3.88. The estimated value of correlation coefficient of the reasoning ability subtest is 0.28 with an error of 0.053 and a t-statistic value of 5.38. Meanwhile, for the general knowledge and comprehension subtest, the correlation coefficient value is 0.25 with an error of 0.058 and a t-statistic value of 4.22. Based on

these data, it can be seen that only the quantitative ability subtest has no effect on the student's Scholastic Assessment Test because the t-statistic value is <1.96 at the 5% significance level. The reading comprehension and writing subtest, reasoning ability, and general knowledge and comprehension subtest have a significant effect on the Scholastic Assessment Test score because the t-statistic value is > 1.96.

The value of the constant (intercept) of 97.03 can be interpreted that if the subtest of quantitative ability, reading comprehension and writing ability, reasoning ability, and general knowledge and understanding is equal to 0 (zero), then the Scholastic Assessment Test value obtained is 97.03. The results of the regression analysis show that the R-square value obtained by the Scholastic Assessment Test is 0.97, meaning that quantitative abilities, reading comprehension and writing ability, reasoning ability, and general knowledge and comprehension are able to explain variations in the Scholastic Assessment Test by 97%.

Research Discussion

This study aims at describing the cognitive abilities of senior high school students in Yogyakarta Special Area based on the CBWE scores in 2021. In addition, this study also wants to find out which subtest has the greatest influence on students' cognitive abilities. The results of data analysis show that the highest mean score of students' cognitive ability in the low group is reading comprehension and writing ability, the highest mean score of students' cognitive ability in the medium group is reasoning ability, and in the high group the highest mean score is quantitative ability. Based on the results of the regression analysis, it can be seen that the reasoning ability subtest has the greatest contribution to the Scholastic Assessment Test scores of high school students in Yogyakarta Special Area.

Reasoning is a mental activity that involves a variety of information to reach conclusions, which provide a more specific picture of the results of the process of observation, facts, and conjectures (Wade & Tavris, 2008). In reaching conclusions, reasoning uses a logical mindset by induction and deduction (David Moshman, 2014). Thinking processes used in reasoning include: paying attention, observing, providing information related to patterns that have been presented in an event or phenomenon. Reasoning allows students to give reasons, argue when students conclude or make a conclusion. To explain what they think, make judgments, make decisions, students can use appropriate language based on reasons or evidence (Fox, Sue., Surtees, 2010).

Reasoning ability is the ability to think logically, actions taken are such as analyzing, proving, evaluating, explaining, concluding, justifying and generalizing (Herbert et al., 2016). Reasoning as a process, allows students to review or rebuild their previous knowledge to make new arguments (Mueller et al., 2014;). The reasoning process involves an approach to investigating, evaluating allegations, and developing arguments to convince oneself or others that the conjectures are true (Goos et al., 2020). By reasoning students are free to be creative, create technology. It is very important to know the students' reasoning ability in class, so that in the future there will be outstanding students, who can compete and are strong in facing various challenges (Richard I. Arends, 2010).

The results of the regression analysis show that the subtest that has the greatest influence on the score of the Scholastic Assessment Test was Reasoning Ability. It is unfortunate that the mean score of reasoning ability in the high group is even the lowest. General cognitive ability can predict academic achievement, there is no specific cognitive ability that contributes to academic achievement after general cognitive ability can be controlled (Rohde & Thompson, 2007). Reasoning ability is positively correlated with students' academic achievement (Ahmad et al., 2020). Therefore, students need to receive training in order to get high scores in academic achievement. Students must receive training to increase their capacity for reasoning (K.V. Rani, 2018). Assessment of reasoning ability is also useful in identifying students who have learning difficulties (Coletta et al., 2007). There are many factors, both internal and external, that influence students in pursuing their education. One that has contributed to learning achievement is reasoning ability. In accordance with the results of data analysis, it is the reasoning ability that has the highest correlation with the Scholastic Assessment Test score.

The reasoning ability possessed by students is a fixed assessment, depending on environmental factors. Reasoning ability can develop in the form of performance if there are stimuli from the environment and training. Assessment is the limit of optimal performance that may be achieved by students. Therefore, it is very necessary for students to develop their reasoning abilities. Achievements achieved by students are an interactive blend of assessment and effort (learning and training). The maximum performance that can be achieved by students is influenced by effort and is limited by their cognitive assessment. The level of

performance that can be shown by individuals is unstable from time to time. Lack of training or learning will reduce achievement. The increasing of training or learning will increase achievement as far as its assessment allows.

The description of the cognitive abilities of senior high school/Islamic senior high school students in Yogyakarta Special Area can be used as an input for researchers in conducting studies on the cognitive abilities of senior high school students, what things must be prepared, so that students are able to face the challenges they will face in higher education. The results of this study provide an initial overview for researchers to develop instruments to measure cognitive abilities, especially measuring the reasoning abilities of senior high school students

Conclusion

The Scholastic Assessment Test at the 2021 Computer-Based Written Examination consists of four subtests, namely quantitative ability, reading comprehension and writing ability, reasoning ability, and general knowledge and comprehension subtest. The results of the Scholastic Assessment Test of SMA/MA students in Yogyakarta Special Area show that the highest mean score is reading comprehension ability. The subtest that has the most influence on the score of the Scholastic Assessment Test is reasoning ability.

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Serikpay K. Tutanov
Abylkas Saginov Karaganda Technical University
100027, Ave. Nursultan Nazarbayev, 56
Karaganda, Kazakhstan
https://orcid.org/0000-0002-4773-6395
E-mail: ser-tutanov@yandex.ru

Miruert S. Tutanova
Abylkas Saginov Karaganda Technical University
100027, Ave. Nursultan Nazarbayev, 56
Karaganda, Kazakhstan
https://orcid.org/0000-0002-7905-3599
E-mail: mikochkat1984@mail.ru

Stress-strain state of rock mass around pillars and chambers considering the angle of occurrence of the ore body

Abstract: The task of the study is to determine the parameters of the unstable-deformed state of the rock mass around the targets and the chamber at various angles of occurrence of the ore body. A vertical section of a rock mass is considered. The deformation along the chamber can be neglected and the task is reduced to flat. The number of methodical finite elements is taken as the solution method. To solve the problem, the characteristic conditions of cleaning chambers and tar-gets are modeled. The geometric parameters of the design scheme succeeded with the maximum approximation to real conditions. The characteristic of a solid body and host rocks is given by the modulus of elasticity, Poisson's ratio, and volumetric weight.

Keywords: rock mass, cleaning chambers, host rocks, tensile stresses, multidimensional mathematical models.

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Introduction

Underground mining of flat and inclined ore deposits with an open mining area causes the abandonment of both inter-chamber and protective (barrier) pillars. Known works show that the main methodological approach in calculating the parameters of the pillars is to determine the reaction of the resistance of a unit area of the ore massif to the acting loads falling on this area. In this case, the acting load is taken from the calculation of the entire column of rocks or within the limits of the arch of natural equilibrium. Both approaches have sufficient grounds for use in determining the dimensions of the pillars. However, they are acceptable when the rock top layer is represented by a homogeneous massif and it is possible to form an equilibrium dome. However, in cases of intermit-tent deposits and in the presence of layered rocks of different strengths, the known methods do not allow the calculation of the dimensions of technogenic spaces, including pillars, with sufficient accuracy. When calculating the parameters of the pillars, they exceed their optimal values, and this leads to the loss of a mineral or to premature collapse of both the pillars and the roof of the chambers and panels.

Thus, the development of technology for the extraction of flat and inclined ore deposits based on an array of powerful quantum-deformed states (QSS), and their influence on the elements of the system, is an important scientific and technical part (Veksler & Tutanov, 1988; Abikak et al., 2023).

Research analysis

The task of the research is to determine the parameters of the stress-strain state (SSS) of the massif, which affects the stability of pillars and treatment chambers, considering creep.

To process studies to determine the stress-strain state of a rock mass, in particular, to determine the stable dimensions of supporting pillars and chambers during field development, using an unconventional method for

constructing multidimensional mathematical models, we obtained the following mathematical model, which considers a complex of natural and man-made factors:

$$\sigma_1^{max} = f(\gamma H, b_2, b_1, h_2, E, h_1),$$

where E is the modulus of elasticity of host rocks, γH - is the load (natural factor), σ1max - is the maximum principal stress, b2 - is the height of the pillar, h1 - is the width of the barrier pillar, h2 - is the width of the inter-chamber pillars, b1 - is the width of the chamber (Ermekov & Makhov, 1990).

The maximum principal stress is chosen as a function. At the same time, the following dependences of the function on the arguments were obtained:

$$\sigma_1^{max} = 5.34291*\gamma H**0.634218- 5.16712,$$

$$\sigma_1^{max} =0.128656*e**(0.116583*b_1) +0.52904,$$

$$\sigma_1^{max} =1.16471 – 3.2359 / h_1,$$

$$\sigma_1^{max} =1.65676*e**(-0.0000081*E),$$

$$\sigma_1^{max} =-0.00789461*b_2 **2+0.0577526*b_2+1.04593,$$

$$\sigma_1^{max} =58.3137*h_2 **(-1.47219) – 3.7791,$$

The correlation coefficient R = 0.965, and the analytical equation is as follows:

$$Y(\sigma_1^{max}) = Y(\gamma H)*Y(b_1)*Y(E)*Y(b_2)*Y(h_1) + Y(h_2)$$

When solving the problem, the parameters (technological, mining and geological factors) were changed in the following limits:

$b_1 = 4÷16$ (m) – chamber width at 3 m intervals;

$b_2 = 3÷11$ (m) – power to be withdrawn (pillar height) at 2 m intervals;

$h_1 = 15÷27$ (m) – width of the barrier pillar at 2 m intervals;

$h_2 = 5÷9$ (m) – width of inter-chamber pillars at 1 m intervals;

$\gamma H = 3.75÷18.75$ (MPa) – pressure at 3.75 MPa intervals;

$E_{sur} = 3.2*10^4÷9.6*10^4$ (MPa) – modulus of rock elasticity with an interval of $1,6•10^4$

The following values are taken as the basic version of the calculation:

γH=7,5 MPa (300 m.), B2=7 m., E_{sur}=32000 MPa, h1=15 m.

In order to determine the influence of inclination angles of the ore body, the paired dependences were initially obtained. The allowable compressive and tensile stresses were chosen as a function (Amusin & Linkov, 1973). The following dependences of allowable stresses on the inclination angles were obtained, for tensile allowable stresses:

$$\sigma_{adm} = 0.34\ \alpha – 0.65, \qquad (1)$$

for compressive allowable stresses:

$$\sigma_{adm}=1.68\ \alpha - 3.2, \qquad (2)$$

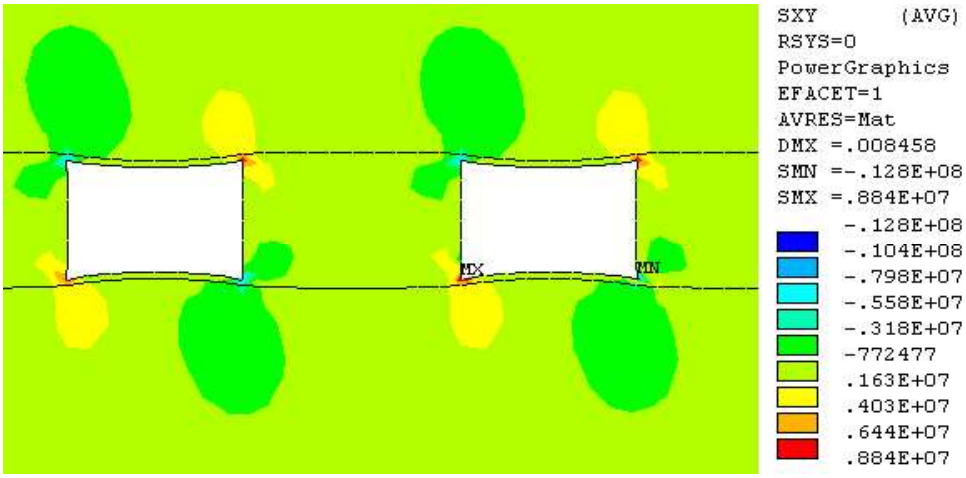
Further, to process research to determine the stress-strain state of a rock mass, in particular, to determine the stable dimensions of supporting pillars and chambers during the development of ore deposits, using a non-traditional method of building multidimensional mathematical models, we obtained a mathematical model that considers the complex natural and anthropogenic factors (Tutanov, 2011; Hu et al., 2015).

The maximum principal stress was chosen as the function. The dependences of the function on the arguments and equation were obtained (Beisembaev et al., 2013).

In order to obtain an equation considering inclination angles instead of allowable tensile stress expression (1) and by formula, obtained for the multidimensional model, we can find complex of factors influencing the stability of pillars and chambers (Shpakov et al., 2015).

Figures 1 and 2 show values of tangential and vertical stresses around chambers. Analysis of tangential and vertical stresses shows that around chambers and pillars, there are tensile stresses, i.e. stresses with positive signs, which increase with the increase of inclination angle. The zone of shear tensile stresses arises in the angular points of the chambers, and the vertical tensile stresses arise in the roof, the ground, and on the sides of the workings (chambers). This indicates that, when the limit stresses occur, rock failure will occur in these areas (Tutanov & Tutanova, 2020).

$\alpha = 0^0$



$\alpha = 10^0$

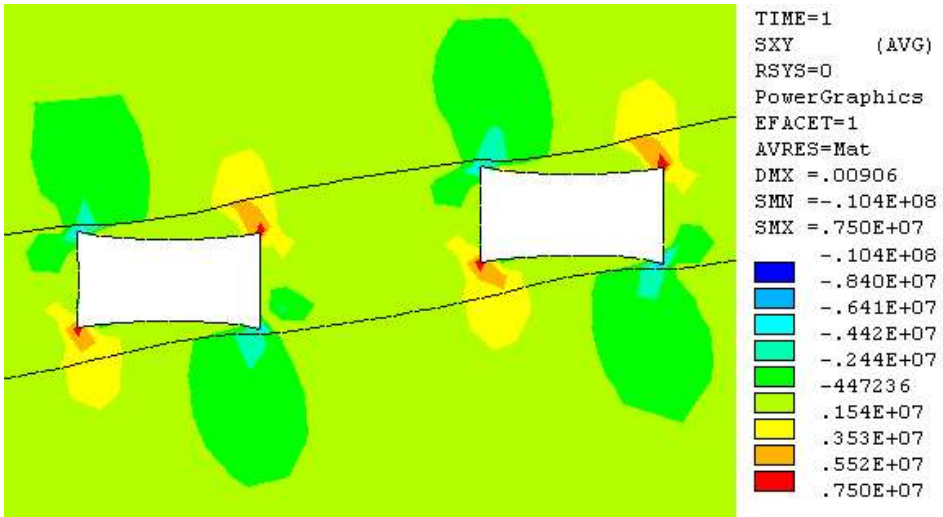
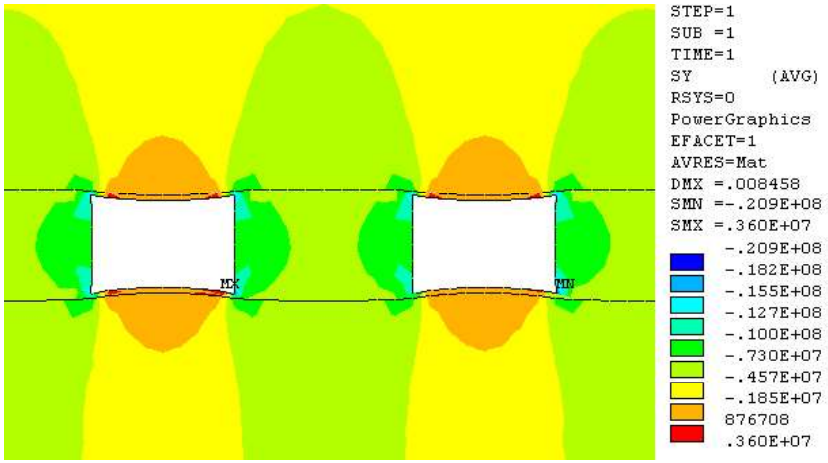


Figure 1 - Tangential stresses in the roof, soil and at their junction with the pillars

α = 0^0



α = 10^0

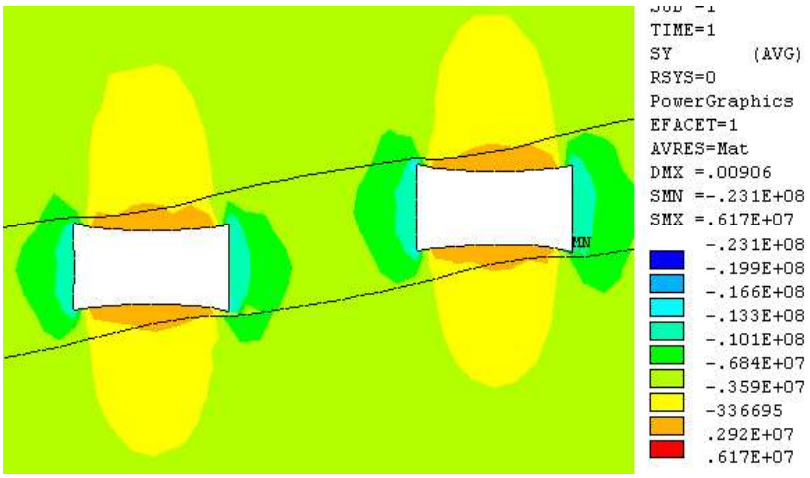
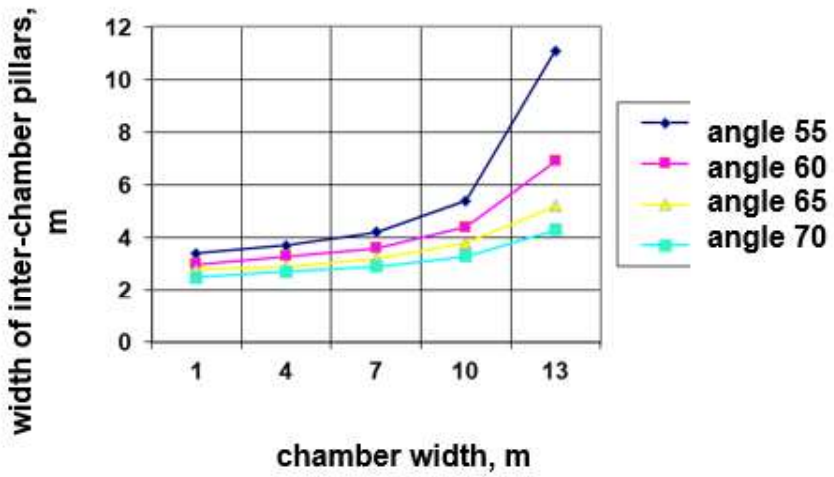


Figure 2 - Vertical stresses in the roof, soil and at their junction with the pillars



γH=7,5 MPa (300 м.), σ_{adm}=0.34 α – 0.65, B2=7 m., E_{sur}=32000 MPa, h1=15 m.

Figure 3 - Dependencies of pillar widths on b1

Thus, the mutual influence of the width of chambers and supporting pillars at different angles of inclination changes according to the obtained curves (Figure 3). Approbation of the methodology for changing conditions of Zhezkazgan was obtained by (Tutanov et al., 2020). At the same time, the dependence of pillar width on various factors, reflecting the main structural elements of the technology of development, was studied.

Conclusion

To sum up, the research methodology allows to establishment of technologically necessary ratios of elements of development systems (parameters of pillars, chambers, panels, etc.) depending on specific conditions. In this case, the optimization of parameters will affect the level of normative losses and stability for the time of excavation of reserves.

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Nurdaulet M. Tasmurzayev
Al-Farabi Kazakh National University, Almaty, Kazakhstan. E-mail: tasmurzayev.n@gmail.com
ORCID ID 0000-0003-3039-6715

Bibars S. Amangeldy
Al-Farabi Kazakh National University, Almaty, Kazakhstan. E-mail: a.s.bibars@gmail.com
ORCID ID 0000-0002-4089-6337

Shona Z. Shinassylov
Al-Farabi Kazakh National University, Almaty, Kazakhstan. E-mail: shona.shinassylov.87@gmail.com
ORCID ID 0009-0002-5491-7255

Yedil S. Nurakhov
Al-Farabi Kazakh National University, Almaty, Kazakhstan. E-mail: y.nurakhov@gmail.com
ORCID ID 0000-0003-0799-7555

Samson Dawit Bekele
Al-Farabi Kazakh National University, Almaty, Kazakhstan
E-mail: samsondawitb@gmail.com
ORCID ID 0009-0005-9719-4343

Smart control system for optimal energy use in the oil and gas sector

Abstract: This paper delves into the development of a smart control system for air conditioning and heating within the oil, gas, and energy sectors. It explores techniques for creating an automated sensor monitoring framework and adjusting sensor settings for temperature and air conditioning management. The proposed intelligent HVAC (Heating, Ventilation, and Air Conditioning) system acquires live data from temperature and leak sensors, along with air conditioning units and switches. The paper introduces the system's structure, its operational principles, schematic representations of the control module, and the monitoring and management setup. The core component of the real-time monitoring and management system is realized through the utilization of the SCADA software for the control and supervision of sensor parameters.

Keywords: Industrial Internet of Things, intelligent Control System, sensor network, real-time monitoring system, energy efficiency.

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Introduction

Thermal comfort, productivity, energy consumption, and overall well-being are significantly influenced by the thermal conditions within buildings, industrial facilities, and various other environments. The primary method of regulating indoor temperatures is through the Heating, Ventilation, and Air Conditioning (HVAC) system. Nevertheless, there is a prevalent issue of localized discomfort within these spaces. To meet the demand for intelligent, on-demand control of indoor thermal conditions, there is a pressing need for innovative strategies to enhance HVAC systems. These intelligent HVAC systems find utility not only in buildings and rooms but also in the Industrial Internet of Things (IIoT), particularly in the oil and gas industry.

Presently, the oil and gas sectors rely on conventional HVAC methods, making intelligent systems an opportunity to provide comfortable working conditions for laborers and equipment, irrespective of extreme climate conditions prevalent in certain oil and gas regions, such as droughts, hot summers, or severe winter temperatures. Moreover, the industry often deals with spaces prone to hazardous gas accumulation, making proper ventilation, an integral HVAC component, crucial for worker safety and explosion prevention. Furthermore, equipment and storage facilities in this sector may require specific temperature maintenance for optimal functioning, a task that HVAC systems can effectively accomplish.

The indoor environment holds paramount importance in people's lives, as approximately 90% of their time is spent indoors (Cheng et al., 2019). Beyond impacting the occupants' thermal comfort and physical health, the thermal conditions inside buildings have a direct bearing on energy consumption (Zhao et al., 2014). HVAC systems are responsible for a significant portion, ranging from 30% to 55%, of a building's total energy usage (Wang et al., 2016). The traditional thermostat-based approach, though straightforward, often falls short in catering to the real-time thermal experiences of occupants, given the thermostat's placement far from where people work.

In essence, there exists a gap between the automatic air conditioning control system and the actual thermal sensations of the occupants. This gap not only complicates efforts to enhance thermal comfort through air conditioning but also impedes energy savings and emissions reduction in buildings. To effectively manage HVAC systems, it is imperative to consider various parameters, including heat and mass transfer processes that can influence air and fluid properties within the system. To optimize HVAC system operation, solving algebraic equations using the Newton-GMRES (Generalized Minimal Residual) method proves essential and is the preferred approach (Imankulov et al., 2021). This method is employed for solving linear and nonlinear algebraic equations that may arise during HVAC system optimization and management.

Numerous research endeavors have aimed to address these challenges (Sheriyev et al., 2016; Retnawati, 2017; Zhapbasbayev et al., 2021; Rohde et al., 2023; Zhapbasbayev et al., 2024). The utilization of human-machine interfaces (HMIs) (Chen et al., 2016), mobile applications (Santosh et al., 2016), and online feedback tools on computers (Samuel et al., 2014) has shown promise in improving thermal comfort, energy efficiency, and environmental well-being by gathering user thermal comfort data. Model-free control techniques, relying on user thermal sensations feedback, have demonstrated significant energy savings (Jazizadeh et al., 2014). Some researchers have integrated user thermal preferences into HVAC system control methods for personalized intelligent control (Ghahramani et al., 2014). Control methods incorporating a thermal comfort model and infrared thermography have enhanced comfort without disrupting daily routines (Zhao et al., 2016). However, infrared thermography may lose accuracy in low-light conditions or when users are distant. To assess subjective thermal sensations, wristbands monitoring skin temperature on the wrist and fingertip have been utilized (Ghahramani et al., 2018). Additionally, wearable devices of laboratory quality have been employed to create personal thermal comfort models for everyday activities (Liu et al., 2019). In our previous research (Tasmurzayev et al., 2022; Tasmurzayev et al., 2021), a software package based on the well-known Internet of Things platform Genesis64 played a pivotal role. This software package represents the 'upper' level of the Smart City system, facilitating process visualization, management, indicator analysis, and predictive process modeling.

To address the challenges, this article endeavors to develop a data management system for room temperature control and a corresponding software and hardware complex. The article is organized as follows: Section 2 covers the development and design process, along with application, server, and database implementation. Section 3 encompasses framework testing and result presentation, with the conclusion drawn in the final section.

Architecture of the System

The intelligent HVAC system is an advanced ventilation solution equipped with 11 different sensors, enabling users to have precise control over each room's temperature at any given moment. This system not only monitors temperature variations in each room throughout the day but also automatically adjusts airflow to maintain the preferred temperature settings of occupants. What sets the intelligent HVAC apart is its ability to track these changes, thanks to its connection to cloud-based technology.

Moreover, beyond temperature control, these intelligent HVAC systems also actively oversee and manage carbon dioxide levels and indoor air quality. By employing real-time energy management and a sophisticated algorithm, these smart HVAC units can adapt and sustain desired room temperatures in response to fluctuations in the external environment.

Figure 1 illustrates the operational space, responsible for monitoring and controlling room temperature and air conditioning. It also houses essential components such as the control box, local server, and monitoring panel, featuring the following functionalities:

- Real-time room condition monitoring.
- Utilization of microcontrollers to regulate the air conditioner and heating system, leveraging devices like Siemens SIMATIC S7-1200, Siemens SIMATIC IoT 2040, and Raspberry PI 4.
- Reduced power consumption, contributing to energy efficiency.

Figure 1. Control Room Configuration

The test setup for the intelligent temperature and air conditioning control system, as depicted in Figure 1, comprises the following key components:

- A control and command cabinet equipped with I/O modules and a programmable controller.
- An array of sensors and actuators.
- The VEGA Absolute wireless data acquisition system, leveraging LoRaWAN technology for communication.
- A video surveillance system.
- The SCADA Genesis64 software installed in an automated workplace referred to as APM.

The monitoring system showcased in Figure 1 serves as an automated system directly linked to the control unit. This system is comprised of a controller and input/output modules, responsible for receiving data from various sources, including temperature sensors, leak detectors, air conditioning units, and switches. Consequently, the control unit can receive this data and issue specific commands to regulate the parameters of executive devices such as LED strips and control valves, with the aid of an intelligent decision-making platform. Furthermore, the core component is integrated with the SCADA monitoring system.

On the testing platform, sensors and executive devices execute control commands generated by the control system and produce primary signals required for further processing. Utilizing cutting-edge LoRaWAN technology, the wireless data collection system VEGA collects information from primary sensors and transmits it to the server via a base station, subsequently forwarding it to SCADA.

Our next step involves the integration of the selected devices into a monitoring program designed to oversee the building's status. We have opted for the use of the ModBus TCP protocol over an Ethernet network, where each device's IP address corresponds to its ModBus address.

To achieve more precise results in this system, we have chosen to employ two software programs that were utilized in our prior research (Tasmurzayev et al., 2021):

1. Open Platform Communication Unified Architecture (OPC UA).
2. Supervisory Control and Data Acquisition System (SCADA).

Furthermore, we have implemented a cloud platform for data collection, allowing us to retrieve data from the structure and manage controllers and programs. To address the need for adaptable data interfacing with the OPC server, explicit object typing has been implemented within the OPC UA server's address space. This involves the use of templates or classes to categorize similar groups of technological parameters. This approach enables automatic responses to changes in volume on the server side and offers control over the completeness of received information. By linking class descriptions to their instances and providing semantic information within the OPC UA server, a template for the list of objects can be created. This eliminates the need for manual entry of a list of class instance names when setting up the interface. Additionally, the OPC UA client can subscribe to the server's notifications regarding address space changes (Nolan et al., 2016).

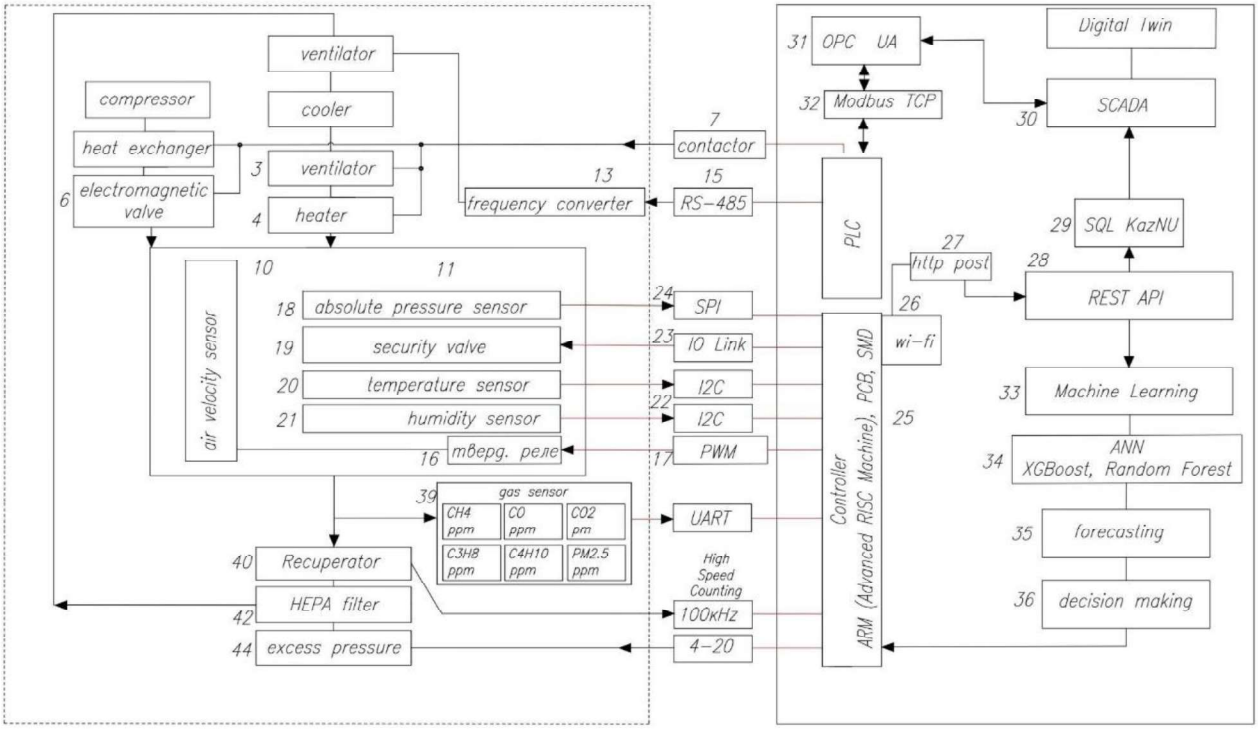

Figure 2. Architecture of the System

In Figure 2, we present a comprehensive architecture of our system, which has been previously discussed in detail. Now, let's delve into how the operation of the oil and gas industry is intricately connected to the intelligent temperature and air control platform, considering that we are optimizing a conventional HVAC system, or more precisely, transforming it into an intelligent HVAC system.

The control and regulation process in the HVAC system within the oil industry involves a series of components and systems working in concert to uphold specific air and climate conditions within oil and gas industry facilities. Here is an overview of the control and regulation process:

- Data Collection: The process commences with the collection of data regarding the prevailing conditions both inside and in the vicinity of the oil and gas industry. This data encompasses various parameters such as temperature, humidity, gas levels, air movement, and more. Sensors (18), (20), and (21) on the left side of the architecture handle the collection of these parameters, with the data being stored in an SQL database (29).
- Data Analysis: The collected data undergoes rigorous analysis to ascertain whether it adheres to predefined standards and requirements. For instance, if the temperature within a well deviates from the specified range, the system identifies it as a deviation. To enable the system to autonomously regulate these parameters and make informed decisions, an intelligent component has been seamlessly integrated. The right side of the architecture illustrates the operational diagram of this intelligent platform, implemented using methods such as Artificial Neural Networks (ANN), XGBoost, and Random Forest (34).
- Decision-Making (36): Based on the outcomes of data analysis, the system formulates decisions concerning necessary adjustments. These adjustments primarily involve modulating the operation of various HVAC devices, including heaters, air conditioners, and fans.
- Execution of Commands: The HVAC system translates these decisions into executable commands aimed at regulating the identified parameters. For example, if the temperature inside a well surpasses the specified threshold, the system may activate the air conditioner to cool the environment.
- Monitoring and Feedback: Concurrently with the execution of commands, the system continuously monitors changes in parameters and the status of equipment. Feedback from this monitoring phase empowers the system to dynamically adapt to evolving conditions and make further adjustments as required. The monitoring system aligns with what is depicted in Figure 1.

- Safety: Ensuring safety stands as a pivotal facet of control and regulation. HVAC systems may encompass emergency ventilation and automatic protection systems, which spring into action in response to hazardous situations such as gas leaks. Security measures are underpinned by a dedicated controller (25), which communicates with data using OPC Server (31) and ModBus (32) protocols. Furthermore, this controller interfaces with additional amplitude-frequency sensors and a safety valve.

This meticulous control and regulation process collectively enable the HVAC system to uphold optimal conditions for both the equipment and personnel operating within the oil and gas industry. The intelligent HVAC management system contributes significantly to safety, operational efficiency, and energy conservation within oil and gas industry operations.

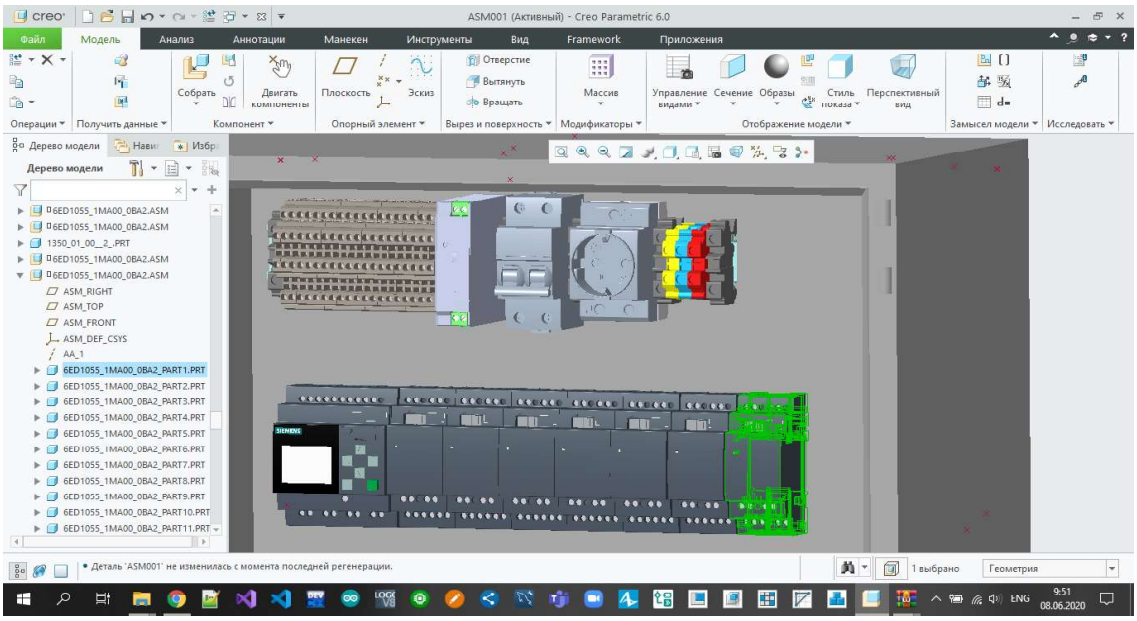

Figure 3. CAD of the control box

The detailed structural diagram of the control unit is provided in Figure 4.

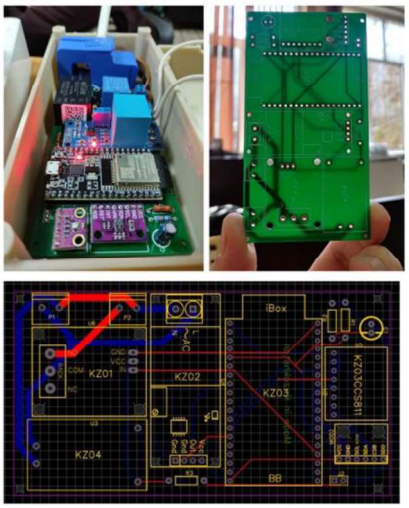

Figure 4. Control and data acquisition module

Research Results

The developed HVAC system comprises three primary components: physical components, an intelligent system, and a control and monitoring system. The control system is driven by SCADA Genesis64.

The provided SCADA system, as depicted in Figure 5, offers a range of valuable capabilities:

- Monitoring and Control: Operators have the ability to closely monitor the current parameters of the HVAC system through the SCADA interface. This includes parameters like temperature, humidity,

ventilation speed, and more. Moreover, operators can make real-time adjustments and take control of the system based on the data at hand.

- Data Collection: The SCADA system serves as an efficient data collector, gathering information from various sensors and HVAC system devices. It also archives this data for subsequent analysis and reporting purposes.
- Real-time Optimization: SCADA plays a crucial role in optimizing the HVAC system's operation in real-time. For example, it can dynamically adjust room temperatures in response to prevailing conditions and specific requirements, thereby enhancing efficiency and comfort.
- Emergency Management: The SCADA system is equipped to respond automatically to emergency situations or deviations in the HVAC system's operation. It not only alerts operators to these issues but also initiates preventive measures to avert potentially serious problems.
- Remote Control: SCADA empowers remote control of the HVAC system, a particularly valuable feature for systems situated in remote or challenging-to-access locations. This remote-control capability facilitates efficient management and maintenance of the system, even when it is not physically proximate to the operators.

The SCADA system consists of several key components, including a tag database, a graphical display module, and a script processor. The graphical display module, as depicted in Figure 5, provides buttons for turning on and off dampers, as well as a window for adjusting variables like pressure, temperature, humidity, and gas levels. It also features buttons for parameter control, an emergency stop button, and windows for configuring pressure and temperature settings. This module allows for monitoring and setting specific parameters for maintenance, with the intelligent platform maintaining these values during operation.

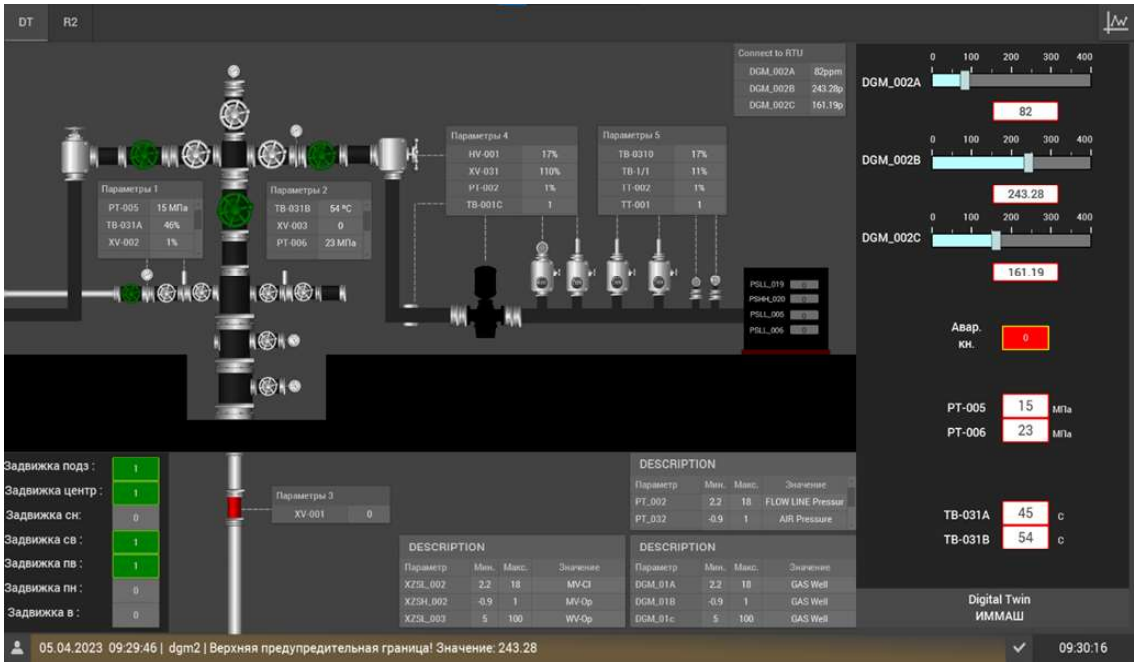

Figure 5. SCADA system

To establish connections among these system components, a communication block, illustrated in Figure 6, is employed. This block plays a vital role in enabling communication and data exchange among controllers, sensors, actuators, and the SCADA monitoring and control system. It collects data from various sensors and devices within the system, including information about indoor environmental conditions and equipment status, such as temperature, humidity, ventilation rates, and pressure. Once collected, the communication block transmits this data to controllers and control devices within the HVAC system, which can include thermostats, ventilation regulators, compressors, and other devices responsible for maintaining comfort and system operation.

The communication block also establishes a connection with the Supervisory Control and Data Acquisition (SCADA) system, allowing operators to monitor the real-time status of the HVAC system and make

control decisions based on the data received. Furthermore, it can relay commands from SCADA operators to controllers and actuator devices in the HVAC system. For example, if there is a need to increase room temperature, SCADA can send commands to adjust thermostats and heaters accordingly.

Another crucial function of the communication block is to detect emergency situations. When sensors detect conditions like gas leaks or other hazards, the communication block transmits this information to the SCADA system, which can automatically trigger emergency procedures, such as shutting down equipment or alerting security services. Additionally, the communication block enables remote control of the HVAC system, which can be especially valuable for systems located in remote or inaccessible locations, such as oil wells.

Figure 6. Communication block

Conclusions

Our research efforts have culminated in the creation of an intelligent system designed to optimize the management of heat supply and air conditioning in enclosed spaces while minimizing energy wastage. This system is built upon a robust framework for control and monitoring and incorporates advanced intelligent modeling.

The system's capabilities, empowered by intelligent automation, serve to reduce the need for human intervention, enhance overall system efficiency, and provide both local and remote monitoring and management of all system states. It also enables the analysis of data within specific timeframes, the early detection of deviations and malfunctions in system components and segments, and the optimization of operational procedures.

This intelligent automation system effectively addresses the challenges associated with excessive heat consumption and the associated costs. It operates as a centralized heat distribution system, ensuring the delivery of required heat levels and enabling year-round air conditioning, regardless of the time of day or prevailing weather conditions, especially in the oil and gas industry.

By implementing monitoring and control of predefined parameters, the intelligent system ensures that these parameters are supplied to oil and gas processes only when necessary, thus minimizing unnecessary energy consumption. Moreover, the system is highly scalable, capable of continuous operation over extended periods without interruptions, and it is designed with environmental considerations in mind.

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Timur T. Bekibaev
Satbayev University
22 Satpaev Street, 050013 Almaty, Kazakhstan
Email: timur_bekibaev@mail.ru
ORCID ID 0000-0001-7030-0015

Uzak K. Zhapbasbaev
Satbayev University
22 Satpaev Street, 050013 Almaty, Kazakhstan
Email: uzak.zh@mail.ru
ORCID ID 0000-0001-5973-5149

Gaukhar I. Ramazanova
Satbayev University
22 Satpaev Street, 050013 Almaty, Kazakhstan
Email: uzak.zh@mail.ru
ORCID ID 0000-0002-8689-9293

Nicole Flindt
Heidelberg Education University
Keplerstraße 87, D-69120 Heidelberg, Germany
Email: flindt@ph-heidelberg.de
https://orcid.org/0000-0002-5583-4809

Nele Rohde
Heidelberg Education University
Keplerstraße 87, D-69120 Heidelberg, Germany
Email: rohde@ph-heidelberg.de
https://orcid.org/0009-0006-2261-1285

Digital Twin of Urban Heat Networks: Optimization of Energy Systems

Abstract: The paper discusses the concept and importance of the digital twin of a heat network for modern energy systems. A digital twin is a virtual representation of a real heat network, which allows system operators to efficiently manage and optimize heat supply operations. The advantages of using digital twins are in predicting network efficiency and reducing energy losses. The main stages of creating a digital twin of heat networks are given, as well as the required functionality for thermal-hydraulic calculations. As an example, the process of creating a digital twin for the heating network of Pavlodar city is described.

Keywords: digital twin, heat network, efficiency optimization, thermal-hydraulic calculations.

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Introduction

Nowadays, the importance of efficient energy management cannot be overemphasized (Zhapbasbayev et al., 2021; Kolesnikov et al., 2021; Ilmaliyev et al., 2022). This is especially relevant for those regions of Kazakhstan where winters are cold and heating networks play an important role in providing heat and hot water to homes, businesses, and infrastructure in cities and towns. The energy efficiency of heating networks is a pressing issue in Kazakhstan, especially due to the rising costs of energy resources. The introduction of more environmentally friendly and efficient technologies can be a priority to reduce emissions and improve the sustainability of the systems.

Currently, the situation with heat networks in Kazakhstan is characterized by several challenges. Firstly, there is a high degree of wear and an increased risk of accidents in heat networks. According to official data for the current year, heat networks are worn out by 57% on average in the country (On approval…, 2023), and in the northern regions of the country the situation is even more critical. Secondly, the growth of the urban population, intensive housing construction, and development of large and small enterprises puts additional load on the existing heating network, which in turn requires more optimal distribution of heat among consumers.

In addition, the problems of irrational utilization of heat energy pose significant challenges for ensuring a reliable and efficient heat supply. Limitations in control and monitoring systems can make it difficult to optimize the operation of heat networks and make rational decisions. In this regard, the development and implementation of digital twins will be a useful tool for the management, monitoring, and operation of heat supply systems. A digital twin is a virtual model of a real object, system, process, or environment created using modern information technologies (Javaid et al., 2023; Aheleroff et al., 2020; Guerra-Zubiaga et al., 2021; Assawaarayakul et al., 2019). A digital twin is an accurate or approximate representation of the physical characteristics and functionality of an object or system in a virtual environment. It gives a digital representation of a material object, can simulate various processes that can take place in production, and predict their operation in different conditions based on real data. Having sufficient information, the digital twin can recommend necessary solutions (Vachálek et al., 2017; Pires et al., 2019). The software, based on reliable data, determines the operating conditions of physical objects, their states in real time (Uhlemann et al., 2017; Pires et al., 2018).

The digital twin can be used to stress-test of thermal network processes, simulating the best possible operation under emergency conditions. The process of creating a digital twin begins with experts analyzing the mechanics of the physical system and its operational factors to develop a mathematical model that correctly describes the original system (Durão et al., 2018; Aheleroff et al., 2021; Negri et al., 2017; Pang et al., 2021). The digital twin software receives raw data from sensors connected to the physical system. The sensors collect important operational data so that the software can simulate what is happening in real-time in the physical system.

The digital twin software is created by collecting real-time data from real heat network objects. This data is then used to create a digital replica to help better understand and analyze real-world objects or systems (Schroeder et al., 2020; Rolle et al., 2020). The main advantage of the digital twin is that it provides real-time data that can help in learning, analyzing, and understanding how objects and systems function. It allows users to analyze, simulate, and optimize the performance of a physical object throughout its lifecycle

The digital twin of a heat network includes information on the network structure, equipment conditions, heat distribution, and other important parameters. Analysis of the conducted research allows us to conclude that the application of a digital twin in a heat network brings the following benefits: ensuring the reliability of the district heating supply; improving the quality of operational and dispatch management and dynamic stability of the property complex. The digital twin allows heat network operators to allocate resources more efficiently, identify potential problems and vulnerabilities in the heat network, thus contributing to accident prevention and improved service, and optimize system operations, resulting in reduced fuel consumption and greenhouse gas emissions.

Let's list the main advantages of implementing a digital twin of the heating network:

1. Improved Heat Network Management: Operators can quickly respond to changes in demand and operational conditions, minimizing downtime and reducing expenses.

2. Increased Efficiency: Optimization of heat network operations leads to reduced heat losses during transmission and distribution, resulting in cost savings.

3. Greater Transparency: A digital twin provides real-time access to data on the state of the heat network, enabling rapid problem detection and resolution.

Thus, the purpose of creating a digital twin of the heating network is to optimize the management of the heating network, improve reliability and safety, as well as to save resources and reduce environmental impact.

Concept and operating principle of the digital twin of heat network

The control of heat networks is a complex multi-parameter problem, as the process modeling must consider the operation modes of pumps, boiler houses in heat and power plants (HPP), heat points, regulation of network gate valves, etc.

In addition, heat network parameters such as heat loads, average temperatures during cold periods, pipe characteristics, and pump operation during long-term operation are subject to changes from year to year and from season to season. Therefore, it is important to carry out periodic modeling and regular verification of the heat network operation modes. This is necessary because modes that were previously safe may turn out to be emergency or energy-costly the following year.

Based on the integrated data, a mathematical model of the heating network is created; the model allows for various analyses and simulations, predicting the behavior of the system under different conditions and evaluating its efficiency.

The digital twin continuously receives the raw data of the heat network in real-time. This data includes information on heat flow, temperature, pressure, and other parameters. Further, using the obtained data, the condition of the heating network is analyzed, potential problems, leaks, and inefficiencies can be identified and emergency situations can be addressed.

A database is being created and integrated into the digital twin, forming a unified virtual representation of the heat network. This includes geometric parameters (pipes, nodes, substations), thermal characteristics (heat losses, temperature regimes), operational parameter data, etc. Based on the analysis results, the digital twin can offer optimal solutions for heat network management. This may include recommendations for equipment regulation, heat redistribution, and even planning investments for system modernization.

The digital twin can also be used to predict the future state of the heat network under various scenarios of load changes, climatic conditions, and other factors. This aids in long-term planning and decision-making. The application of geoinformation technologies in centralized heating systems is driven by several factors, such as the clarity of information representation, the ability to use a graphical base (map of a city, district, settlement), ease of overlaying the heat network scheme onto the city map with its linkage to existing buildings and structures, quick input of the initial data required for engineering calculations, and the convenience of analyzing the results obtained from the calculations.

Architecture and main elements of the digital twin

The main elements of the digital twin for a heat network include:

1. Location Data: This includes the coordinates of pipelines, nodes, and substations within the heat network, typically integrated with a Geographic Information System (GIS).
2. Network Topology: Information about the structure and connections between different elements within the heat network.
3. Thermal Characteristics: Data regarding heat losses, temperature regimes, and other thermal properties.
4. Mathematical Model: This describes the physical processes occurring within the real heat network and may encompass equations for heat exchange, hydraulic calculations, and other mathematical models.
5. Algorithms: These utilize data and models for monitoring, diagnostics, forecasting, and optimization of heat network operations.
6. Graphic Interface: A user-friendly interface that allows operators and engineers to interact with the digital twin, visualize data, and receive reports and notifications.
7. Simulation and Virtualization Tools: These enable testing and analysis of various scenarios involving changes to heat network parameters.
8. Database: This stores all parameters related to heat network objects, as well as historical data on heat supply system operations for subsequent analysis and reporting.

Heat network parameters

Objects within the heat network (HN) can be viewed as nodes and edges in an undirected graph of the network. Among the nodes of the HN are heat chambers (HC), central heating points (CHP), pumping stations (PS), heat and power plants (HPP), pipe branching points, and pipe parameter change points. The edges of the HN graph represent sections of pipes between nodes, where the flow rate of the heat transfer medium and pipe parameters remain constant in terms of length.

The parameters of the HN are categorized into the following groups:

- Structure of Connection of HN Objects.
- Parameters of Pipe Sections.
- Parameters of Pumping Stations.
- Parameters of Heat and Power Plants.
- Parameters of Heat Chambers.

For HN, a clear structure of connecting HN components must be defined, which describes the hydraulic connections between network nodes. The connection of network nodes should be accomplished through network edges, which correspond to the respective sections of pipes.

The parameters for pipe sections include the following data for both forward and return pipes:

- Length of the pipe section.
- Internal and external diameters of the pipe.
- Roughness of the inner pipe wall.
- A list of local resistance objects with corresponding coefficients or the value of the total local resistance coefficient.
- Thickness and type/grade of pipe insulation (or insulation thermal conductivity coefficient).
- Thermal conductivity coefficient of the surrounding soil (for underground pipe installation).
- Elevation points of the pipe axis and ground surface.
- Factory-tested maximum pressure rating.
- List of pipe defects. For each defect, its location along the pipe section and its maximum pressure should be specified.
- Year of commissioning.

PS and HPP are considered sources of pressure supply into the network and include the following data:

- List and schematic diagram of pump unit connections.
- Presence of a pressure-reducing valve at the station's outlet.
- Presence of a Variable Frequency Drive (VFD). When a VFD is present, it needs to be linked to the corresponding pump units.
- Parameters of each pump unit (PU).

The parameters for each PU within a PS or HPP should include the following data:

- Passport relationship between head and flow rate of the pumped water.
- Passport relationship between the pump's efficiency and the flow rate of the pumped water.
- Passport operating range for the flow rate of pumped water.
- Passport value of rotor rotation frequency.
- Nominal power of the electric motor.
- Electric motor efficiency at nominal load.
- Rotor rotation frequency of the electric motor.

For HPP, which is considered as a source of heat transfer medium, the parameters should include, in addition to the previously mentioned ones, the following data:

- Number of heat outputs.
- Efficiency of boiler units or turbine units (depending on the type of heater in the HPP).
- Type of combustible fuel.

For HC and CHP, which are considered as consumers of the heat transfer medium, and are assumed to be connected to the corresponding distribution network (one or several district networks), and where the pressure in the respective network can be regulated by valves in the HC or CHP, located at the inlet of the supply and return pipelines of the distribution network (DN), the parameters for HC and CHP should include the following data:

- Maximum height of buildings connected to the DN with the specified HC or CHP.
- Dependency of the heat transfer medium consumption by the connected DN on the available pressure after the valves in the node.
- Dependency of local resistance on the degree of opening of the valve on the supply pipeline of the DN.
- Dependency of local resistance on the degree of opening of the valve on the return pipeline of the DN.
- Additionally, for each HN object in the city, tariffs for electricity from power plants and HPPs, as well as tariffs for combustible fuel at HPPs, should be determined.

Data Collection and Analysis for the Heat Network

The creation of a digital twin for the heat network begins with the development of a virtual replica of the network using data regarding its structure, parameters, geographical location, and other characteristics. These data can be obtained from relevant organizations that manage or own urban heat networks, and they can also be collected through sensors, Geographic Information Systems (GIS), thermal imaging, satellite imagery, and other sources.

The digitization of the urban heat network will be carried out using the following initial data, as illustrated in Fig. 1: characteristics of pipelines; and heat supply objects.

Data collection and analysis for the heat network allows system operators to manage and monitor its operations more effectively, identify issues at early stages, and optimize processes to enhance the reliability and efficiency of the heat supply system. To collect data, the following steps are necessary:

- Placement of sensors and probes at various points within the heat network to monitor various parameters such as temperature, pressure, heat flow, and equipment efficiency.
- Use of automatic data collection systems that regularly read information from sensors and transmit it to a central server.
- Creation of GIS maps of the heat network, including information about the location of pipes, nodes, and other infrastructure elements.
- Implementation of monitoring and control systems that enable operators to monitor the heat network's performance in real-time and respond to potential problems.
- Data processing using specialized software platforms and algorithms for analysis and interpretation.
- Conducting regular inspections and surveys of the heat network to identify potential problems.
- Analysis of heat consumption data by various consumers and assessment of system efficiency.
- Presentation of data in the form of graphs, charts, and reports for ease of interpretation and decision-making.
- Use of data to optimize the heat network's operations and predict future changes in consumption and heat network parameters.
- Application of machine learning algorithms for data analysis.

Next, we carry out problem identification, i.e., we need to identify potential problems in the operation of the heating network, such as leakages, inefficiencies, and overloads by analyzing the data.

The next step is to assess the efficiency of the heat supply system, as well as its energy utilization factor. It is necessary to compare the actual performance with the designed performance.

Finally, the data should be used to predict future heat demand and changes in the heat network parameters, which will allow planning of long-term measures.

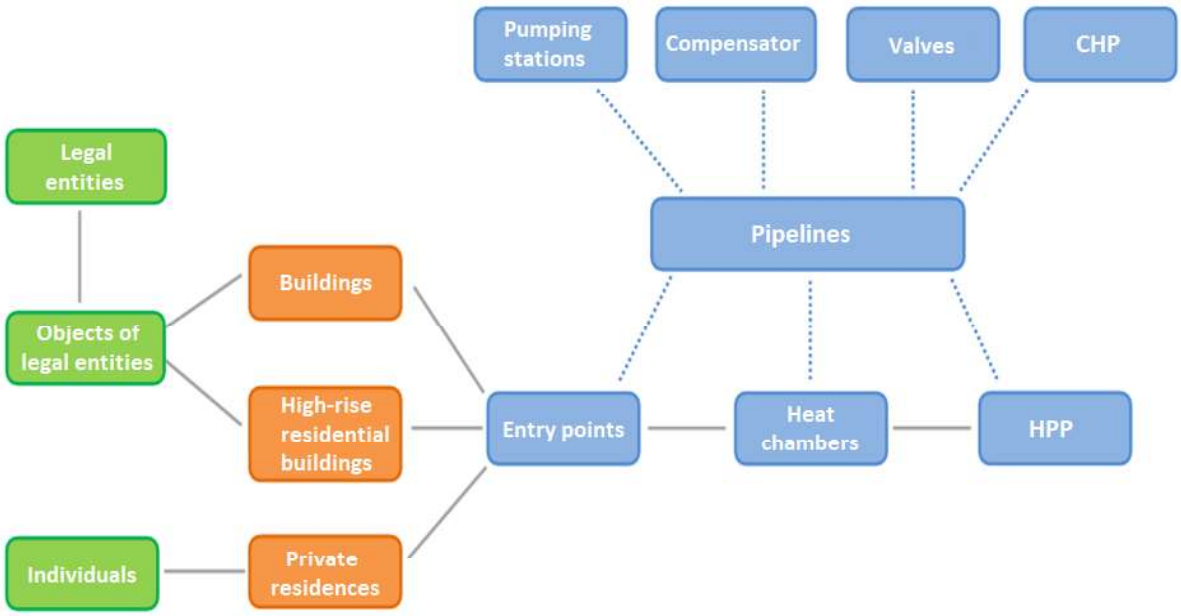

Fig. 1. Objects of the Urban Heat Network for Digitization

Types of calculations performed by the digital twin

The digital twin program will perform the following types of calculations:

1) adjustment calculation of the heat network;
2) verification calculation of the heat network;
3) calculation of heat losses;

4) calculation of hydraulic shock;

5) calculation of the reserve capacity of the heat network section.

The purpose of adjustment calculation is to ensure that all consumers connected to the district heating network receive the necessary amount of thermal energy and network water at an optimal operating mode of the centralized heating system as a whole.

As a result of the adjustment calculation, the following are determined: the identification numbers of elevators, the diameters of nozzles and throttling devices (for consumers, CHPs, and cluster washers), as well as the locations for their installation.

The calculation is carried out considering various schemes for connecting consumers to the heat network and the degree of automation of the connected heat loads.

The purpose of verification calculation is to determine the actual consumption of the heat transfer fluid at various sections of the district heating network and at consumers, as well as the amount of thermal energy received by the consumer at a given water temperature in the supply pipeline and available head at the heat source. In this process, it is possible to analyze the hydraulic and thermal operation modes, as well as to forecast changes in the internal air temperature of consumers. Calculations can be conducted with various input data, including emergency situations, such as the shutdown of individual sections of the district heating network, transfer of water and thermal energy from one source to another through one of the pipelines, and others.

Verification calculations allow for the calculation of any accidents or incidents on the district heating network pipelines and the heat source. The results of the calculation include flow rates and pressure losses in the pipelines, pressures at network nodes, including available pressures at consumers, the temperature of the heat transfer fluid at network nodes (considering heat losses), indoor air temperatures at consumers, flow rates, and water temperatures at the inlet and outlet of each heating system. When multiple heat sources are connected to one network, the distribution of water and thermal energy between the sources is determined.

Calculation of heat losses of a heat network is an important part of designing and assessing the efficiency of a heat supply or heating system. This calculation makes it possible to determine the amount of heat that is lost in the process of heat transfer through heat networks and structures. Knowing the heat losses allows us to optimize the system and save resources.

The goal of this calculation is to determine the normative heat losses through the insulation of the pipelines over the course of a year. Heat losses are calculated annually, broken down by each month, considering the operation of the district heating pipelines during different periods (summer and winter).

The results of the calculation can be viewed both as a summary for the entire district heating network and for each individual heat source and each Central Heating Plant (CHP). It can also be analyzed according to different owners of district heating sections.

Calculating thermal losses helps assess the efficiency of the heating system and can be valuable in making decisions regarding system modernization or optimization to save energy and resources.

The purpose of hydraulic regime calculation is to determine the various temporal states of the heat supply system (distribution of pressure, temperature, and flow rates) and the actual thermal load received by the consumer nodes of the heat supply system when the operation mode of the pumping stations (PS) or heat and power plants (HPP) is changed or when the parameters of the regulating valves in the consumer nodes of the heat supply system are altered. Thus, in both cases, a non-stationary transient process is considered from the initial established state of the heat supply system to a new state. In the case of simulating a transient regime, it is assumed that changes in the operation mode of the PS, HPP, or valves occur relatively smoothly. In the case of simulating a hydraulic shock, it is assumed that changes in the operation mode of the PS, HPP, or valves occur very abruptly (e.g., sudden pump shutdown in the heat supply system), which can lead to the occurrence of a hydraulic shock in the pipes of the heat supply system.

The methodology for calculating the heat network pipe section reserve depends on many factors, including the condition of the network, its parameters, and the availability of data.

To perform this calculation, all available data about the pipelines are required, including their technical specifications (diameter, wall thickness, material), installation date, and previous historical data on repairs and replacements.

Data regarding the condition of the pipes resulting from in-pipe diagnostics is necessary to assess the level of corrosion and wear. The assessment may involve determining the remaining wall thickness and the assumed corrosion rate.

Based on the corrosion and wear assessment data, as well as the current condition of the pipelines, the remaining life can be determined for each pipeline section. This can be expressed in terms of years, load cycles, or percentage of wear.

It is essential to identify the pipeline sections where the remaining life is the lowest and where there is the highest risk of failure or deterioration.

Remaining life refers to the duration of safe operation of the pipeline under permissible parameters from the current moment until its projected ultimate condition. The forecasting of the remaining resources of the pipeline is based on the results of the technical condition assessment, the study of mechanical properties and microstructure of the material, an evaluation of the actual load on the main load-bearing elements of the pipeline, and hydraulic (pneumatic) testing with a trial pressure.

Monitoring the condition of heat networks is crucial for ensuring their efficient operation and for responding to changes and emergencies promptly. The implementation of a real-time monitoring and control system allows operators to react to fluctuations and incidents immediately.

The digital twin should include a specialized module for viewing various historical measurements. In this module, historical data can be viewed in two modes:

- Viewing changes in historical data over time for the selected period of HN operation, i.e. the data of selected measurements are displayed as curves on a graph with the abscissa axis being the time scale.
- Viewing the status of the HN along its length for a specific date: the data is displayed either as points on a graph with the abscissa axis being the pipeline route kilometer or as a colored map of the HN.

These capabilities enable operators to gain insights into the past performance of the HN, identify trends, and assess its current condition. It also provides a valuable tool for troubleshooting and making informed decisions to optimize the operation and maintenance of the district heating system.

Optimizing the operation of heat networks

A digital twin of HN can help optimize its operation, performance, and efficiency in real-time, leading to significant economic and environmental benefits.

To optimize the operation of a district heating system, it is necessary to integrate the software with various information systems, such as SCADA (Supervisory Control and Data Acquisition), and ensure regular access and data updates to keep the information up to date.

Using the digital twin, various scenarios of the HN operation can be modeled, including changes in load, temperature distribution, equipment control, and more. By analyzing the results of modeling, optimal solutions can be determined to improve the efficiency and reliability of the system.

Integrating real-time control with the digital twin allows for rapid response to changes in the system. Automated algorithms can be used to optimize system operations, such as load management and heat distribution.

Furthermore, data from the digital twin can be used to forecast future states of the system and predict potential failures. Diagnostic algorithms can automatically detect and warn of potential issues.

Data analysis and optimization of the district heating system enable more efficient and cost-effective operation, ensuring high reliability and meeting the needs of users.

Creation of a digital twin of the district heating system for the city of Pavlodar

We are currently developing a digital twin of the heating network of Pavlodar city. The following steps have been taken:

- Data collection, including information about the distribution of pipelines, heat consumption, equipment characteristics, and more. At this stage, maps of the city's heating network have been digitized (Fig. 2), including 44 main heating networks, 587 network nodes (thermal chambers, pump stations, CHP, HPP outlets, branching, and pipe transition points), 623 sections of heating pipelines along the city streets, and 900 local pipe resistances.

- Creation of a data input interface (Fig. 3), modules for conducting thermal-hydraulic network calculations, a result viewing interface, and a database.

The following data have been entered into the database of the Digital Twin:

- Parameters of pipeline sections: pipe diameters and lengths, inner wall roughness, local pipe resistances, insulation thickness and type, burial depth, maximum allowable pressures, list of pipe defects, and elevation marks.

- Network pipeline connection structure: the location of heating network objects, pipe locations, and connections.

- Pump station parameters: a list and location of pump units, head and efficiency curves of rotors, and parameters of pump motors.

- HPP parameters: a list and location of pump units, head and efficiency curves of rotors, motor parameters, parameters of boiler units and turbo units, and the number of heat outputs.

- Thermal chamber parameters: the relationship between heat carrier flow and available chamber head, the minimum required static head for high-rise buildings.

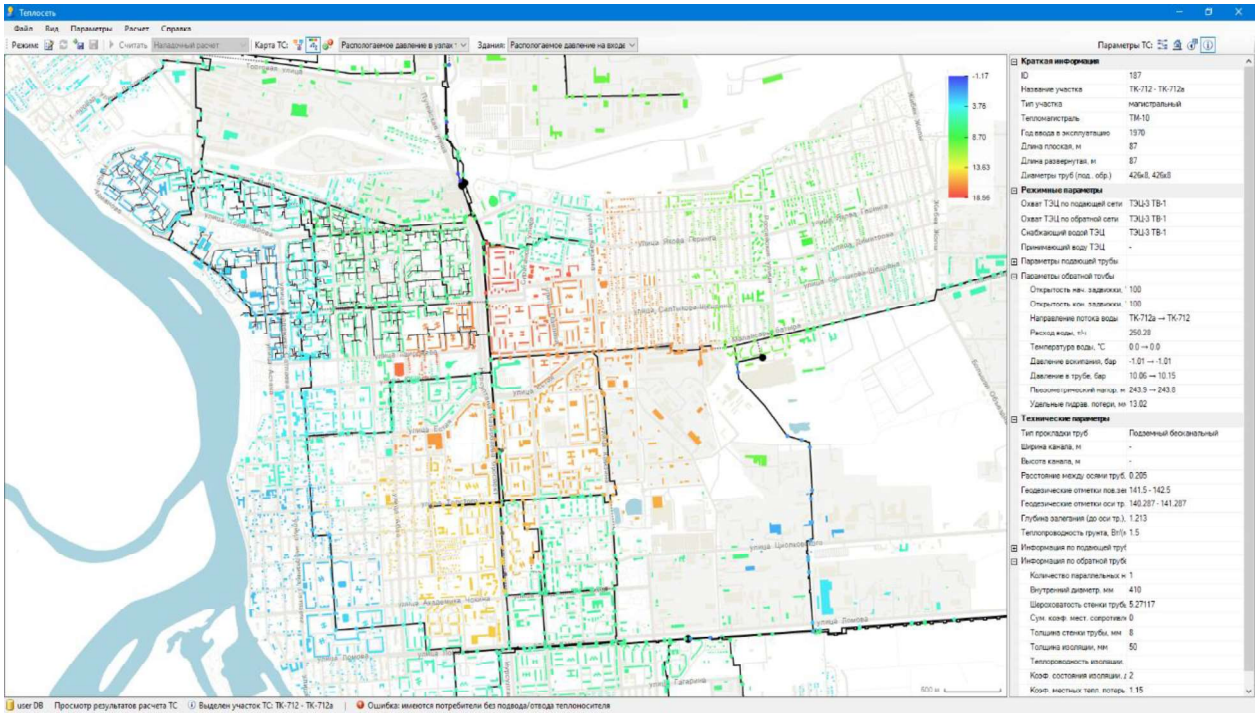

Fig. 2. Digital Twin Interface

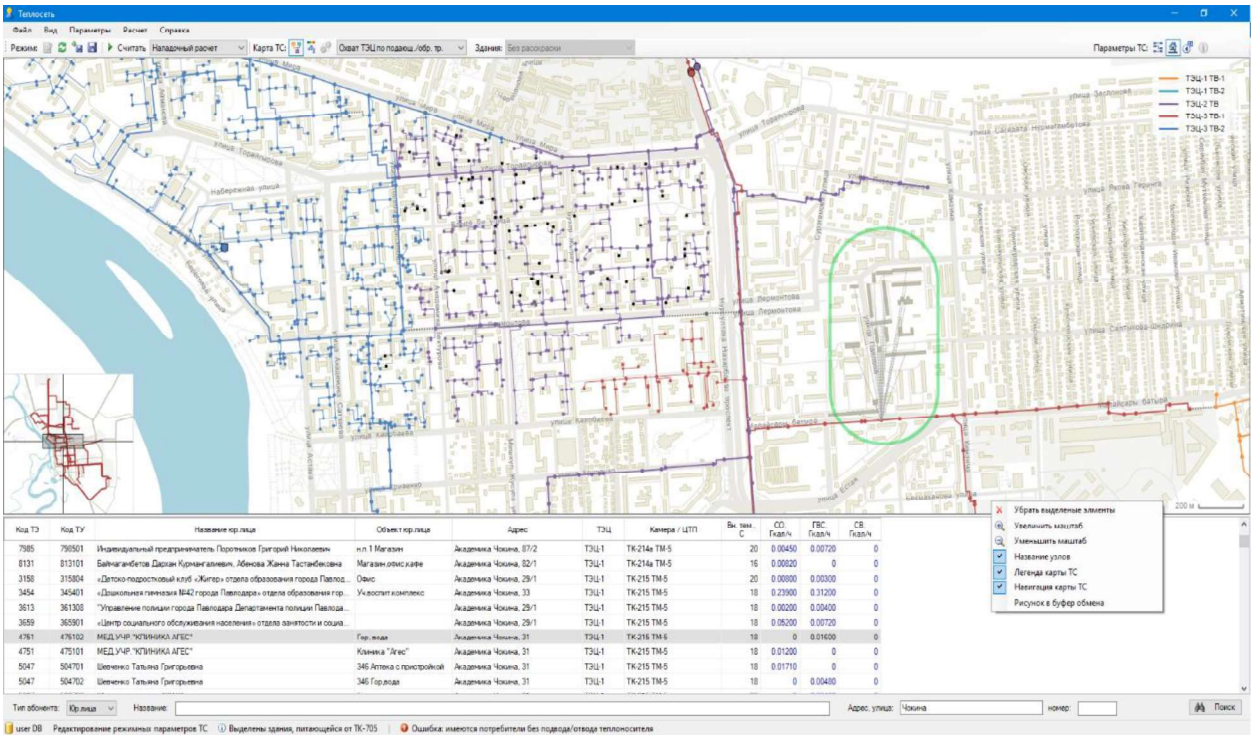

Fig. 3. Data Input Interface

Algorithms have been developed for the following types of calculations:

• Thermal-hydraulic network calculations;

• Selection of the required temperature mode for HPP;

• Selection of the required operating mode for pumps at pumping stations and HPP;

• Optimization calculations to ensure the required thermal mode with minimal costs for the operation of HPP and PS.

For a more visual representation, the calculation results are displayed (Fig. 4) in the form of tables, graphs, diagrams, or on a color-coded map of the entire heating network. Various filters and slices can be made over the output data, as well as the coloring of heat network elements. The following parameters of the heating network can be obtained from thermal-hydraulic calculations:

• Pressure distribution in the network, which allows for assessing the dynamics and pressure variations in the heating network at different sections. This provides information about the load level and potential bottlenecks in the system.

• Temperature distribution in the network to represent the thermal regime.

• Flow rate of the heat transfer medium in the network, which allows evaluating the efficient use of resources and identifying opportunities for energy savings.

• Pressure at the inlet/outlet of the pumping station and HPP. Monitoring pressure at pumping stations and HPP is a critical factor for ensuring the reliable operation of the system.

• Temperature of the heat transfer medium at the outlet/inlet of HPP.

• The amount of electricity consumed by pumps at the PS and HPP, which allows for assessing the efficiency of pumping stations' operation and optimizing their energy consumption.

• The amount of fuel burned at HPP for balancing energy costs and resource savings.

These calculation results provide operators and engineers with valuable information for more effective management and optimization of the city's heating network, contributing to the stable and efficient heat supply of Pavlodar.

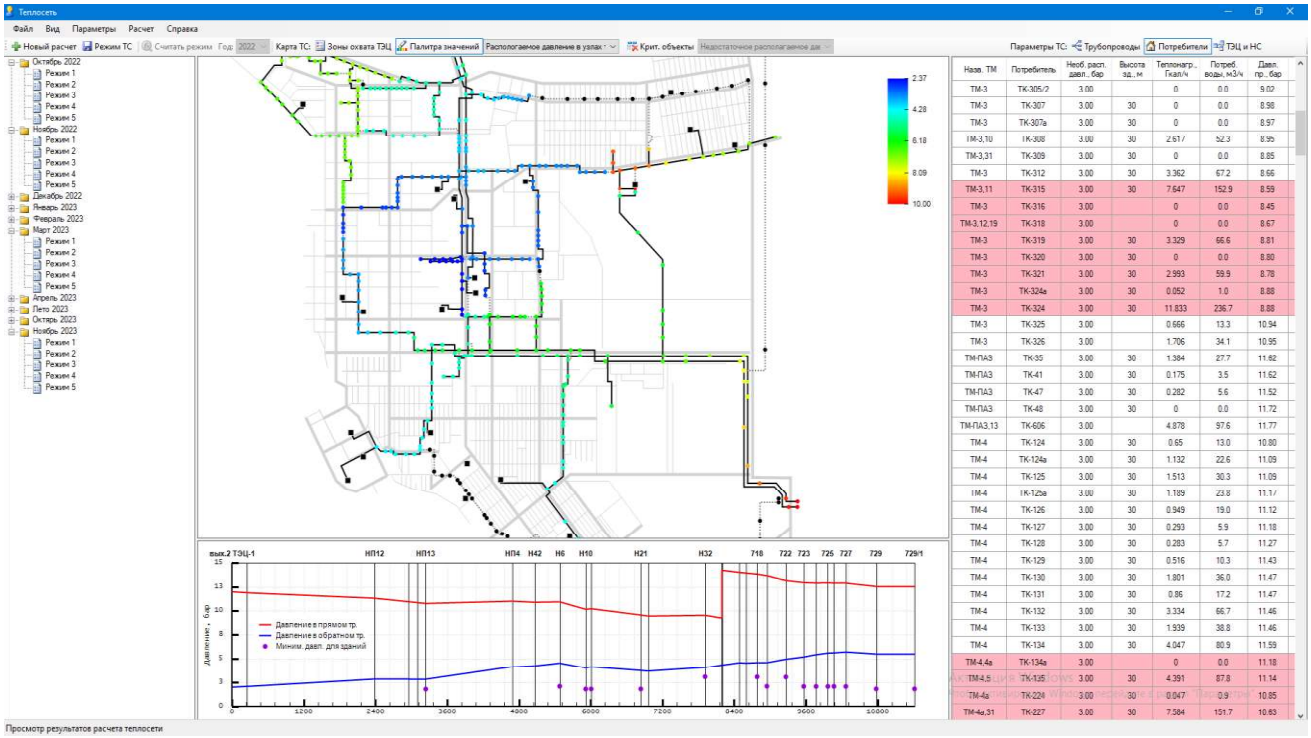

Fig. 4. Calculation results output

The further development stages of the digital twin program for the heating network may include the following steps to expand its functionality:

1) Integration of the digital twin with control and monitoring systems to obtain real-time network status information, increase responsiveness, and automate responses to changes.

2) Development of a module for optimization calculations to ensure the required thermal regime for heating the population.

3) Modeling and analysis of various scenarios of the heating network's operation to assess efficiency, forecast loads, and optimize heat distribution.

4) Determination of the system's reliability (forecasting emergency situations) in heat supply.

5) Predicting future states of the system and diagnosing potential problems, which will aid in planning repairs and maintenance.

Conclusions

In the contemporary economic climate, characterized by acute oscillations in global market prices of nickel and cobalt, an exigent issue arises regarding the economically viable processing of low-grade oxidized nickel ores indigenous to Kazakhstan. In an endeavor to address this, we proposed a novel and more promising hydrometallurgical methodology as a feasible alternative to the extant ore processing techniques being implemented within the nation.

The novelty of our technology revolves around the comprehensive extraction of nickel and cobalt from oxidized nickel-cobalt-bearing resources. This innovative approach is distinctive in its obviation of the high-temperature process. Conventionally, this process is notorious for the emission of noxious gases and has a proclivity for energy profligacy. Our method, thus, not only minimizes environmental hazards but also underscores energy conservation - features that are instrumental in driving the transition towards sustainable mining practices.

Upon meticulous analysis of the experimental data gleaned from our research, we ascertain that our groundbreaking technology facilitates enhanced extraction efficacy of nickel and cobalt from refractory oxidized ores. We therefore postulate that the deployment of this technology in industrial-scale operations can potentially revolutionize the nickel and cobalt mining landscape by augmenting metal recovery rates, thereby maximizing resource utilization and industrial efficiency.

In summary, our work is not only responsive to the immediate challenges posed by fluctuating commodity prices, but it also sets a benchmark for future endeavors in the field, thus pushing the frontier of sustainable mining practices. Further research will be instrumental in understanding the scalability of this innovative technology and its broader implications for the industry.

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Irina V. Shadrunova
Research Institute of Comprehensive Exploitation of Mineral Resources of the Russian Academy of Sciences, Russia
E-mail: shadrunova_@mail.ru
ORCID ID 0000-0003-3520-2705

Ekaterina V. Kolodezhnaya
Research Institute of Comprehensive Exploitation of Mineral Resources of the Russian Academy of Sciences, Russia
E-mail: kev@uralomega.ru
ORCID ID 0000-0002-0252-4479

Modern trends in waste recycling technologies of incinerators

Abstract: In 2021, the Government of the Russian Federation set the executive authorities the task of decarbonizing Russian industry and developing an action plan for the transition to carbon regulation and sequestration of carbon dioxide emissions. One of the directions of carbon dioxide sequestration is mineral carbonation. The idea of the work is to use mineral carbonation, as an alternative to natural mineral raw materials, slags from the combustion of solid non-combustible waste. The technology of carbon sequestration by mineral carbonation of technogenic raw materials is at the research stage, therefore it is necessary to assess the potential of using waste incinerators. To solve the tasks, the material composition of the slags of one of the incinerators was studied in detail. The possibility of slag enrichment with the production of copper-containing preconcentrate has been established. The content of minerals capable of participating in carbonation was determined, and the carbonation potential was estimated based on the calculated values. The requirements for man-made waste for their use as raw materials for carbonation are formulated. The factors that have a restraining effect on the introduction of mineral carbonation technologies are highlighted.

Keywords: incinerators, slag from incineration of non-combustible waste, carbon sequestration, carbonation potential, extraction of copper from technogenic raw materials.

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Introduction

The increase in the level of consumption, and as a result, the formation of a huge amount of industrial and household waste, has global consequences for the environment. The world annually produces more than two billion tons of household waste (MSW) that requires placement and disposal. In Russia, the area of landfill territories is about 13 million hectares (Gunich et al., (2018)). Despite the efforts being made, the problem of increasing the volume of waste has not yet been solved. One of the solutions to this problem, at this stage of society's development, is the construction of plants for sorting and incineration of solid waste.

Today there are two incinerators operating in Russia and it is planned to build another one. When burning garbage, 70-75% of MSW components are burned. Unburned solid residues – slags and ash, are exported and stored in dumps that are a source of pollution of the atmosphere and groundwater. Waste incineration slag is a silicate raw material, the composition of which varies widely. The composition of the slag depends on the composition of solid waste and the technological parameters of incinerators. According to the federal classifier of waste in Russia, waste incinerators belong to the 3-4 hazard class. However, slags contain compounds of eco-controlled metals in quantities exceeding the established maximum permissible concentrations (MPC) for soils, and the amount of some metals is comparable to their content in industrial deposits (Hungarian et al., 2018; Bagryantsev, 2016).

Slag processing schemes include crushing the material to a size of less than 50 mm, separation into fractions of 0 – 3 mm, 3 – 8 mm, and 8 – 50 mm, and magnetic separation (Fig. 1). The fraction of 0 – 3 mm and the tailings of processing material larger than 3 mm are sent to landfills for storage (Kolodezhnaya et al., 2022). Waste incinerator slag sorting tails contain compounds of non-magnetic metals: copper, zinc, lead, and aluminum. The development of technology for the recovery of copper from slags will reduce their negative

impact on the environment and obtain additional products - polymetallic concentrate. Slag enrichment tailings can be used as raw materials for the production of building materials.

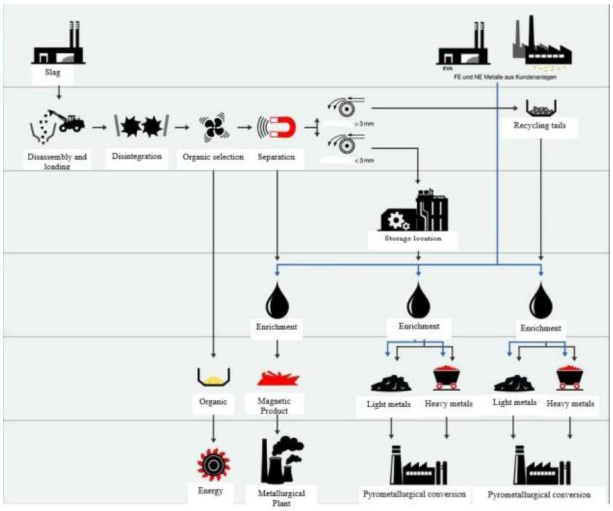

Figure 1. Scheme of dry mechanical treatment of slag from garbage incineration

Blast furnace slags are used and disposed of in concrete technology, for example, in the production of binders. One of the constraining factors in the way of using slag enrichment tailings from garbage incineration in the production of products and structures is the presence (in addition to metals) of free calcium and magnesium oxides, which cause an uneven change in volume during hardening and low strength of the slag binder without an activator. One of the possible ways to solve this problem may be the artificial carbonation of slags by emissions from industrial enterprises (Voronin et al., 2017; Huijgen & Wouter, 2005).

In 2021, the Government of the Russian Federation set the executive authorities the task of decarbonizing Russian industry and developing an action plan for the transition to carbon regulation and sequestration of carbon dioxide emissions (Decree of the Government of the Russian Federation No. 3052-r dated October 20, 2021, Special Report "Global warming by 1.5°C" accessed 15 October 2021). The task of reducing the dangerous anthropogenic impact on the environment remains a priority, I do not look at global economic and geopolitical challenges. The development of the scientific foundations of the technology of sequestration of industrial emissions is an urgent scientific and technical task. There are demonstration pilot plants for carbon dioxide capture and sequestration (Annual report of the International Energy Agency "On the prospects of World Energy up to 2050" (World Energy Outlook, 2022; Moazzem et al., 2012; Olajire, 2013). Figure 2 shows the main technological routes of priority sequestration technologies.

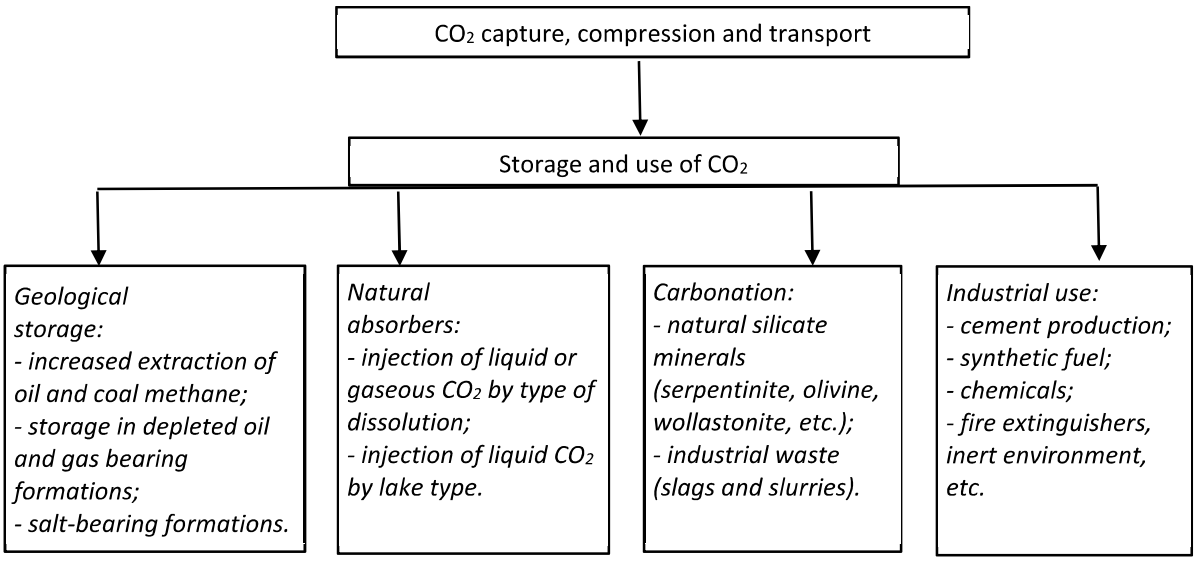

Figure 2. Scheme of application of CO_2 capture, storage and use technologies

One of the directions of carbon dioxide sequestration is mineral carbonation in industrial installations. In the process of mineral carbonation, carbon dioxide interacts with natural minerals to form stable solid carbonates. The most responsive components for mineral carbonation are oxides of divalent metals calcium and magnesium (Ca2+, Mg2+), which occur in the form of silicates, aluminosilicates, and hydroxides: serpentinite ($Mg_3Si_2O_5(OH)_4$), olivine ($(Mg,Fe)_2SiO_4$), wollastonite ($CaSiO_3$), etc. The mineral carbonation process will require 3.2 – 7.4 tons of pure natural silicates to bind $1m^3$ CO_2.

At the same time, the content of calcium and magnesium ions in soluble compounds capable of hydration in technogenic raw materials is crucial. The presence of elements such as Fe, Pb, Cr, Al, and metallic impurities adversely affects the carbonation process, therefore, the use of slags as raw materials for carbon sequestration is possible only after the recovery of metallic impurities. The described technologies are at the research stage and at the moment it is important to assess the possibility of enrichment and the potential for carbonation of slag from garbage incineration.

Research Methods

Analysis of the literature data confirms the presence of phases required for mineral carbonation in waste incineration slags. The carbonation potential is the required amount of man–made waste (in units of mass) to bind $1m^3$ of carbon dioxide [12]. The applicability of the slags was evaluated on the basis of the material and granulometric composition.

The objects of the study are 4 samples of waste sorting tailings from garbage incineration, selected from different points of the technological process. The results of the determination of granulometric, elemental, and phase compositions of 4 samples of tailings of slag processing from garbage incineration are presented.

The determination of the granulometric composition of slag was carried out according to the Russian standard GOST 8735 – 88 «Sand for construction works. Test methods».

The chemical composition of slag samples was determined by the X-ray fluorescence method on the ARL QUANT'X X-ray energy dispersion spectrometer of Thermo Scientific. A feature of the XFA method is the possibility of quantitative analysis of the composition of elements in complex multicomponent mixtures.

The phase composition of the slag was determined using the defractometer "D2 PHASER" and the licensed version of the program "Diffrac.Eva.V2.1", the database on mineralogy «PDF-2». Qualitative analysis was carried out using the licensed version of the program "Topas 4.2".

Research experiment

The granulometric composition of the slags is presented in Table 1.

Table 1. Particle size distribution of an input material

Marking of the sample	Total residue on sieves with a cell, mm, %						
	1.0	**0.5**	**0.315**	**0.2**	**0.1**	**0.04**	**>0.04**
1	0.0	0.0	17.8	33.5	77.6	97.1	100.0
2	46.7	65.4	78.2	84.4	93.6	98.5	100.0
3	49.7	65.4	76.7	83.6	93.5	98.3	100.0
4	0.0	0.0	3.3	10.5	67.9	91.4	100.0

Samples «2» and «3» are dry, loose material with a size of up to 1 mm. The content of particles smaller than 0.1 mm is 6.4 – 6.5%, which ensures reduced dusting of the material. Samples «1» and «4» are dust products with a size of less than 0.315 mm. The moisture content of the starting material was 0.2%, and the bulk density was 920 kg/m^3. During the magnetic analysis of the material, 9.2% of the magnetic fraction was isolated. The results obtained show the heterogeneity of slag processing tailings. A particle size of less than 1 millimeter is preferable for raw materials entering mineral carbonation, as this will ensure a sufficient contact surface and permeability of the material layer.

The analysis of the elemental composition (Table 2) showed the presence of up to 25% calcium and 1-2% magnesium in the sample material. The specific features of the slag formation of incinerators determine the silicate structure of calcium and magnesium-containing phases. Copper, lead, and zinc are also present in the material. To determine the possibility of slag enrichment, it is necessary to establish the form of separation of metal-containing phases.

Table 2. The chemical composition of an input material

Marking of the sample	Mass concentration (%) chemical element															
	Si	Ca	Fe	Mg	Al	Ti	P	Zn	Mn	Cu	Cr	Pb	K	Cl	SO_3	Mass loss during calcination
"1"	20.5	14.8	10.0	1.9	5.1	0.6	0.3	0.6	0.2	0.6	0.1	0.1	0.7	0.2	1.0	1.9
"2"	11.6	24.9	7.6	0.7	3.7	1.2	0.6	0.8	0.1	0.5	0.1	0.2	0.9	1.1	4.9	8.2
"3"	7.1	19.0	23.5	0.0	2.9	0.7	0.2	0.7	0.3	0.3	0.1	0.1	0.6	1.0	4.3	7.9
"4"	8.3	20.6	4.5	0.8	12.9	0.7	0.0	2.0	0.2	1.3	0.1	0.2	0.8	1.2	4.3	10.1

The studied material contains up to 20% of amorphous phases. The presence of melilite in the samples is (5 – 12%), anhydrite (1-3%), calcium silicates (4-7%), okermanite (9-11%), and glass phase (up to 20%), having weakly hydraulic properties, it allows us to consider slag processing tailings as raw materials for the production of building materials. In samples "2", "3", and "4" the presence of ettringites (up to 11%) was established, which, apparently, is due to the technology of their cooling. The presence of metallic aluminum (1-5%) in the material of samples "1" and "2" was found. The evaluation of the material composition showed the presence of slags of 21-39% (depending on the size) of phases capable of participating in CO_2 binding.

Iron in the material is represented by magnetite (up to 15%), hematite (1 – 5%), wustite (2 – 3%), as well as mackinawite (up to 1%) and is part of cuprospinel and franklinite.

Copper and zinc are present in the form of cuprospinel (1 – 2.5%) and franklinite (1-2%), and can also be part of both amorphous phases and present as alloying elements in other crystalline phases.

When enriching the material of the 0-0.315mm fraction on the concentration table, a heavy fraction with a mass fraction of copper of 13-16% was obtained. The yield of this product was up to 10%. To increase the mass fraction of copper, the concentrate was re-cleaned. The obtained data on the material composition of materials and the degree of their gravitational enrichment can be used in the development of technical solutions and recommendations for the enrichment of slags and the reduction of eco-controlled metals in slags sent for storage.

When slag interacts with the environment, the process of hydration of the active phases occurs: tricalcium silicate (Ca_3SiO_5), bicalcium silicate (β -Ca_2SiO_4), tricalcium aluminate ($Ca_3Al_2O_6$), single-calcium aluminate ($CaAl_2O_4$), mayenite ($Ca_{11.3}Al_{14}O_{32.3}$). The hydration products of these phases are bound by carbon dioxide (Table 3).

Table 3. Carbonation reactions of slag phases of incineration plants

Reaction equation	ΔG, kJ/mol
$Ca(OH)_2+CO_2(gas)\rightarrow CaCO_3(solid)+ H_2O(liquid)$	-74,92
$1/3(3CaO\cdot Al_2O_3\cdot 6H_2O)(solid)+CO_2(gas)\rightarrow CaCO_3(solid)+2/3Al(OH)_3(solid)+H_2O(liquid)$	-79,11
$1/3(3CaO\cdot Al_2O_3\cdot 3CaSO_4\cdot 31H_2O)(solid)+CO_2(gas)\rightarrow CaCO_3(solid)+ CaSO_4\cdot 2H_2O(solid)+2/3 Al(OH)_3(solid)+22/3H_2O(liquid)$	-72,57
$CaO\cdot Al_2O_3\cdot 10H_2O+CO_2(gas)\rightarrow CaCO_3(solid)+2Al(OH)_3(solid)+7H_2O(liquid)$	-97,83

The carbonation potential of slag from garbage incineration calculated by size classes is presented in Table 4. To bind 1 m^3 of carbon dioxide, 7.9 – 37 kg of slag will be required, depending on the size of the slag, the data obtained can be used in the development of technical solutions and the design of carbon capture and burial plants.

Table 4. Carbonation potential of slags from garbage incineration

Fraction		Carbonation potential, kg of slag per 1 m^3 of CO_2
Slag of the current process	8 – 32mm	28.5
	1 – 8mm	18.6
	0 – 1mm	18.0
Slag from the dump	8 – 32mm	27.7
	1 – 8mm	37.0
	0 – 1mm	7.9

Conclusions

The conducted studies have shown that Cu, Zn, and Pb are present in waste incineration slags as independent metal phases and alloys, and are part of iron oxides and silicates. Reduction of Cu, Zn, and Pb content in the starting material can be achieved by enrichment by gravity methods in an aqueous medium on a concentration table. The separation of metals into separate products is due to the high density of copper-zinc alloys and lead. As a result of technological tests, a concentrate with a mass fraction of copper up to 16% was obtained and its yield will be 10-12%.

The presence of 21-39% of phases capable of participating in CO_2 binding in the slags has been established. Waste incineration slags can be used as an alternative to natural sources of raw materials for carbon dioxide sequestration. The carbonation potential of the slag was 7.9 – 37 kg per 1 m^3 of CO_2. Binders from waste incineration slags can be used for the manufacture of light inorganic building materials in the production of concrete and ceramic bricks.

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Maksim A. Pakhomov
Kutateladze Institute of Thermophysics, Siberian Branch of the Russian Academy of Science, Lavrent'ev Ave., 1, 630090, Novosibirsk, Russia
E-mail: pakhomov@itp.nsc.ru

Uzak K. Zhapbasbayev
Satbayev University, 050013, Satpaev str, 22a, Almaty, Kazakhstan
https://orcid.org/0000-0001-5973-5149
E-mail: uzak.zh@mail.ru

RANS modeling of the transition of a non-isothermal flow of a Newtonian fluid to a viscoplastic state in a pipe

Abstract: A mathematical model of the movement and heat transfer of a turbulent non-isothermal non-Newtonian fluid through a pipe wall with a cold surrounding space has been developed and simulated numerically. Fluid turbulence is described in the framework of the isotropic two-parameter k–$\tilde{\varepsilon}$ model. The Newtonian properties of the fluid in the initial cross-sections of the pipe transformed gradually into a viscoplastic non-Newtonian Bingham-Schwedoff fluid state due to heat transfer through the pipe wall between the heated fluid and a cold environment. The value of its streamwise velocity in the axial zone increased significantly when the fluid moved along the pipe. On the contrary, it decreased in the near-wall zone and the height of the region with a zero fluid velocity increased. This occurred due to the viscoplastic properties of a non-Newtonian fluid. The height of the region with a zero fluid velocity in the pipe increased gradually as the non-Newtonian fluid (waxy crude oil) moved through the pipe. A noticeable increase in the level of turbulent kinetic energy in the axial zone of the pipe and its noticeable decrease in its near-wall region were observed. A significant increase in the average dynamic viscosity and yield stress in the near-wall part of the pipe was shown. The boundary of the area of existence of Newtonian properties of fluid was determined. The height of the region with a zero fluid velocity in the pipe increased gradually as waxy crude oil moved through the pipe and reached $y/R \approx 0.1$ at $x/D = 15$.

Keywords: RANS, Newtonian and non-Newtonian fluids, Bingham-Schwedoff fluid, viscoplastic, yield stress, turbulent flow, heat transfer.

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Introduction

Turbulent non-isothermal flows of non-Newtonian viscoplastic fluids in pipes (Bingham-Schwedoff fluid) are of great practical importance (Barnes, 1999), since they are found in many industrial installations (various heat exchangers, pipelines, bearings, centrifuges, oil production from deep water, wastewater treatment systems, etc.). One example of such a fluid is waxy crude oil. Considering the latest discoveries in geological exploration, the value of such oil reserves will only increase in the future. The main difficulties associated with transporting such a fluid through pipelines are the strong dependence of viscosity and yield shear stress on fluid temperatures due to their content of asphaltenes, paraffins, and resins (see monographs by Beisembetov et al., 2016; Tugunov & Novoselov, 1972) and reviews (Aiyejina et al., 2011; Chala et al., 2018; Elkatory et al., 2022). Waxy crude oil at high temperatures obeys the laws of a Newtonian fluid, and when its temperature decreases, the viscoplastic properties of non-Newtonian fluids appear (Aiyejina et al., 2011; Chala et al., 2018; Elkatory et al., 2022). Such oils have a high solidification point (from 285–303 K), which can be higher than the temperature of the surrounding soil environment (Beisembetov et al., 2016; Zhao et al., 2020; Ghannam et al., 2012). The flow of waxy oil, which is originally a Newtonian fluid, is cooled by heat transfer into a colder environment through the pipe wall. This leads to a change in the rheological and physicochemical properties of the oil along the pipe length. The complex rheological properties of such fluids are characterized by a sharp increase in viscosity at a decrease in their temperature (Beisembetov et al., 2016; Zhao et al., 2020).

Finally, it causes appearance of a critical stress value, it is also known as the yield stress (Barnes, 1999; Beisembetov et al., 2016).

One of the rheological properties of waxy oil is its yield shear stress, which can cause the formation of a "stagnant zone", where the flow velocity is zero (Chala et al., 2018; Beisembetov et al., 2016). This also leads to a decrease in the working area of the pipe cross-section (Chala et al., 2018). The formation of a "stagnant zone" can lead to two scenarios for the development of the flow of a complex rheological fluid. In the case of insufficient kinetic and thermal energy of the flow, the "stagnant zone" blocks the working cross-section of the pipeline, the hydraulic resistance increases sharply, and the pipeline section becomes "frozen" (Ghannam et al., 2012; Zhao, 2020; Zhapbasbayev et al., 2021; Hussain et al., 2023). If the kinetic and thermal energy of the fluid flow is sufficient, then with a decrease in the working cross-section of the pipe, the flow velocity increases, and this leads to the dissipation of the kinetic energy of the flow to the thermal energy near the "stagnant zone" boundary (Beisembetov et al., 2016). The velocity magnitude increases from the wall to the pipe center in this case and the velocity gradient in the region of the boundary between the "stagnant zone" and the flow of the Newtonian fluid also increases. This leads to the self-heating of the fluid in this area (the amount of heat generated is directly proportional to the square of the velocity gradient (Beisembetov et al., 2016). Within the theoretical limits, the flow enters the regime of a "hydrodynamic thermal explosion" (Bostanjiyan & Chernyaeva, 1966). Heat losses along the pipe length decrease due to an increase in the flow velocity and the fact that the fluid near the pipe walls serves as a thermal insulator. The area of the "stagnant zone" stabilizes in practice (Aiyejina et al., 2011), and the friction along the pipe length decreases (Beisembetov et al., 2016; Tugunov & Novoselov et al., 1972).

The complex rheological properties of a Bingham-Schwedoff (BS) fluid are determined by a nonlinear increase in viscosity and yield shear stress with a decrease in its temperature, which leads to the non-Newtonian state of a waxy crude oil. For laminar flow regimes, many publications have focused on the study of heat transfer in such fluids flowing in a pipe (Zhao, 2020; Bostanjiyan & Chernyaeva, 1966) and behind a backward-facing step (Danane et al., 2020). Some works have dealt with the study of the turbulent flow of a non-Newtonian polymer solution (viscoelastic) (Cruz & Pinho, 2003; Iaccarino et al., 2010; Masoudian et al., 2016), power law (Gavrilov & Rudyak, 2016), Herschel–Bulkley (Malin, 1997) and BS (Pakhomov & Zhapbasbayev, 2021) fluids. These studies used various models of turbulence at different levels: k–ε (Cruz & Pinho, 2003; Iaccarino et al., 2010; Malin, 1997; Pakhomov & Zhapbasbayev, 2021), $v2$–f (Masoudian et al., 2016; Gavrilov & Rudyak, 2016) and k–ω SST (Lovato, et al., 2022). The complexity of the numerical modeling of such flows connected to the developed turbulence models can hardly be verified directly using the experimental benchmark. It should be noted that the level of turbulence anisotropy of a non-Newtonian fluid is higher than that of a Newtonian fluid (Masoudian et al., 2016; Sahu et al., 2007). A few large eddy simulation (LES) (Gnambode et al., 2015; Amani et al., 2023) and direct numerical simulation (DNS) (Gavrilov & Rudyak, 2017; Singh et al., 2017) studies have been carried out to study visco- and pseudo-plastic turbulent fluids in the last two decades. Data were obtained on the mean streamwise velocity, distributions of the components of the Reynolds stress tensor, wall friction, balance of shear stresses, and the turbulent kinetic energy for a steady turbulent flow with Reynolds numbers in the range Re = 5000–20000. Heat transfer in such flows has not yet been considered in the literature, and only one recent work has been found (Gnambode et al., 2015). The DNS and Reynolds-averaged Navier–Stokes (RANS) studies of fluid flow and heat transfer for a non-Newtonian turbulent liquid polymer were carried out in this paper. The time mean statistics of temperature fluctuations, turbulent heat flux, thermal turbulent diffusivity, and budget in terms of the temperature variance were predicted and compared with those of the Newtonian fluid.

The study of mixing and linear instability of miscible and immiscible Newtonian and non-Newtonian fluids has great importance due to the relevance in chemical industry and waxy crude oil transportation through the pipelines (Usha & Sahu, 2019).

It should be noted that the results of numerical studies of the flow turbulent structure and heat transfer in the process of transition of the Newtonian turbulent BS fluid (waxy crude oil) in pipes to the non-Newtonian viscoplastic fluid has not yet been presented in the literature, except our recent paper (Pakhomov & Zhapbasbayev, 2021). The aim of the present paper is to investigate the flow and heat transfer in a turbulent hydrodynamically steady-state incompressible non-Newtonian fluid flowing through a pipe. This study may be of interest to scientists and research engineers dealing with the design and transport of waxy crude oils in pipelines. This present book chapter is an extended form of previously published article in the following journal Case Studies Thermal Engineering (Pakhomov & Zhapbasbayev, 2021).

Mathematical model

Physical Model of a Non-Newtonian Viscoplastic (Bingham-Schwedoff) Fluid

A schematic view of the flow configuration is shown in Fig. 1. A non-isothermal viscoplastic non-Newtonian fluid (waxy crude oil) flow along an underground pipe with an inner diameter (I.D.) $D = 2R = 0.2$ m, length $L = 3$ m, and depth to pipe axis $H = 2$ m. The mean-mass velocity of the liquid flow at the pipe inlet was $U_{m1} = 0.2$ m/s and its initial temperature $T_1 = 298$ K. The ambient temperature (soil) was $T_{Soil} = 273–298$ K. The pipe material was stainless steel and the pipe wall thickness $\delta = 2$ mm. It was assumed that the temperature of the pipe wall from its outer side was equal to the soil temperature $T_{W2} = T_{Soil}$. The temperature of soil was a constant value. The density of fluid flow in the inlet cross-section $\rho_1 = 835$ kg/m^3. The Reynolds number of the flow, determined from the flow parameters at the inlet (for a Newtonian fluid) $\mathrm{Re} = U_{m1}D_1/\nu_{W1} = 8200$.

A few problems regarding the development of a mathematical model of any non-Newtonian turbulent fluid based on Reynolds-averaged equations (RANS) have to be solved (Gavrilov & Rudyak, 2016): 1) a model for the averaged effective dynamics viscosity coefficient should be developed; 2) a closure for correlations of the viscosity pulsation with the strain rate tensor, which does not appear for a Newtonian turbulent fluid should be constructed; 3) a non-Newtonian turbulent diffusion term should be determined; and 4) a contribution of viscosity fluctuations to the equation for the transport of the dissipation rate ε should be considered.

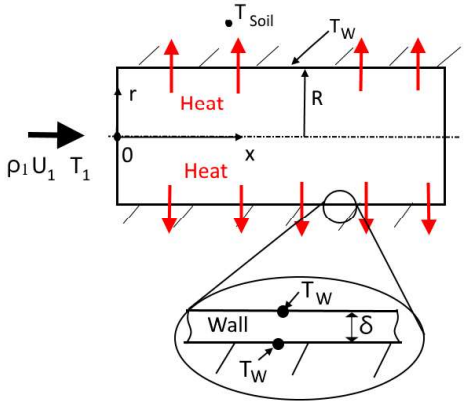


Fig. 1. Schematic of the flow configuration

Rheological Properties of a Non-Newtonian Fluid

In a non-Newtonian viscoplastic state, the effective molecular viscosity μ_{eff} can be modeled using the linear Bingham-Schwedoff rheological fluid model (De Kee, 2021). The effective molecular viscosity μ_{eff} of a fluid has the form (Bingham, 1922; Wilkinson, 1960; Klimov, et al., 2005):

$$\mu_{eff} = \begin{cases} \mu_p + \tau_0 \left|\dot{\gamma}\right|^{-1}, & \text{if } |\tau| > \tau_0 \\ \infty, & \text{if } |\tau| \le \tau_0 \end{cases}, \quad (1)$$

where $\tau_0 > 0$ is the yield shear stress, and μ_P is the plastic viscosity, $\boldsymbol{\tau} = \mu_{eff}\mathbf{S}$ is the shear stress tensor, and $\mathbf{S} \equiv \sqrt{2S_{ij} \cdot S_{ij}}$ is the strain rate tensor for instantaneous turbulent quantities and $S_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)$ is the second invariant of the strain rate tensor. For a Newtonian fluid, the yield shear stress $\tau_0 = 0$ and the effective viscosity are constant and equal to the molecular viscosity of the corresponding fluid. The Bingham-Schwedoff model is a simple viscoplastic fluid model that linearly relates the yield shear stress to the viscosity (Bingham, 1922; Wilkinson, 1960; Klimov, et al., 2005).

The main difficulty in the numerical modeling of viscoplastic flows, including a turbulent regime, with the help of expression (1), is associated with the existence of a singular molecular viscosity in regions where the shear stress is less than τ_0. This difficulty is overcome by using various improvements of the basic rheological model (Bingham, 1922; Wilkinson, 1960; Klimov, et al., 2005). The approach of (Papanastasiou, 1987) was used in this work, where the effective viscosity was approximated by the following smooth function. It limits the value of effective viscosity as the shear rate tends to zero $\boldsymbol{\tau} \to 0$:

$$\mu_{eff} = \mu_p + \tau_0 \frac{\left[1 - \exp\left(-10^3 |\mathbf{S}|\right)\right]}{|\mathbf{S}|}. \quad (2)$$

The effective viscosity coefficient for a turbulent flow is the sum of the averaged coefficients of molecular viscosity μ and turbulent viscosity μ_T, similar to those of a Newtonian fluid (Iaccarino et al., 2010; Masoudian et al., 2016; Gavrilov & Rudyak, 2016; Pakhomov & Zhapbasbayev, 2021). The expression for the coefficient of the averaged dynamic viscosity of the turbulent non-Newtonian fluid considering (1), has the form:

$$\mu_{eff}^{T} = \left\langle \mu_{eff} \right\rangle + \mu_T = \mu_p + \tau_0 \left\langle |\mathbf{S}|^{-1} \right\rangle + \mu_T. \quad (3)$$

The averaged turbulent viscosity of the non-Newtonian fluid μ_T in Eq. (3) was determined in accordance with the turbulence model (Hwang & Lin, 1998) considering the appearance of the non-Newtonian behavior of the fluid using Eqs. (12–14) (see below). The viscosity of the non-Newtonian fluid in turbulent flows depends not only on the average turbulent velocity of the flow, but also on fluctuations of the shear rate tensor (Iaccarino et al., 2010; Masoudian et al., 2016; Gavrilov & Rudyak, 2016; Pakhomov & Zhapbasbayev, 2021). The instantaneous value of dynamic viscosity is represented as a sum of the averaged and pulsation components: $\hat{\mu} = \langle \mu \rangle + \mu'$. The expression for the mean shear rate in the non-Newtonian fluid has the following form and consists of two terms (Iaccarino et al., 2010; Masoudian et al., 2016; Gavrilov & Rudyak, 2016; Pakhomov & Zhapbasbayev, 2021):

$$\left\langle \mathbf{S}^2 \right\rangle = 2\left\langle S_{ij} \cdot S_{ij} \right\rangle = 2\left\langle S_{ij} \right\rangle \cdot \left\langle S_{ij} \right\rangle + 2\left\langle S'_{ij} \cdot S'_{ij} \right\rangle. \quad (4)$$

The variables in triangular brackets $\langle\ \rangle$ in Eq. (4) represent averaging, and the superscript (prime) refers to the fluctuation characteristics. The first term is determined by the gradients of the average flow velocity. The second one defines the averaged pulsation shear rate, and it is determined by the approach of (Gavrilov & Rudyak, 2016).

$$\rho\varepsilon = 2\left\langle S'_{ij} \cdot S'_{ij} \right\rangle \mu. \quad (5)$$

Then, the expression for the averaged shear rate (4) considering (5), based on the averaged viscosity model (Gavrilov & Rudyak, 2016), can be written as:

$$\langle \mathbf{S} \rangle = \sqrt{2\left\langle S_{ij} \right\rangle^2 + \left(\rho\varepsilon\right) / \langle \mu \rangle}. \quad (6)$$

The average effective molecular viscosity of the non-Newtonian turbulent fluid is related to the average shear rate by an expression similar to that used for defining for instantaneous turbulent quantities (1), i.e.:

$$\left\langle \mu_{eff} \right\rangle = \mu_p + \tau_0 \cdot \left\langle |\mathbf{S}|^{-1} \right\rangle. \quad (7)$$

Thus, the value of the average molecular viscosity of the turbulent Bingham-Schwedoff fluid can be predicted using Eqs. (6) and (7) and an iterative process. To determine the parameters of the current iteration when calculating the average strain rate, the effective viscosity was taken from the previous iteration: $\langle \mathbf{S} \rangle^{l} = \sqrt{2\left\langle S_{ij} \right\rangle^{2,\,l} + \left(\rho\varepsilon^{l}\right) / \langle \mu \rangle^{l-1}}$. The value of effective viscosity was then predicted on the new iteration layer: $\langle \mu \rangle^{l} = \mu_P^{l} + \tau_0^{l} \cdot \left\langle |\mathbf{S}|^{-1} \right\rangle^{l}$ and the process was repeated (Gavrilov & Rudyak, 2016).

The Governing Equations for a Non-Newtonian Non-Isothermal Turbulent Fluid

The governing equations are given in symbols of vector analysis operations, although they are solved for an axisymmetric flow in cylindrical coordinates. The set of steady-state axisymmetric RANS equations of continuity, momentum in axial and radial directions, and the energy of a turbulent incompressible generalized Newtonian fluid has the form:

$$\begin{aligned}
&\nabla \cdot \left(\rho \mathbf{U}\right) = 0 \\
&\nabla \cdot \left(\rho \mathbf{U}\mathbf{U}\right) = -\nabla P + \nabla \cdot \left(2\mu_{eff}\mathbf{S}\right) + \nabla \cdot \left(-\rho\left\langle \mathbf{u}'\mathbf{u}' \right\rangle\right) + \nabla \cdot \left\langle 2\mu'_{eff}\mathbf{S}' \right\rangle \\
&\nabla \cdot \left(\rho C_p T \mathbf{U}\right) = \nabla \cdot \left(\lambda \nabla T\right) + \nabla \cdot \left(-\rho C_p \left\langle \mathbf{u}' t' \right\rangle\right) + \boldsymbol{\tau} : \mathbf{S}.
\end{aligned} \quad (8)$$

Here, ρ, μ, λ, and C_P are the density, dynamic viscosity coefficient, thermal conductivity coefficient, and heat capacity of the fluid, respectively; $\mathbf{U} \equiv \left(u_x,\ u_r\right)$ is the velocity vector, ($u_x = U$, $u_r = V$) are the fluid velocity components in the axial (x) and radial (r) directions, respectively; P is the mean pressure; $\left\langle u_i u_j \right\rangle$ and $\left\langle u_j t \right\rangle$ are the Reynolds stress and turbulent heat flux. The last terms in the equations of motion and energy of system (8) consider the effects of heat release during viscous dissipation of kinetic energy in a non-Newtonian fluid (Beisembetov et al., 2016) and have the form (Beisembetov et al., 2016). The turbulent Reynolds stress $-\rho\left\langle \mathbf{u}'\mathbf{u}' \right\rangle$ and turbulent heat flux $-\rho C_p\left\langle \mathbf{u}'t' \right\rangle$ were written according to Boussinesq hypothesis. The expression $\nabla \cdot \left\langle 2\mu'_{eff}\mathbf{S}' \right\rangle$ in equation (8) is found according to representation of (Gavrilov & Rudyak, 2016).

In contrast to the RANS equations for a Newtonian fluid, the system of Eq. (8) contains additional terms representing the effect of the non-Newtonian behavior of the turbulent non-isothermal fluid. The fourth term on the right-hand side of the momentum equation describes the energy consumption of motion of a non-Newtonian fluid associated with an increase in viscosity and yield shear stress with a decrease in its temperature (Beisembetov et al., 2016). The second term on the right-hand side of the energy equation considers the heat release during the viscous dissipation of energy in a non-Newtonian fluid (Beisembetov et al., 2016).

It should be noted that all equations of set (9) were numerically solved in the form appropriate to an axisymmetric flow, but for brevity, they are given below in general Cartesian tensor form.

The Reynolds stress $\left\langle u_i u_j \right\rangle$ in the fluid phase was determined using the Boussinesq hypothesis:

$$-\rho\left\langle u_i u_j \right\rangle = 2\mu_T S_{ij} - \frac{2}{3}\rho k\delta_{ij} = \mu_T\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \frac{2}{3}\rho k\delta_{ij}, \tag{10}$$

where $\delta_{ij} = 1$ at $i = j$, and $\delta_{ij} = 0$ at $i \neq j$.

To build the mathematical model of the viscoplastic non-Newtonian fluid, it is necessary to establish a correlation between the deviators of the stress tensor and the strain rate tensor [35,36,39]:

$$\tau_{ij} = -\tau_0 + \mu_{eff}\left(\frac{\partial U_i}{\partial x_i} + \frac{\partial U_j}{\partial x_j}\right). \tag{11}$$

The turbulent heat flux in the non-Newtonian fluid was obtained according to the Boussinesq hypothesis, which have the form:

$$\rho\left\langle u_j t \right\rangle = -\frac{\mu_T}{\mathrm{Pr}_T}\frac{\partial T}{\partial x_j}. \tag{12}$$

Here, Pr_T is the turbulent Prandtl number. It was determined in accordance with (Kays, 1994), where it was shown that for the range of variation of the molecular Prandtl number Pr = 1–100, the turbulent Prandtl number was $\mathrm{Pr}_T = 0.85 + 0.7/\mathrm{Pe}_T$, where $\mathrm{Pe}_T = \mathrm{Pr}\left(\nu_T/\nu\right)$.

The Two-Equation Turbulence Model

$$\nabla \cdot \left(\rho\mathbf{U}k\right) = \nabla \cdot \left[\left(\mu_{eff} + \frac{\mu_T}{\sigma_k}\right)\nabla k\right] + 0.5\nabla \cdot \left(\mu\frac{k}{\tilde{\varepsilon}}\right)\nabla\varepsilon_{\bar{W}} + \rho\left(\Pi_k - \varepsilon\right), \tag{13}$$

$$\nabla \cdot \left(\rho\mathbf{U}\tilde{\varepsilon}\right) = \nabla \cdot \left[\left(\mu_{eff} + \frac{\mu_T}{\sigma_\varepsilon}\right)\nabla\tilde{\varepsilon}\right] - \nabla \cdot \left(\mu\frac{\tilde{\varepsilon}}{k}\right)\nabla k - \frac{\rho\tilde{\varepsilon}}{k}\left(C_{\varepsilon 1}f_1\Pi_k + C_{\varepsilon 2}f_2\tilde{\varepsilon}\right), \tag{14}$$

$$\mu_T = C_\mu f_\mu \frac{\rho k^2}{\tilde{\varepsilon}}. \tag{15}$$

The system of equations of the turbulence model (Matvienko, 2011) resembles the equation system for a Newtonian fluid. The influence of non-Newtonian characteristics in the turbulence model was considered by the tensor of averaged shear rate. The averaged dynamic viscosity of a fluid depends not only on the

averaged, but also on the pulsation parameters of the turbulent non-Newtonian flow (Gavrilov & Rudyak, 2016).

Here k is the turbulent kinetic energy, $\tilde{\varepsilon}$ is the rate of its dissipation, and μ_T is the turbulent dynamic viscosity. The constants and damping functions in models (13)–(15) have the form [40]: C_μ = 0.09; $\sigma_k = 1.4 - 1.1\exp\left[-\left(0.1 y_\lambda\right)\right]$; $\sigma_\varepsilon = 1.3 - \exp\left[-\left(0.1 y_\lambda\right)\right]$; $C_{\varepsilon 1}$ = 1.44; $C_{\varepsilon 2}$ = 1.92; f_1 = f_2 = 1; $f_\mu = 1 - \exp\left(-0.01 y_\lambda - 0.008 y_\lambda^3\right)$; $y_\lambda = y / \sqrt{\nu k / \tilde{\varepsilon}}$ is the Taylor micro-scale; $\Pi_k = \mu_T \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) \frac{\partial U_i}{\partial x_j}$ is the turbulence production from the average motion; $\varepsilon = \tilde{\varepsilon} + \varepsilon_W$ is the full dissipation of gas turbulence energy; $\varepsilon_W = 2\nu \left(\frac{\partial \sqrt{k}}{\partial x_j} \right)^2$ is the value of TKE dissipation in the near-wall zone, and $\widehat{\mu}$ is the instantaneous value of dynamic viscosity of the non-Newtonian fluid (Gavrilov & Rudyak, 2016).

The Effect of Temperature on a Non-Newtonian Fluid

The non-isothermal fluid (waxy crude oil) has the properties of a Newtonian fluid (Beisembetov et al., 2016) at the pipe inlet. As a result of heat transfer with the surrounding cold medium through the pipe wall and a decrease in the flow temperature in its near-wall part, the effective viscosity increases, and yield shear stress appears. In a waxy crude oil this leads to the appearance of a non-Newtonian state. A decrease in the temperature of fluid can cause crystallization of the wax, and the release of the heat of the phase transition (Beisembetov et al., 2016; Zhao, 2020; Zhapbasbayev et al., 2021). The total amount of latent heat ΔH is defined by the form (Voller & Prakash, 1987):

$$C_P = \begin{cases} C_S, & t < t_S, \quad \text{in solid state,} \\ C_{Int}, & t_S \le t \le t_L, \quad \text{in transition zone,} \\ C_L, & t > t_L, \quad \text{in fliquid state,} \end{cases} \tag{16}$$

where C_S, C_L, and $C_{Int} = \left\{ \int_{t_S}^{t_L} C_L(t)dt + \chi H_{1\to 2} \right\} / \left(t_L - t_S\right)$ are the thermal conductivity of wax in solid, liquid, and transition states, t_L and t_S are the initial and final values of the temperature of wax formation in the oil flow, χ is the wax fraction in the oil, $H_{1\to 2}$ is the specific enthalpy of the wax phase transition (Beisembetov et al., 2016). In Eq. (16): t_L = 32 ^{0}C, t_S = 22 ^{0}C, $H_{1\to 2}$ = 41.03 [kJ/kg], χ = 0.15.

The heat capacity C_L, plastic viscosity μ_P, yield shear stress τ_0, density ρ, and thermal conductivity λ of waxy crude oil as a function of temperature are described by empirical formulas of (Beisembetov et al., 2016):

$$C_L(t) = \left(53357 + 107.2 \cdot t\right) / \sqrt{\rho_{20}}\ , \text{[J/(kg·°C)]}$$

$$\mu_P(t) = 0.3585 \cdot \exp\left(-0.1792 \cdot t\right), \text{[Pa·s]}$$

$$\tau_0\left(t\right) = 589.56 \cdot \exp\left(-0.567 \cdot t\right), \text{[Pa]}$$

$$\lambda\left(t\right) = 5.057 \cdot \left(1 - 0.00054 \cdot t\right) / \sqrt{\rho_{20}}\ , \text{[W/(m·°C)]}$$

$$\rho(t) = \rho_{20}\left[1 + \zeta \cdot \left(20 - t\right)\right], \text{[kg/m}^3\text{]},$$

where ρ_{20} = 835 kg/m^3 is the fluid density at 20^{0}C and ζ = 0.000738, [1/^{0}C] is the coefficient of volumetric expansion. Table 1 presents the yield shear stress τ_0, and plastic viscosity μ_P vs fluid vs their temperature.

Table 1. The dependence of yield shear stress, and plastic viscosity of non-Newtonian fluid

t, ^{0}C	T, K	τ_0, Pa	μ_P, Pa·s
0	273	589.6	0.3585
5	278	34.62044	0.14634
10	283	2.03286	0.05974

15	288	0.11937	0.02438
20	293	0.00701	0.00995
25	298	4.1156E-4	0.00406
30	303	2.41662E-5	0.00166

Boundary Conditions

No-slip conditions are set on the wall surface for the velocity and the condition of heat transfer with the environment medium is set for the temperature of the wall:

$$r = R = D/2:\ U = V = k = \tilde{\varepsilon} = 0 \text{ and } -\lambda_W \left(\frac{\partial T}{\partial r}\right)_W = \alpha_1 \left(T_m - T_W\right), \quad (17)$$

where r is the radial distance from the pipe axis, λ_W is the coefficient of thermal conductivity of the liquid determined from the wall temperature, h is the heat transfer coefficient from the oil flow in the pipe to the colder environment through the wall, $T_m = \frac{8}{U_{m1} D^2} \int_0^{D/2} T(r) U(r) r dr$ is the mean-mass temperature of the liquid in the considered cross-section, and the lower subscript "W" is the parameter determined according to the conditions on the pipe wall. The value of the heat transfer coefficient h from the fluid to the soil through pipe surface is determined by the formula (Beisembetov et al., 2016; Zhapbasbayev et al., 2021):

$$\frac{1}{hD} = \frac{1}{\alpha_1 D} + \sum_{i=1} \frac{1}{2\lambda_i} \ln \frac{D_{i+1}}{D_i} + \frac{1}{\alpha_2 D_2} \quad (18)$$

α_1 and α_2 are the "internal" and "external" heat transfer coefficients, D_1 and D_i are the inner and outer diameter of the pipe, and λ_i is the thermal conductivity of the pipe wall (stainless steel). The heat transfer coefficient α_1 is determined by considering the Fourier hypothesis for the heat flux:

$$\alpha_1 = \frac{-\lambda_W \left(\partial T / \partial y\right)_W D}{T_m - T_{W1}}, \quad (19)$$

The heat transfer coefficient α_2 is determined using the formula (Beisembetov et al., 2016):

$$\alpha_2 = \frac{2\lambda_{Soil}}{D_2 \ln\left[\frac{2H}{D_2} + \sqrt{\left(\frac{2H}{D_2}\right)^2 - 1}\right]}, \quad 20)$$

where λ_{Soil} is the thermal conductivity of the soil, and H is the depth of the pipe axis. The symmetry conditions are set on the pipe axis for all variables.

$$r = 0:\ \frac{\partial U}{\partial r} = \frac{\partial V}{\partial r} = \frac{\partial T}{\partial r} = \frac{\partial k}{\partial r} = \frac{\partial \tilde{\varepsilon}}{\partial r} = 0. \quad (21)$$

In the inlet section ($x = 0$), uniform distributions of velocity and temperature were specified over the cross-section of the pipe. At the outlet edge ($x = L$), the computational domain condition was set for all variables.

Thus, the system of equations (1)–(16) with the corresponding input and boundary conditions (17)–(21) is a closed system of equations that describes the processes of turbulent heat transfer in a waxy crude oil flow and allows the prediction of all the required quantities.

Numerical solution

The mean transport equations and the turbulence model were solved using a control volume method on a staggered grid. The QUICK scheme was used to approximate the convective terms, and the second-order accurate central difference scheme was adopted for the diffusion terms. The velocity correction was used to satisfy the continuity through the SIMPLEC algorithm, which couples the velocity and pressure.

All numerical simulations are performed using the "in-house" code. A non-uniform grid (in both axial and radial directions) was used and a grid refinement was applied in the inlet and the near-wall regions. The first cell was located at a distance in wall units $y_+ = yU_*/\nu = 0.3$–0.5 from the wall, where U_* is the friction velocity obtained for the flow in the inlet pipe, and ν is the kinematic viscosity. At least 10 control volumes

(CV) must be generated to resolve the mean velocity field and turbulence quantities in the viscosity-affected near-wall region ($y_+ < 10$). Grid sensitivity studies are commonly carried out to determine the optimum grid resolution that gives a mesh-independent solution. For all numerical investigations performed in this study, a basic grid with 1000×80 CV along the axial and radial directions was used. The part of the basic grid is given in the Fig. 2a. Grid convergence was verified for three grid sizes: coarse 750×50 and fine 1500×120 CV. The computational domain consisted of two sections and the length of each section is 10 m (x/D = 50). The conditions in the outlet of the first section were as the inlet conditions for the second one. Grid convergence is verified for three grid sizes is used for the "in-house" code: coarse 500×40, basic 1000×80 and fine 1500×120 CV control volumes (see Fig. 2b).

Differences in the value of TKE predicted for the non-Newtonian fluid flow is less than 0.1%. The maximum error $e_{\max}$ is defined as: $e_{\max} = \max_{i=1,\,N} \left| k_i^n - k_i^{n-1} \right| \le 10^{-6}$, where N is the total number of CVs in corresponding direction, the subscript i is the specific CV, and the superscript n is the iteration level. The computational grid is nonuniform both in the streamwise and transverse directions. The coordinate transformation is suitable for such a two-dimensional problem:

$\Delta\psi_j = K \times \Delta\psi_{j-1}$,

where $\Delta\psi_j$ and $\Delta\psi_{j-1}$ are the current and previous steps of the grid in the axial or radial directions and K = 1.08 (axial direction) and K = 1.05 (radial direction).

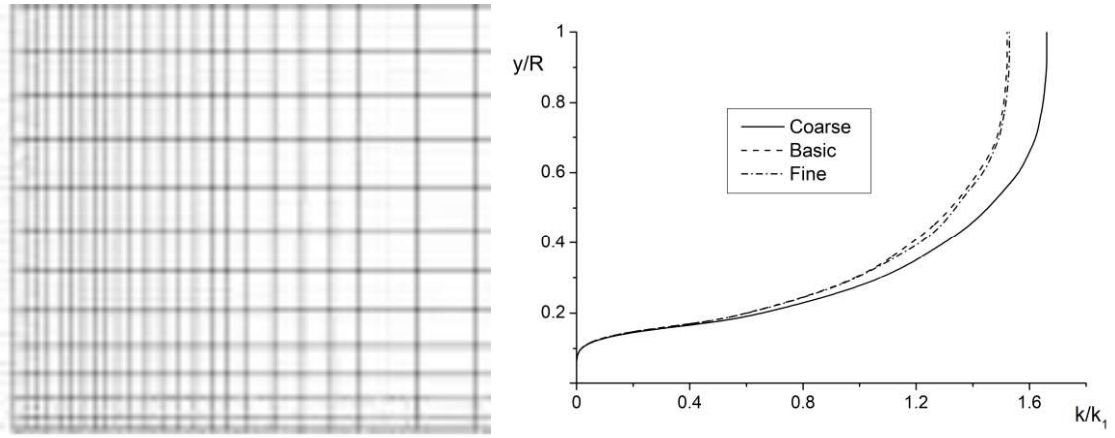


Fig. 2. Basic mesh grid (not in scale) (a) and grid convergence test (b) of "in-house" numerical code

Numerical results and discussion

A non-isothermal viscoplastic non-Newtonian fluid (waxy crude oil) flow along an underground pipe with an I.D. $D = 2R$ = 0.2 m, length L = 20 m (x/D = 100), and depth to pipe axis H = 2 m. The mean axial velocity and temperature profiles were uniform at the pipe inlet. All simulations were carried out in the region of hydrodynamic and thermal stabilization in a steady-state fluid flow in the pipe. Waxy crude oil in the inlet cross-section is considered as a Newtonian fluid. As fluid moves, the process of heat transfer through the pipe wall to the surround cold environment (soil) starts, and therefore the oil temperature is decreased. This leads to a sharp increase in viscosity and yield shear stress by decreasing of the fluid temperature. The velocity distribution will change both along the pipe length and along its cross-section

The profiles of dimensionless mean axial velocity U/U_{m1} (a), kinetic energy of turbulence k/k_1 (b), temperature $\Theta = (T - T_{W1}) / (T_1 - T_{W1})$ (c), average dynamic viscosity $\mu_{eff}/(\mu_T+\mu)$ (d), and yield shear stress $\tau_0/\tau_{0,1}$ (e) are shown in Fig. 3. Here, $y = R–r$ is the distance from the wall, R is the pipe radius, r is the radial distance from the pipe axis, μ represents the molecular viscosity of a Newtonian fluid (waxy oil), and $\tau_{0,1}$ is the yield shear stress at T = 293 K. The profiles of all parameters considered were uniform at the pipeline inlet (line *1*).

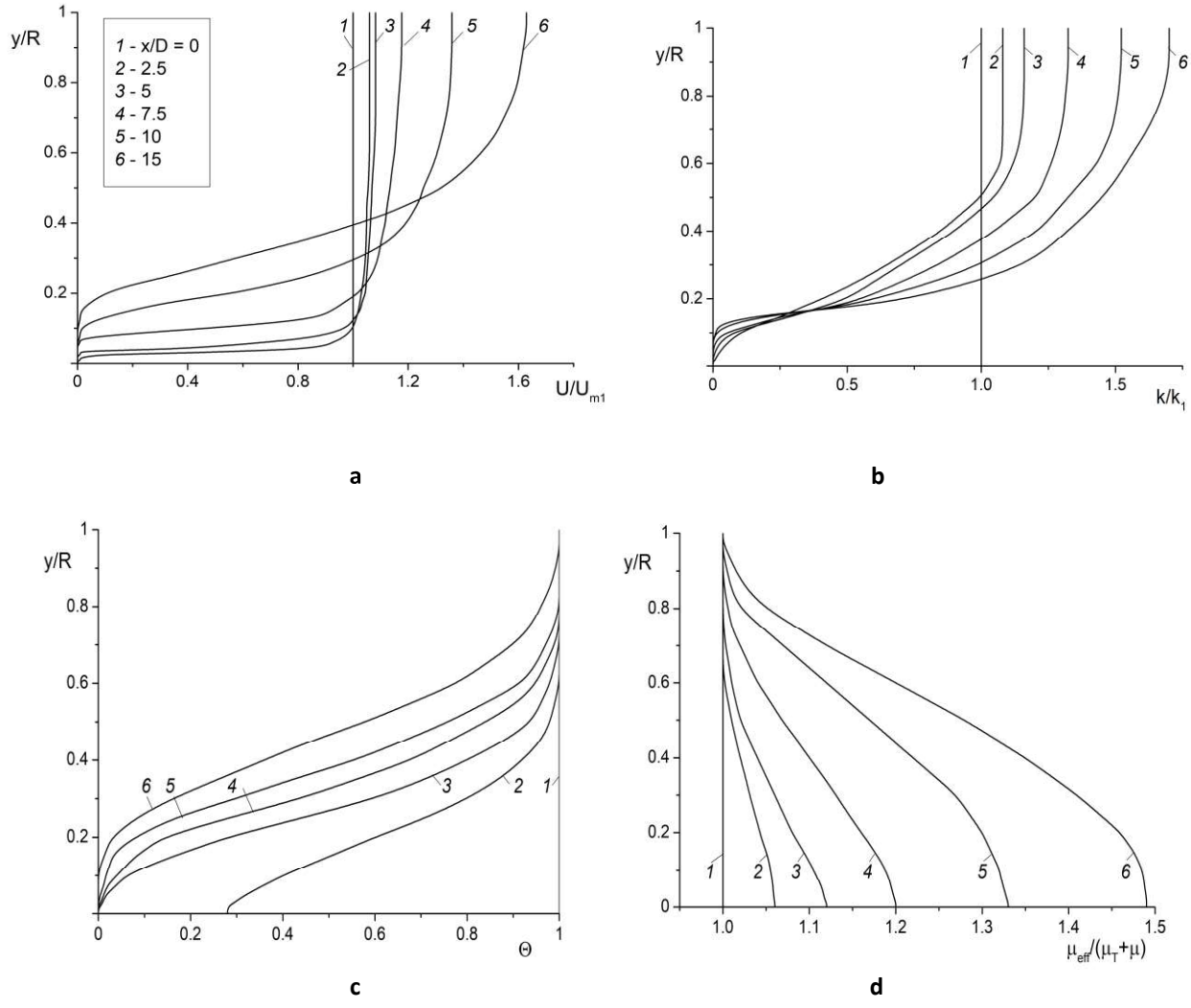
The inlet profile of the mean longitudinal velocity component was significantly deformed due to the process of heat transfer of the fluid with the soil environment through the pipe wall (see Fig. 3a). The value of the axial velocity was zero and it increased and reaches its maximum value in the axial region on the pipe wall.

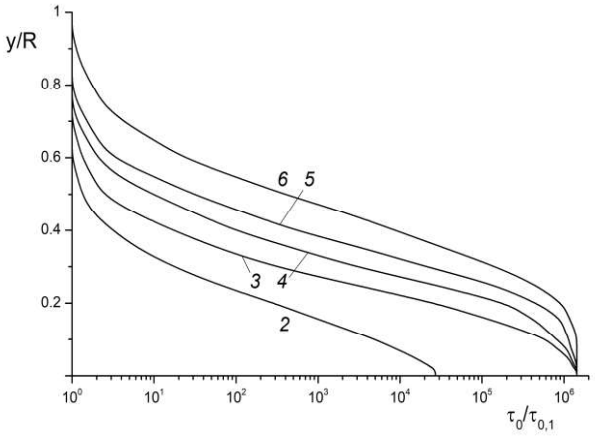
The values of the longitudinal velocity in the axial zone increased as the fluid moved along the pipe length. On the contrary, it decreased in the near-wall zone. The value of the mean axial fluid velocity in the axial region of the pipe increased by more than 1.6 times in comparison with the inlet velocity. The transverse profiles of fluid turbulence also underwent significant changes as the fluid moved along the pipe length (see Fig. 3b). An increase in the level of turbulent kinetic energy in the axial zone of the pipe (by more than 1.5 times) and its noticeable decrease in its near-wall region were observed, which was associated with the corresponding changes in the profile of the mean longitudinal velocity (see Fig. 3a). Fluid turbulence is determined by the known relationship for an axisymmetric flow:

$$2k = \left\langle u'^2 \right\rangle + \left\langle v'^2 \right\rangle + \left\langle w'^2 \right\rangle \approx \left\langle u'^2 \right\rangle + 2\left\langle v'^2 \right\rangle.$$

It should be noted that the use of an isotropic two-parameter $k-\tilde{\varepsilon}$ model (Rudman & Blackburn, 2006), written with partial consideration of the rheological properties of a non-Newtonian fluid, has limitations when simulating turbulent non-Newtonian flows. This is explained by the significant anisotropy of the components of the Reynolds stress tensor in non-Newtonian flows (Masoudian et al., 2020; Gavrilov & Rudyak, 2016). Therefore, this approach is the first step towards to describing the fluid flow and heat transfer in turbulent non-Newtonian flows.

The flow of waxy crude oil was originally a Newtonian fluid at the pipe inlet. Then, it cooled via heat transfer with the soil environment through the pipe wall. The decrease in the temperature of the fluid (see Fig. 3c) led to a change in its rheological and physicochemical properties and viscoplastic properties began to appear (De Kee, 2021; Bingham, 1922; Wilkinson, 1960; Klimov, et al., 2005). Therefore, with a decrease in the fluid temperature in the near-wall zone during heat transfer with the wall, the values of the average dynamic viscosity coefficient $\mu_{eff} = \mu_P+\mu_T+\mu$ (see Fig. 1c) and the yield stress τ_0 (see Fig. 3d) increased significantly.





e

Fig. 3. Radial profiles of dimensionless distributions of mean axial velocity (a), turbulent kinetic energy (b), temperature (c), averaged effective dynamic viscosity (d), and yield shear stress (e). D = 0.2 m, U_{m1} = 0.2 m/s T_1 = 298 K, T_{Soil} = 273 K

These two figures give clear information about the effect of non-Newtonian (viscoplastic) behavior on the fluid flow. It is known (Chala et al., 2018; Elkatory et al., 2022; Zhao, 2020) that at temperature $T \leq 293$ K, the yield shear stress τ_0 appears in the near-wall zone (see Fig. 3d), and this also leads to the velocity deceleration of the turbulent non-Newtonian fluid. It is obvious that with a decrease in the flow through the cross-section of the pipe with a constant mass flow rate of fluid along the pipe length, the axial velocity should increase, which is observed in Fig. 3a. The size of the near-wall section with a lower temperature increased towards the pipe axis and through the movement of fluid along the pipe length. This led to an increase in the average dynamic viscosity of the waxy crude oil and the yield shear stress.

The radial profiles of temperature, and the average dynamic viscosity along the pipe length show that waxy crude oil had the properties of a Newtonian fluid over the cross-section of the pipe in the temperature range $T \geq 293$ K, while in the temperature range $T < 293$ K, it had the properties of a viscoplastic (non-Newtonian) fluid. This is in qualitative agreement with the data of numerical calculations for the laminar flow of non-Newtonian fluids in a pipe (Zhao, 2020). Therefore, it seems important to determine the boundaries of existence of the Newtonian properties of a turbulent non-isothermal flow of waxy oil.

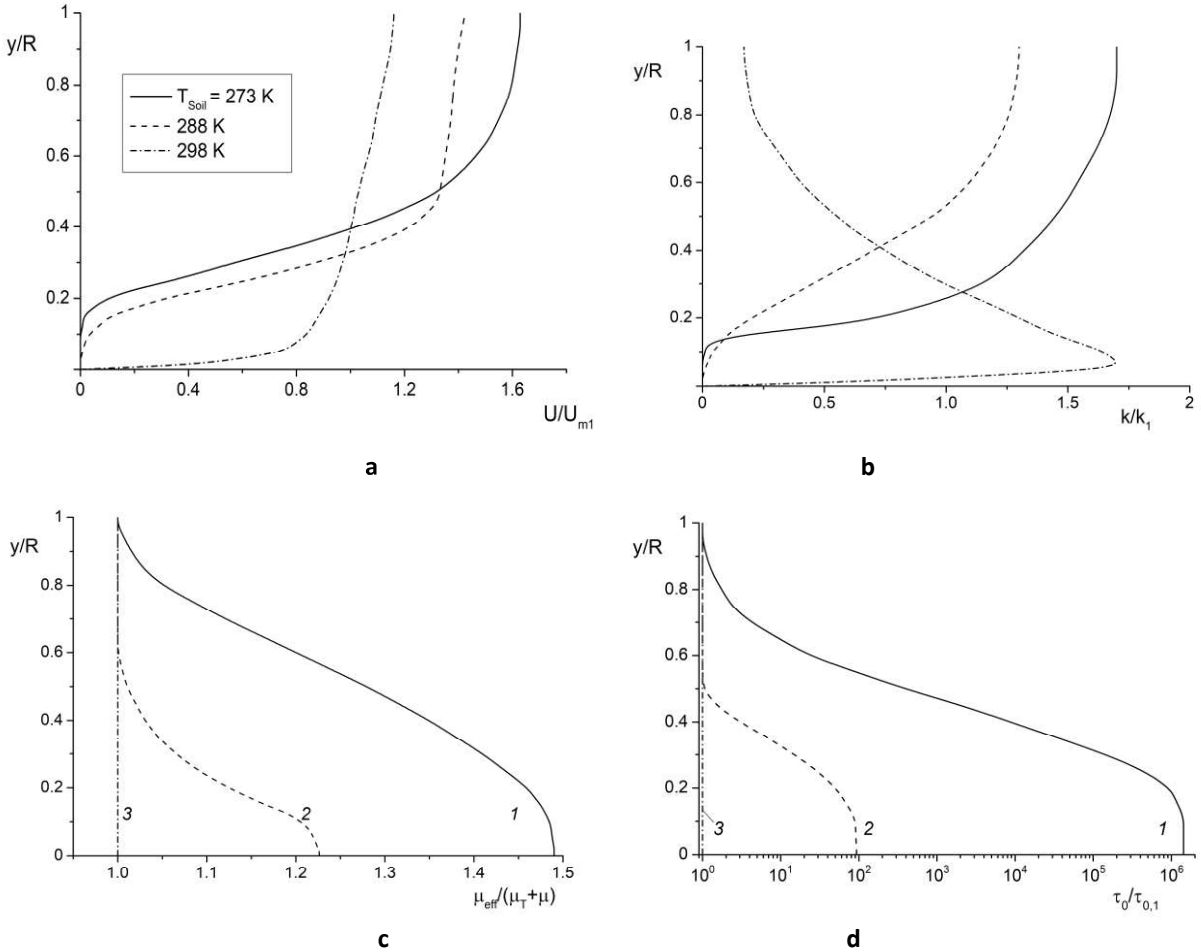
The results of numerical predictions on the effects of the surrounding environment's temperature T_{Ssoil} on the distributions of dimensionless mean axial velocity (a), kinetic energy of turbulence (b), coefficient of average dynamic viscosity (c), yield shear stress (d), and Reynolds stresses (e) over the pipe cross-section are presented in Fig. 4. The viscoplastic properties in distributions of the mean longitudinal velocity, turbulent kinetic energy, average viscosity, and yield shear stress, characteristic of the Bingham-Schwedoff fluid, were most clearly revealed at ambient temperature T_{Soil} = 273 K (*1*). The fluid flow characteristics at T_{Soil} = 298 K (*3*) fully agree with simulations for the Newtonian fluid with other conditions being identical. The profiles of the axial velocity had a form characteristic of the flow in the section of hydrodynamic stabilization (see Fig. 4a). The fluid turbulence had a characteristic maximum located in the near-wall region of the pipe (see Fig. 4b). The dynamic viscosity did not differ from the viscosity of a turbulent flow of a Newtonian fluid (see Fig. 4c). The yield shear stress was completely absent (see Fig. 4d). The prediction at T_{Soil} = 288 K (*2*) was characterized by the fact that the viscoplastic properties of the fluid were already beginning to appear.

The dimensionless Reynolds stresses $\langle uv \rangle_+ = \langle uv \rangle / u_*^2$ in the fluid are shown in Fig. 4e with varying temperatures of the surrounding soil, where u_* is the wall friction velocity for a Newtonian fluid. Reynolds stress for the axisymmetric flow were calculated by the relationship $\langle u_i u_j \rangle = -\nu_T \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right) + \frac{2}{3} k \delta_{ij}$. A decrease in the temperature of the surrounding soil had a noticeable effect on the level of Reynolds stress. The Reynolds stress in the flow of the non-Newtonian fluid (*2* and *3*) were noticeably higher than the corresponding value for a Newtonian fluid (*1*), with all other conditions being identical. In the near-wall and axial parts of the pipe, the Reynolds stress were equal to zero, since in these parts of the pipe the velocity

gradient and the level of turbulent kinetic energy were equal to zero (see Figs. 3a and 3b). The maximum Reynolds stress occurred in the near-wall part of the pipe for the whole investigated temperature range and there was a shift in the position of the maximum towards the pipe axis with a decrease in the temperature of the fluid. For example, for a Newtonian fluid at T_{Soil} = 298 K, the position of maximum was at a distance $y/R \approx 0.1$, while for T_{Soil} = 273 K the coordinate $y/R \approx 0.2$. This was explained by an increase in the thickness of the near-wall layer with the appearance of yield stresses.

Changes in the position of the points of mean axial flow velocity $U = 0$ (*1*), velocity $U = U_{m1}$ (*2*), and liquid temperature T = 293 K (*3*) and 298 K (*4*) along the pipe length are shown in Fig. 5. The solid lines (*1* and *2*) refer to the axial mean velocities of the fluid and the dashed lines (*3* and *4*) refer to the temperatures. The value of longitudinal velocity of fluid on the pipe wall was always zero, but in this case, line *1* in Fig. 5 shows the upper boundary of existence of the zone with a zero fluid flow velocity from the pipe wall. The height of the region with a zero fluid velocity in the pipe increased gradually as the waxy crude oil moved along the pipe length and reached $y/R \approx 0.55$ at x/D = 100 (x = 20 m). The position of the point where the fluid velocity was equal to the velocity in the inlet cross-section $U = U_{m1}$ (*2*) shifted gradually towards the pipe axis and $y/R \approx 0.9$ at x/D = 100. This was related to an increase in the fluid velocity in the flow core due to flow deceleration in the near-wall part of the pipe. It should be noted that the value of maximum fluid velocity in the axial region of the pipe increased significantly, while in its near-wall part it decreased due to flow cooling (see Fig. 5a).

The height of the region with the fluid temperature T = 293 K (*3*) shifted towards the pipe axis as it moved along the pipe length and reached $y/R \approx 1$ at x/D = 100. In terms of its physical implications, this was the upper boundary of the area of existence of the non-Newtonian fluid behavior. The yield shear stress in waxy crude oil (Bingham-Schwedoff viscoplastic non-Newtonian fluid) appears at t = 20°C and this value of temperature is a threshold for yielded and unyielded regions. In the region with temperature T = 298 K (*4*), this region also shifted towards the pipe axis and $y/R = 1$ at $x/D > 50$. This confirms the data of our numerical predictions, shown in Fig. 3, on the significant effect of fluid temperature on the processes of turbulent transport of momentum and heat in a non-Newtonian Bingham-Schwedoff fluid.



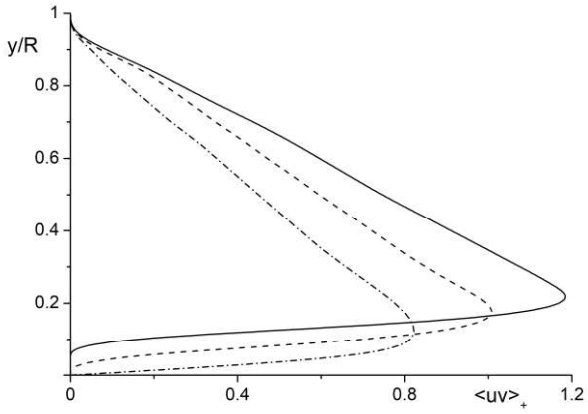


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Fig. 4. The dimensionless mean axial velocity (a), turbulent kinetic energy (b), average effective dynamic viscosity (c), yield shear stress (d), and Reynolds stress (e) plotted for different soil temperatures. *x*/*D* = 15, *x* = 3 m

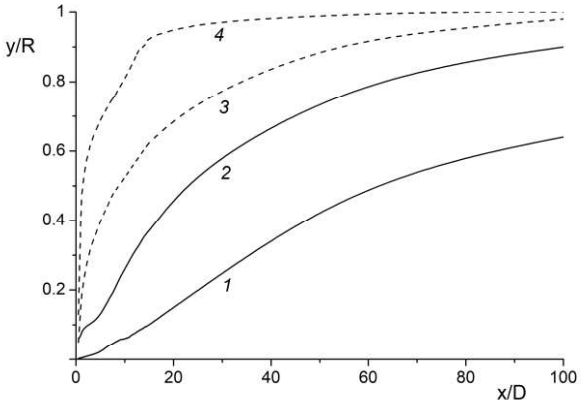
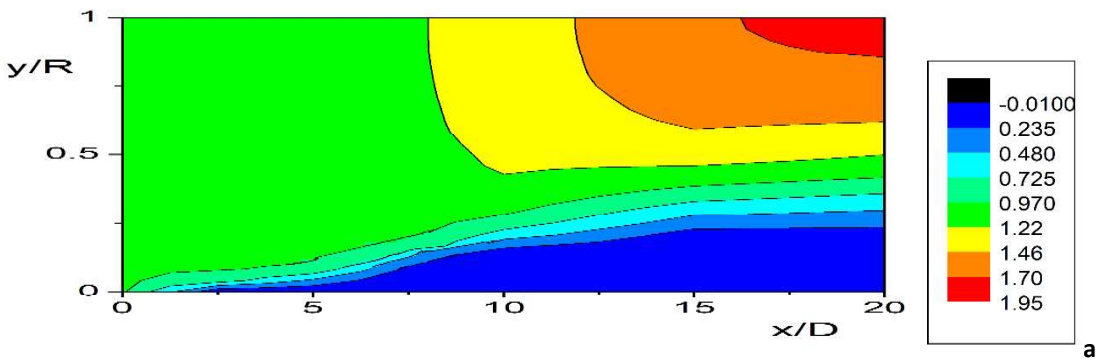


Fig. 5. The distributions along the pipe length of mean axial velocity of the flow equal $U = 0$ (*1*), mean axial velocity of the flow equal $U = U_{m1}$ (*2*), and temperatures equal $T = 293$ K (*3*) и $T = 298$ K (*4*). $T_1 = 298$ K, $T_{Soil} = 273$ K

The contour plots of the mean axial velocity (a), temperature (b), kinetic energy (c), and average effective dynamic viscosity (d) in the are given in the Fig. 6. These contours clearly show the main features of turbulent motion and heat transfer in the turbulent non-isothermal non-Newtonian fluid and they confirm the main conclusions in the abovementioned Figures 3–5. There is no flow motion in the "bottom" direction from the line $U/U_{m1} = 0$ and the flow accseleration is obtained in the "upper" direction from the line $U/U_{m1} = 1$ (see Fig. 6a). The behavior of the Newtonian fluid is observed in the "upper" zone from the line $T = 298$ K, and the line $T = 293$ K is the lower bundary for the existence of the yeld shear stress (see Fig. 6b). In the "upper" direction from the line $k/k_1 = 1$ is predicted the additional turbulence production due to the flow accseleration (see Fig. 6c). The line of average effective dynamic viscosity $\mu_{eff}/(\mu_T+\mu_1) = 1$ is the "lower" boundary for the existence of the properties of the Newtonian fluid (see Fig. 6d).



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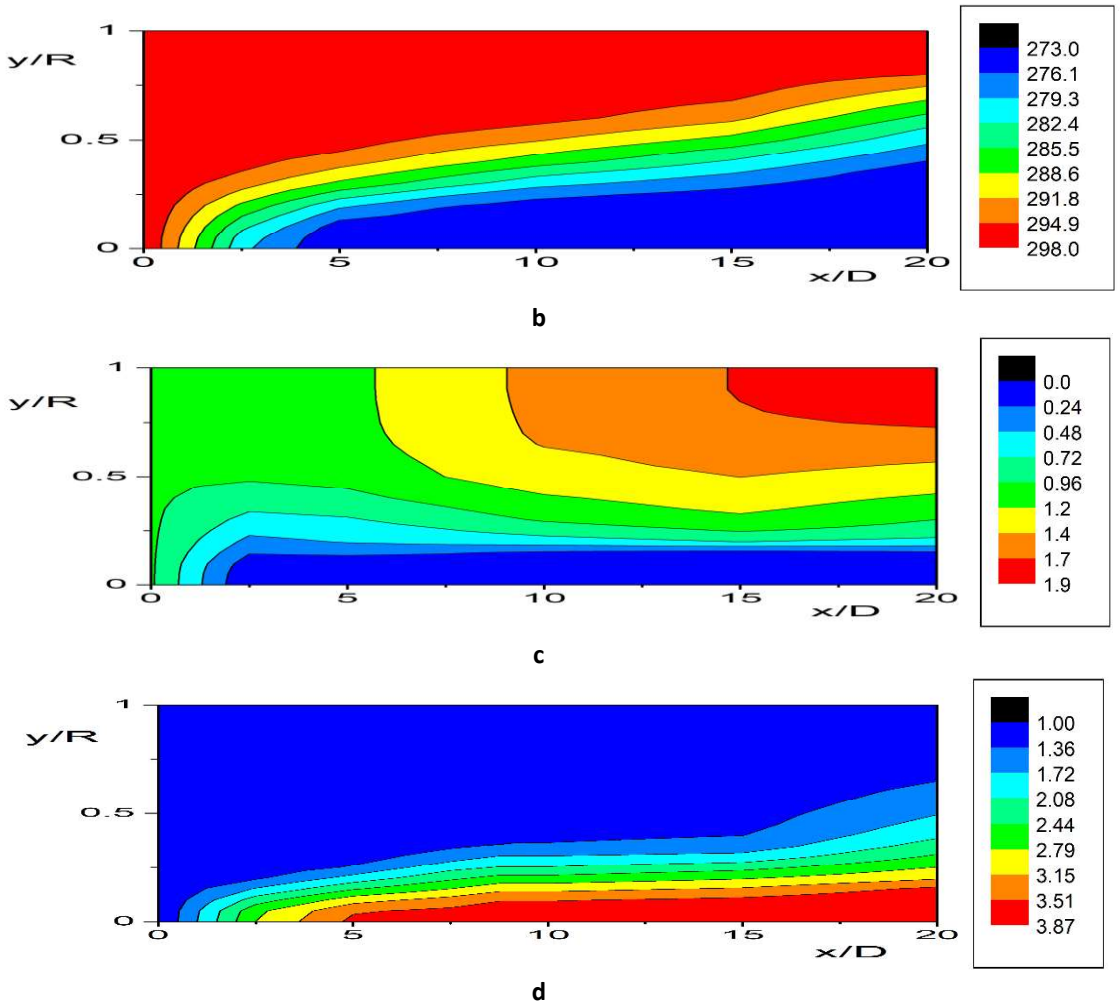

Fig. 6. Contours plots of mean axial velocity U/U_{m1} (a), mean temperature T, K (b), turbulent kinetic energy k/k_1 (c), and average effective dynamic viscosity $\mu_{eff}/(\mu_T+\mu_1)$ (d). The transverse height of the plots is not in the scale. U_{m1} = 0.2 m/s, T_1 = 298 K. T_{Soil} = 273 K, Re = 8200

Comparison with results of other authors for laminar and turbulent non-newtonian fluids

Turbulent Isothermal Non-Newtonian Flow

Fig. 7 shows a comparison of DNS data (Singh et al., 2017) and RANS predictions by the author for the distributions of dimensionless axial velocity $U_+ = U/u_*$ (a) and kinetic energy of turbulence $k_+ = k/u_*^2$ (b) in universal wall coordinates $y_+ = \rho u_* y/\mu_W = \rho u_* (R-r)/\mu_W$ for a Newtonian fluid (*1* and *3*) and for a turbulent Bingham-Schwedoff fluid (*2* and *4*). Here, R is the pipe radius and r is the current radial coordinate. The solid points represent the DNS data (Singh et al., 2017) and the lines are the author' predictions. The logarithmic velocity profile is also shown in Fig. 7a.

In the viscous (y_+ <5) and buffer (5 < y_+ < 30) areas, the simulations for a turbulent Newtonian and the non-Newtonian fluids gave almost the same values and there was a good quantitative agreement with the data of (Singh et al., 2017) (see Fig. 7a). It could be concluded that a change in the yield shear stress was not observed within the viscous sublayer and the difference between non- and Newtonian fluids was minimal. According to the distributions of axial velocities, an excess was noted according to the RANS computations (up to 10%) in comparison with the DNS data in the logarithmic layer (30 < y_+ < 200). In the logarithmic layer (lines *2* and *4*), this difference did not exceed 10%, and the author's velocity profile was similar to that of a Newtonian fluid.

Distributions of turbulent kinetic energy predicted by the author also agreed satisfactorily with the DNS data (Singh et al., 2017) in the viscous sublayer and in the logarithmic region (the difference did not exceed 15%) (see Fig. 9b). Here NF and NNF are the Newtonian and non-Newtonian fluids respectively. As well as for DNS, in the logarithmic layer at y_+ = 10–55, an additional generation of turbulence in the Bingham-Schwedoff fluid was shown as a comparison to the Newtonian fluid (an excess of up to 10%). Whereas, for y_+ > 100, the

results of DNS results showed the opposite: an insignificant suppression of turbulent kinetic energy (no more than 5–7%), which was not predicted by the author's RANS model. The authors of (Singh et al., 2017) explained this by a change in the ratio between longitudinal and transverse pulsations. The position of the peak in the turbulence level according to the RANS data was shifted towards the pipe axis (by 20%) in comparison with the DNS data (Singh et al., 2017) for both types of investigated fluids. The position of TKE maximum by DNS was $y_+ \approx 16$, and according to RANS computations, it was $y_+ \approx 20$.

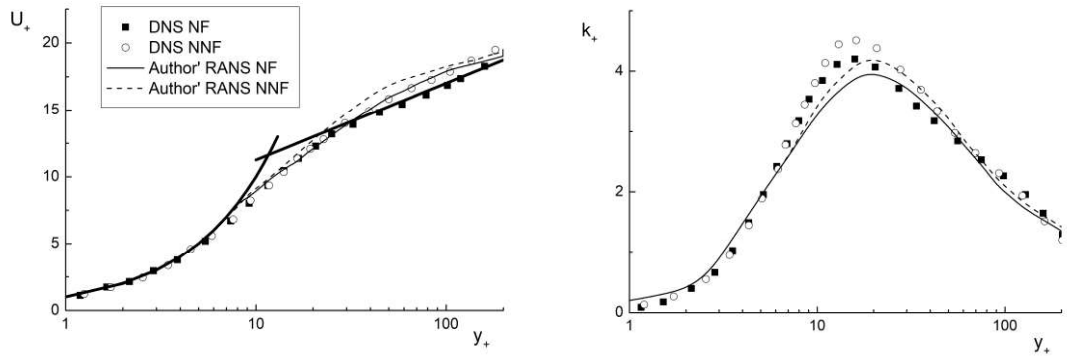

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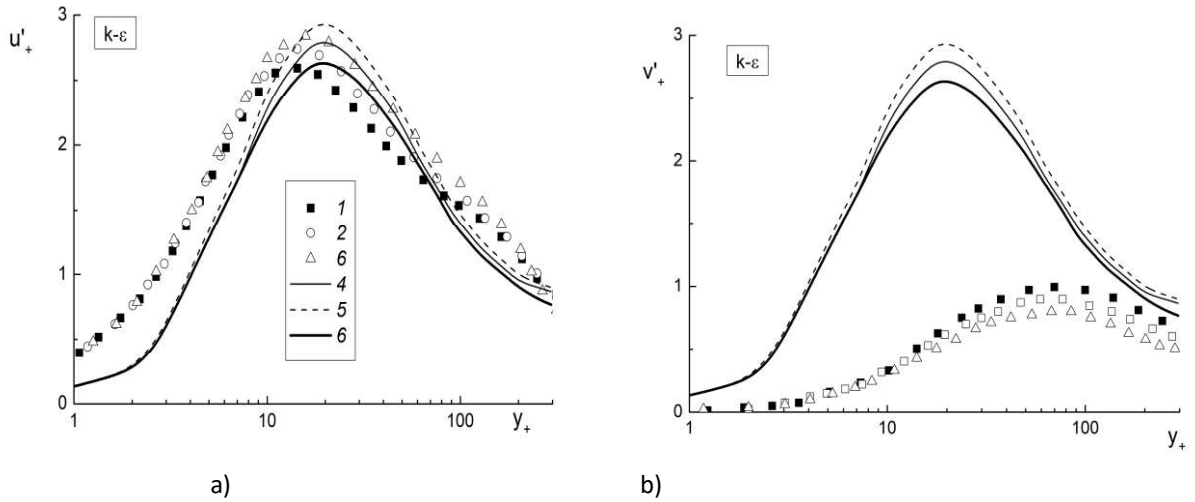
Fig. 7. The mean axial flow velocity (a), and turbulence (b) plotted in wall coordinates for turbulent Newtonian (*1* and *3*), and BS (*2* and *4*) fluids respectively. Points are DNS of (Singh et al., 2017), curves are author' RANS simulations. Re = 1.1×10^4, $\mathrm{Re}_\tau = 323$, $U_{m1}/u_* = 16.24$, $\tau_0/\tau_W = 1.1$

Comparison of DNS (Singh et al., 2017) and our RANS calculations for dimensionless distributions of axial velocity pulsations (a) and pulsation (b) for Newtonian fluid (lines *1* and *3*) and for Bingham-Schwedoff turbulent fluid (*2–6*) is shown in Fig. 8. In Fig. 8 points are DNS (Singh et al., 2017), lines are RANS calculation of authors using $k-\tilde{\varepsilon}$ model [36], $\mathrm{Re} = U_{m1}D_1/\nu_{W1} = 1.3\times10^4$, $\mathrm{Re}_\tau = u_*R_1/\nu_W = 323$. Lines *1* and *3* are Newtonian fluid; curves *2* and *4* are non-Newtonian fluid $\tau_0/\tau_W = 1.1$; lines *3* and *6* are non-Newtonian fluid at $\tau_0/\tau_W = 1.2$. The axial (see Fig. 8a) and the radial (see Fig. 8b) velocity pulsation profiles show differences with the DNS (Singh et al., 2017). The axial and radial components of the Reynolds stresses are typically determined in the isotropic $k-\tilde{\varepsilon}$ model: $u' = v' = 2k/3$. The axial averaged velocity profile along the tube cross section is qualitatively similar to the one for a Newtonian fluid. This is characteristic both for the DNS (Singh et al., 2017) and for our RANS calculations. However, the isotropic $k-\tilde{\varepsilon}$ model (Matvienko et al., 2011) does not even qualitatively describe the complex distribution of velocity pulsations over the pipe cross section and significant anisotropy of axial and radial velocity pulsations of BS fluid. This is especially noticeable in the profiles of the radial velocity pulsations (see Fig. 8b).



a) b)

Fig. 8. Comparison of the results of RANS calculations of axial $u'_+ = u'/u_*$ (a) and radial $v'_+ = v'/u_*$ (b) velocities fluctuations. Points *1–3* are the DNS (Singh et al., 2017), lines *4–6* are authors' simulations; *1* and *5* are the Newtonian fluid; *2* and *4* are the non-Newtonian fluid $\tau_0/\tau_W = 1.1$; *3* and 6 are the non-Newtonian BS fluid $\tau_0/\tau_W = 1.2$

Conclusions

A numerical model for the simulation of the turbulent fluid flow and heat transfer of a non-Newtonian Bingham-Schwedoff fluid has been developed. The mathematical model is based on a RANS approach with considerations of the non-Newtonian behavior of the fluid. Fluid turbulence was described using the isotropic two-parameter k–$\tilde{\varepsilon}$ model.

The Newtonian properties of fluid in the initial cross-sections of the pipe transformed gradually into a viscoplastic non-Newtonian fluid state due to heat transfer between the heated fluid in the pipe with a cold environment through the pipe wall. The value of axial velocity in the axial zone increased (up to 1.6 times in comparison with the velocity profile at the inlet), while in the near-wall zone, on the contrary, it decreased, and the height of the region with zero fluid velocity increased. A significant increase in the level of turbulent kinetic energy in the axial zone of the pipe (by more than 1.5 times) was noticed alongside its decrease in the near-wall region. The boundary of the area of existence of Newtonian properties of fluid was determined. It was found that the height of a region with fluid temperature $T \geq 293$ K decreased along the pipe length and it was $y/R \approx 0.6$ at $x/D = 15$. A significant increase in the average dynamic viscosity and yield stress in the near-wall part of the pipe was shown.

The characteristics of a turbulent isothermal Bingham-Schwedoff fluid within a viscous sublayer almost did not differ from the main Newtonian fluid regularities. In the logarithmic layer, the velocity profile for the non-Newtonian fluid had a form qualitatively similar to that of the Newtonian fluid. An excess of the axial velocity was characteristic for both types of non-Newtonian fluids with a logarithmic profile.

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Aigul M. Uteshkalieva
Kh. Dosmukhamedov Atyrau University, Atyrau, Kazakhstan. E-mail: aigul-bekbol@mail.ru
ORCID: https://orcid.org/0000-0002-7571-6279

Zulfiya A. Madeniyetova
Kh. Dosmukhamedov Atyrau University, Atyrau, Kazakhstan. E-mail: zulfiya3131@mail.ru
ORCID: https://orcid.org/0009-0003-0067-5024

Intra-school control - as part of the management system of an educational institution

Abstract: This article provides an explanation of intra-school control as part of the management system of an educational institution. The pedagogical activity of any school is characterized by comprehension of the accumulated work experience, the search for new ideas, the achievement of a high level of pedagogical excellence in the organization of educational activities, the emergence and dissemination in the pedagogical, parental, and managerial environment. and a new understanding of the values of education, when education becomes a priority in the lives of the younger generation. And in every school, one of the real levers for such development is the apparatus of intra-school control. In-school observation should be motivated and stimulating, based on knowledge of the capabilities and interests of all participants in the educational process. On the one hand, its result is a qualitative improvement in relations within a certain group and between them, on the other hand, it contributes to the degree of professional growth and achievements of teachers and students.

Keywords: Intra-school control, forms, types, forms, methods, principles of intra-school control.

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Introduction

The pedagogical activity of any school is characterized by comprehension of the accumulated work experience, the search for new ideas, the achievement of a high level of pedagogical excellence in the organization of educational activities, the emergence and dissemination in the pedagogical, parental, and managerial environment. and a new understanding of the values of education, when education becomes a priority in the lives of the younger generation. And in every school, one of the real levers for such development is the apparatus of intra-school control.

Intra-school monitoring (ISM) is a comprehensive study and analysis of the educational process in a school with the aim of coordinating all work in accordance with the assigned tasks. In-school monitoring is a necessary link. Because as a result of this, the regulatory function begins to work, making the necessary adjustments to the analysis process, as well as to the process of planning and organizing activities. The purpose, content and methods of corrective actions in the management process are determined by the control function, which, by identifying non-compliance with standards and requirements, provides information about where, what, how and when it is necessary to implement correctly. The selectivity and accuracy of the adjustment function completely depend on the level of quality of intra-school control.

The purpose of intra-school control:

- ensure compliance of the functioning and development of the pedagogical process at school with the requirements of the state educational standard;

- improvement of the educational process, taking into account age characteristics, interests, educational opportunities and health status of students.

Objectives of intra-school control:

- establishing violations and non-compliance with legislative and other regulatory legal acts in the field of education and taking measures to prevent them;
- analysis and expert assessment of the effectiveness of the teaching staff;
- identifying negative and positive trends in the organization of the educational process and developing proposals for their elimination and development;
- analysis of the results of implementing orders and regulations at school;
- providing methodological assistance to teachers.

Intra-school control is one of the most important functions of management, which is directly related to the functions of analysis and goal setting: without analysis, data is dead, without goals there is no management.

The intra-school control of the school is carried out in order to improve the activity of the educational organization, as well as to improve the quality of school education based on the study and analysis of the educational process in accordance with the national requirements (normatives), the requirements of students and teachers.

The intra-school control plan for the academic year is prepared in accordance with the order of the Ministry of Education and Culture of the Republic of Kazakhstan dated April 6, 2020 No. 130 "On approval of the list of mandatory documents and their forms for teachers of secondary, technical and professional, post-secondary educational institutions". In educational organizations, it is recommended to carry out intra-school control in the form of planned or urgent inspections, monitoring and administrative work in accordance with the regulation on intra-school control approved by the pedagogical council (Uteshkalieva et al., 2022a; Uteshkalieva et al., 2022b).

Due to their importance, problems of management activities of heads of educational institutions constantly attract the attention of a large circle of teacher-researchers. Konarzhevsky Yu.A., M.P. Portnov, V.P. Simonov, V.A. Slastenina, A.I. Tebyakin, T.I. Shamova and other studies are devoted to various aspects of management of educational institutions.

What should a modern school principal look like? This question is usually associated with another newbie question: "Where to start?" Scientist-teacher M.P. Portnov, who has extensive experience in practical work, shares his thoughts on the skill and culture of management and advises the school director to organize his activities at the first stage. A successful start is a step towards high professionalism (Portnov, 1981).

PI. Tretyakov reveals the main methods of managing the transfer of a school from a working mode to a developing one. Particular attention is paid to the formation of intra-school management structures and the development of principles of self-government. Considering the person-oriented approach of the school of democratization of the entire management system, one can observe their focus on final results on the path to success (Tretyakov et al., 2000).

Yu.A. Konarzhevsky, using some managerial positions, identifies points of contact between the theoretical positions of management and intra-school management (Konarzhevsky et al., 2000).

Shamova T.I. provides a general description of education systems and their management; pays special attention to school; deeply reveals the meaning of the educational process (Shamova et al., 2002).

Control is one of the most complex activities of the head of an educational institution, requiring a deep understanding of the function and role of the function, understanding of its target orientation, and mastery of various technologies (Fig. 1).

Control is a component of intra-school management, the beginning of management activities.

Intraschool control is a complex and multifaceted process and, like any whole, has a certain order, organization of interconnected parts, each of which performs certain functions.

Yu.A. Konarzhevsky believes that internal control of a school is one of the most important management functions, which is directly related to the function of analysis and goal setting; without analysis, observational data is dead, and in the absence of goals there is nothing to control (Konarzhevsky et al., 2000; Shamova et al., 2002).

Intra-school control is not only a part of the management system, but also the system itself, so its formation and organization must meet all the requirements of the system approach and, first of all, be clearly

structured. The structure of intra-sschool control of the school reflects the organization of control at all levels: external - state, public and internal - pedagogical (Pidkasastiy, 1995).

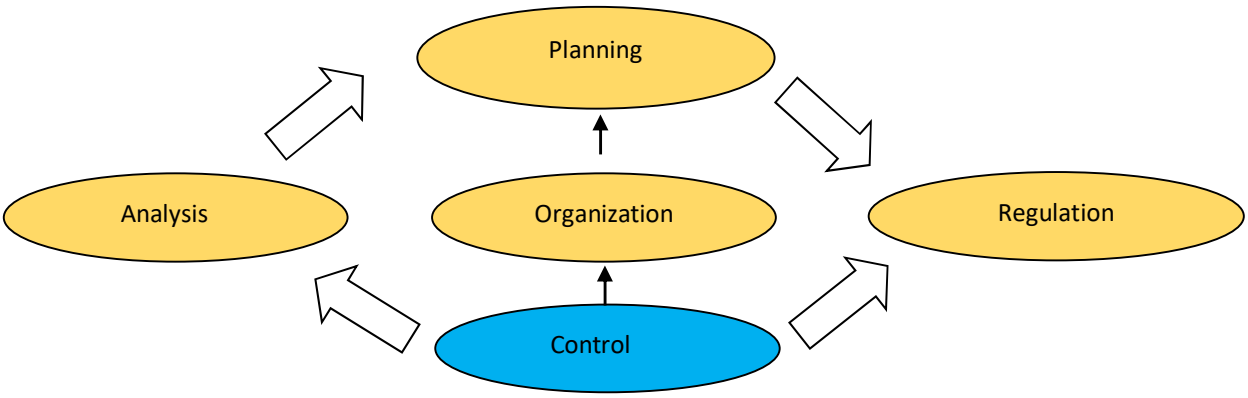

Fig. 1. Place and role of control in the intra-school management mechanism

Objects of intra-school control:
- Learning process:
✓ implementation of training programs;
✓ level of education of students;
✓ teacher productivity;
✓ individual work with students.
- Educational process:
✓ level of education of students;
✓ quality of work of class teachers;
✓ participation of parents in the educational process;
✓ work with "difficult" children;
✓ quality of intra-school activities.
- Methodological work:
✓ methodological level of each teacher;
✓ dissemination of teaching experience;
✓ advanced training of teachers.
- Scientific and experimental work:
✓ degree of scientific validity of innovations;
✓ level of scientific training of teachers;
✓ research activities of students.
- Psychological condition:
✓ degree of psychological comfort/discomfort of students and teachers;
✓ psychological readiness of the team to solve problems.
- Providing the necessary conditions for educators:
✓ labor protection;
✓ sanitary and hygienic conditions;
✓ provision of educational and methodological literature;
✓ provision of educational and technical equipment.

Type of intra-school control (in relation to the entity performing control):

✓ Collective control (involved in all levels of management: administration, pedagogical team, students, delegation of parents with external powers).
✓ Mutual control (college mentoring by means of mutual participation in class).

✓ Self-control (performed by self-reporting).

✓ Planned administrative control (performed by a member of the administration according to the plan of intra-school control).

✓ Unscheduled administrative control (performed by an administrative member in unforeseen cases).

- *Forms of intra-school control (classified by the scope of management objects):*

✓ Generalized control in the classroom (allows to monitor the pedagogical impact of teachers in the same group on students in the same team and to determine the features of this effect using the comparison method. It is used 4 times a year, lasts one or more days. Members of the administration participate in all lessons in the same class to determine the causes of problems) . The level of education and upbringing of students under general control; teacher quality and teaching methods; may be the quality of the class teacher's work.

✓ Frontal supervision (enables full supervision of the work of one teacher or the entire methodological department. Lasts 10-20 days. Helps to study and spread experience). The following can be attributed to frontal control: the condition of teaching subjects, the level of work of class teachers in parallel classes.

✓ Thematic monitoring (aimed at studying the level of education and students' mastery of specific topics and the performance of tasks in the lesson process, as well as checking the ability of each teacher to use the main components of modern lessons in rational methods and forms in practical activities). Thematic monitoring can be aimed at studying the level of students' knowledge on any educational topic or the work of the class teacher in one direction;

✓ Personal supervision (assessment of the performance of an individual teacher. It is used to provide effective assistance in the work of a teacher in order to ensure his proper work. The reason for personal supervision of a teacher may be his low level of methodology or performance.

✓ Overview control (used for general familiarization with the professional level of the entire team of teachers or a part of it at the beginning of the year). Review control may be aimed at examining the state of school documentation and the state of teachers' work behavior.

-*Methods of intra-school control:*

✓ Monitoring (organized by participation in classes, activities, which will be analyzed later).

✓ Documentation review (various documentation is evaluated: class documents, lesson plans, etc.).

✓ Questionnaire - oral/written (considered as interview, survey).

✓ Testing (conducted to measure individual differences between teachers and students).

✓ Operational analysis (analysis of the recently held event, lesson).

✓ Retrospective analysis (evaluation of school activity by other persons) (Kurachitsky, 2020; Fang Yuqi et al., 2022).

Principles that make the process of in-school control effective:

- consistency (the project of the intra-school control plan is developed throughout the current year, control topics are determined on the basis of past inspections and decisions (conclusions) made on them. It ensures the creation of psychological conditions for the systematic nature of intra-school control. Conditions for the development of all objects of the educational institution);
- validity (real idea, understanding what, when and for what purpose should be monitored);
- completeness (covering all components and areas of the life system of the school, as well as the effectiveness of their interaction in achieving goals and objectives);
- competence of the inspector (sufficient level of competence of people preparing for the upcoming inspection);
- transparency (this is one of the important principles of the IB. Each direct participant of the IB should know what "level" he is at in order to further plan his future development);
- continuity (this principle is important when monitoring the results of the teacher's work, especially because it makes the process of developing his professional competence continuous);
- consistency - systematic control; creation of a control system that allows to manage the entire course of the pedagogical process at the school;
- objectivity - checking the activity of a teacher or pedagogical team in accordance with the requirements of state standards and educational programs based on developed and agreed criteria;
- efficiency - the decision made (conclusion) should be implemented, focused on real, positive changes, growth).

Periods of intra-school control:

I. Preparation period:

• determining the goal;
• control planning;
• choice of control type and forms;
• definition of standards;
• creating an inspection team;
• instructing inspectors.

II. Diagnostic period:

• participation in classes;
• receiving control work;
• work with documentation;
• student surveys.

III. Analysis of information, conversation with teachers.

IV. Final stage:

• draw conclusions;
• preparation of proposals;
• preparation of conclusions;
• discussion of the results (at the pedagogical council, etc.)
• providing methodological assistance.

Control conditions:

• providing timely and accurate information about the state of school work;
• effectiveness of control, timely assistance to teachers as needed, dissemination of best practice;
• high culture of inspectors, their competence;
• prevention of stressful situations, support of good initiatives.

Places where inspection results are reviewed:

• in meetings with the director or his deputies;
• in administrative councils;
• At meetings of the Board of Directors;
• in pedagogical councils.

Methods of summarizing control results:

• definition;
• report;
• graphic report;
• conversation, etc. (Iskakova, 2014).

Intra-school monitoring should end with the formulation of recommendations for improving the work of the monitored, and, if necessary, with recommendations for providing assistance to them. And the positive achievements found should become the benefit of the team and the public by spreading the best practice and best work models in order to improve the entire educational process.

Conclusions

Today, intra-school control in the educational institution management system is an actual issue. In conclusion, I would like to highlight the conditions that contribute to the success of intra-school control:

- ✓ a system of working with teachers to increase the activity, responsibility and independence of all participants of the educational process;
- ✓ relying on the achievements of pedagogical management, technological efficiency, the use of interactive methods, information technologies, the ability to spread best practice;
- ✓ provide objective, respectful, reliable control; - priority of positive character, success;
- ✓ formation of a data bank to ensure control and must have: control programs, information collection and processing technologies, control results evaluation parameters, etc.;
- ✓ wide participation of professional associations, transfer of some control functions, state-public character, teachers' work on self-control and self-evaluation, involvement of external experts, transparency, etc.

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Yernar Tursyn
Satbayev University, Kazakhstan
E-mail: 991201301147-M@stud.satbayev.university
ORCID ID 0009-0008-9192-0449

Investigation of the structural properties of amorphous films obtained by high-frequency magnetron sputtering

Abstract: This article presents a study of amorphous films obtained using the high-frequency magnetron sputtering (HFMS) method and their potential applications in various industries. Materials play a crucial role in the modern world, and the development of new materials with unique structural and functional properties has become a paramount task in the scientific and engineering community. HFMS is a powerful method for synthesizing amorphous materials with high structural purity and controllable properties. The article commences with a description of the experimental setup and methods for obtaining amorphous films using HFMS, including the operational principles of the equipment, the selection of materials for sputtering, and process parameters. Special attention is given to the magnetron as a key component of the setup. Subsequently, the article explores various fields of application for amorphous films obtained through HFMS, including integrated circuits, sensors, solar cells, medical devices, optical coatings, and more. HFMS provides the capability to create materials with specific characteristics, making it an essential tool for developing novel materials and enhancing existing technologies. The study of amorphous films and their applications in diverse industries constitutes a significant area of scientific research, and this article offers an overview of synthesis methods and potential material applications.

Keywords: Amorphous films, high-frequency magnetron sputtering (HFMS), structural properties, material applications, synthesis methods.

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Introduction

In today's world, materials are paramount across various industries, from electronics to energy, making the development of new materials with unique structural and functional properties a pressing concern (Johnson, 2000; Ilmaliyev et al., 2022; Nussupov et al., 2014). This study explores amorphous films synthesized using high-frequency magnetron sputtering (HFMS) and their diverse potential applications.

HFMS is a leading-edge method for producing amorphous materials with exceptional structural purity and controlled properties (Johnson, 2000). The process utilizes a magnetron with a magnetic system and cylindrical cathode target, creating a magnetic field that enhances electron-atom collisions within the cathode material (Garcia, 2002). The HFMS process begins with ionizing the working gas, typically argon, using a high-frequency source. Accelerated argon ions collide with the cathode, liberating atoms and depositing them on the substrate as amorphous films (Chen, 2001; Garcia, 2002; Kenzhaliyev et al., 2021).

HFMS excels in delivering structurally pure films, suitable for applications requiring material purity. It also offers adjustable film thickness. HFMS finds applications in integrated circuits, sensors, flat-panel displays, thin-film solar cells, and lithium-ion batteries. It's also employed in producing biocompatible coatings, nanoparticles for medical devices, and optical coatings for mirrors and filters (Smith, 1998; Wan, 1999; Kusherova et al., 2023).

HFMS stands as a potent technology for synthesizing amorphous films with remarkable structural and functional properties, serving various fields, from electronics and energy to medicine and optics.

The HFMS Method and Its Principles

High-Frequency Magnetron Sputtering (HFMS) is a process for synthesizing amorphous films based on the utilization of a magnetron. The primary component of the HFMS setup is the magnetron, consisting of a

magnetic system and a cylindrical cathodic plate. Within the magnetron, a magnetic field is created, which holds electrons near the cathode surface, increasing the likelihood of electron collisions with cathode material atoms.

The process begins with the ionization of the working gas, typically argon, by a high-frequency source. Argon ions are accelerated toward the cathode, where they collide with the atoms of the cathode material. These collisions result in the release of atoms from the cathode, a process known as "sputtering." Subsequently, these atoms are deposited onto the substrate surface, forming an amorphous film. However, thanks to the magnetron and the magnetic field, high structural purity of the films is ensured.

One distinctive feature of HFMS is the ability to precisely control film thickness, making this method highly versatile for various applications. Film thickness can be adjusted over a wide range, allowing for the creation of films with specific characteristics.

Experimental Setup and Methods

In a study conducted in 2000, modern analytical methods were employed to investigate the structural properties of amorphous films produced by the HFMS method. One of the key methods used was X-ray diffraction, which enables the examination of the crystalline structure of materials. Additionally, electron microscopy techniques were used to analyze the surface morphology of the films and determine their chemical composition.

Research Results and Discussion

The research findings revealed essential characteristics of amorphous films obtained through the HFMS method. The amorphous nature of these films was confirmed by X-ray diffraction, which did not detect characteristic crystalline peaks in the diffraction spectra. This indicates that the films are amorphous and lack a crystalline structure.

The structural purity of these films was also high, making them suitable for various applications that require material purity. Such materials can be used in integrated circuits, where even the slightest defects can lead to malfunctions.

Furthermore, the study demonstrated that the thickness of films obtained using HFMS can be easily tuned and controlled, making them even more attractive for various technical applications. This parameter can be critical, for example, in solar cells, where the thickness of the active layer affects the efficiency of solar energy conversion.

Applications in Various Fields

Amorphous films produced using the HFMS method have found wide applications in various fields. In the energy sector, these films are used to create thin-film solar cells, which can enhance the efficiency of solar energy conversion into electricity. In this field, even a small improvement in efficiency can have a significant impact.

In electronics, amorphous films obtained through HFMS are employed in integrated circuits, sensors, and flat-panel displays. Their structural purity and controlled thickness make them ideal for use in microelectronics.

In medicine, these films are used to create biocompatible coatings and nanoparticles that can be utilized in medical devices and pharmaceuticals. Their chemical structure and stability make them safe for use in the human body.

In optics and laser technology, amorphous films have been applied to create optical coatings, mirrors, and filters. Their structural purity and controlled thickness enable the production of optical elements with outstanding properties.

Conclusions

"In the year 2000, a study of the structural properties of amorphous films produced via the high-frequency magnetron sputtering method underscored the significance of this approach in the development of new materials and the enhancement of existing technologies. Scientific investigations in this field continue to evolve, and HFMS remains a potent tool for synthesizing amorphous materials with exceptional structural and functional characteristics. Subsequent research efforts may be directed toward optimizing HFMS parameters

and expanding the scope of application for these materials. This opens new avenues for the advancement of innovative technologies and the progress of science and engineering."

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Kydyrmolla M.K.
"Institute of Metallurgy and Ore Beneficiation" JSC
Satbayev University, Almaty, Kazakhstan
E-mail: magzhank04@gmail.com
ORCID ID: https://orcid.org/0009-0001-2988-7288

Smagulov D.U.
"Institute of Metallurgy and Ore Beneficiation" JSC
Satbayev University, Almaty, Kazakhstan
E-mail: d.smagulov@satbayev.university
ORCID ID: https://orcid.org/0000-0002-0599-8741

Ybyraiymkul D.T.
"Institute of Metallurgy and Ore Beneficiation" JSC
Satbayev University, Almaty, Kazakhstan
E-mail: d.ybyraimkul@satbayev.university
ORCID ID: https://orcid.org/0000-0003-1506-6531

Studying the influence of electrolyte composition on the structure and properties of the surface layer of aluminum alloys during plasma-electrolytic processing

Abstract: Plasma electrolytic oxidation (PEO) is a new processing process used primarily to produce a thick and dense surface layer of metal oxides, especially light metals, to improve wear and corrosion resistance. If we compare the surface layers obtained by the PEO method with the surface layers obtained by conventional anodic oxidation, then, first of all, they are more resistant to wear and corrosion. It is widely used in mechanical engineering, petrochemical, and biomedical industries. Many studies have been carried out to determine the characteristics of surface layers obtained by PEO. This review attempts to summarize and explain some fundamental aspects of the PEO process, the formation mechanism of the surface layer, the processing conditions affecting the process, the main characteristics of the process, and the mechanical and tribological properties. In addition, recent developments in nanocomposite surface layers and their applications are discussed with examples. It also highlights the importance of this process, its current trends, and the scope of future work. In this case, pay attention to the breakdown of dielectrics, which appears several times on the surface of the workpiece. These discharges play a central role in the process since it is mainly due to the associated plasma that the substrate is oxidized and the coating is formed. The details are complex because discharge characteristics are affected by a number of processing parameters. The relationship between electrical conditions, electrolyte composition, surface microstructure, and rate of discharge performance has become clearer in recent years, and these improvements in understanding are summarized here. There is a significant opportunity to more effectively control the process with specific objectives in terms of coating performance and energy efficiency, and efforts are being made to identify the key factors that contribute to this.

Keywords: plasma electrolytic oxidation, electrolyte composition, aluminum alloys, oxidation process, surface layer, corrosion resistance, mechanical properties, sulfuric acid, chromic acid, oxalic acid, wear resistance.

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Introduction

Plasma electrolytic oxidation (PEO) is one of the new methods of electrochemical treatment of surface layers. This method allows the processing of thick, hard, and dense surface layers of ceramics with layers of aluminum, titanium, and magnesium. The PEO process is known as micro-arc oxidation, plasma-chemical oxidation, and anodic oxidation. PEO uses environmentally friendly weakly alkaline and acidic electrolytes, in which oxide layers are formed under the influence of high electrical voltages (Lu et al.,2016; Kaseem et al.,). During this process, the thickness of the oxide surface layer on the packaging increases from tens to hundreds of microns, which can significantly improve corrosion resistance, wear resistance, and thermal strength properties. The PEO process has been studied for a long time and is considered a better approach for the

biomedical, electronics, aerospace and automotive industries than other traditional surface finishing processes (Rapheal et al., 2016). The phenomenon of electrolytic discharge in plasma was first discovered and described in article (Sluginov et al., 2012), and later this process was further studied in article (Simchen et al., 2020) in 1920 as a feature of the development of electrolytic capacitors. These phenomena were successfully studied by Brown and his colleagues in the early 1970s and used to create ceramic layers on aluminum alloy coatings in alkaline electrolytes (Brown et al., 1971). They called this method anodic spark deposition. Since then, researchers have continued to study this process, and it became practical after significant changes were made in the 1980s and 1990s (Kurze et al., 1986; Malyshev et al., 1984; Krysman et al., 1984; Yerokhin et al., 1998). With the advent of industrial production and improvement of technology, this process was called PEO. This process has been developed and used commercially by companies such as Keronite in the UK; bioengineering companies such as Innovent, Cermanod, Meotec in Germany and Nobel Biocare in Switzerland; Keystone Dental in the USA; Research and practical use of Nano Prime in Poland continues.

The formation of surface layers by the PEO method is a complex process, since it involves three operations simultaneously: electrochemical reactions, plasma-chemical reactions, and oxygen thermal diffusion reactions. The layers produced by these reactions are typically three-layer structures with a porous outer layer, a dense intermediate layer, and a thin inner dense layer. Various methods have been developed for treating the surface of metals and their alloys intended for producing coatings. Examples of coating metals include chemical modification, anodizing, electroplating, organic cladding, laser cladding, vapor deposition (physical vapor and chemical vapor), and thermal/cold spraying (Seshan et al., 2001). Most of these methods use toxic or harmful chemicals to form the surface layer of the packaging and require proper care and monitoring during use. The above-mentioned surface layer formation processes may have some limitations related to the coating or substrate material, mainly caused by low adhesion forces, overlap of surface layers and the growth of pores and cracks, leading to potential equipment failure. In contrast, the PEO process is less complex because it typically uses non-hazardous and environmentally friendly solvents and achieves the highest performance oxide surface layer at low cost and long life.

Anodization or anodic oxidation is a classical method of surface treatment of metals and their alloys in order to form a protective oxide layer (Chu et al., 2015). In this process, a uniform voltage or current is applied between two electrodes in an electrolytic solution to create a thick oxide layer on the metal substrate of the anode. Anodizing was first used on an industrial scale in 1923 to improve the protective properties of seaplane aluminum (Ebnesajjad et al., 2013). The oxalic acid anodizing process was patented in 1923 (in Japan) and was primarily used for architectural purposes. The anodizing process is typically carried out at low operating temperatures and high current densities. Here, the surface structure and chemical composition of the surface oxide layer can be changed by adjusting parameters such as electrolyte concentration and composition, electrical parameters, and substrate composition. The PEO process is an advanced version of the anodizing method, which uses the high potential to generate chemical, thermal, and plasma reactions in the substrate to form a thick and dense ceramic oxide surface layer. The PEO process also allows the formation of new surfaces of different colors and textures, providing wear and corrosion resistance, thermal stability, dielectric properties, good bioactivit,y and biocompatibility (Lu et al., 2016; Rizwan et al., 2018). A similar process to PEO is hard anodizing because it produces a thicker, stronger coating than conventional anodizing.

Literature review

1. The mechanism of formation of the surface layer in the PEO process

In the PEO process, changing the current mode between alternating current, direct current, bipolar, and unipolar current modes can lead to significantly different modifications of the surface layer. Key parameters such as current density, voltage intensity, pulse fluctuation, and positive/negative duty cycle influence the PEO procedure and the properties of the resulting surface layer (Martin et al., 2013). In addition, these parameters affect the characteristics of the PEO process, such as advanced stress fracture, local melting and oxidation of the coating, solidification, and recrystallization processes, and in turn significantly affect the microstructure and properties of the surface layer. The PEO process uses a wide range of voltages (95 to 750 V) with alternating or direct current between the cathode and anode. When the circuit is closed, the cathode and anode obey Faraday's and Ohm's laws. In this case, the metal coating together with a counter electrode (usually stainless steel or a graphite cathode) serves as a working electrode (anode) (Gao et al., 2014). Both electrodes are immersed in a slightly alkaline electrolyte. The electrodes are then connected to an external power source to begin the surface formation process. During the PEO process, electrochemical oxygen

evolution and metal oxidation reactions occur at the anode (equations (1) and (2)). In this case, due to a strong electric field, anodic generation of oxygen occurs, and oxygen anions (O_2–) move to the anode and form metal oxide in the coating. Depending on the coating, electrolyte composition, and chemical activity, this may result in surface dissolution or the formation of an anodic oxide film (equation (3)). At the same time, intense evolution of hydrogen gas (equation (4)) and reduction of cations (equation (5)) occurs on the cathode surface. Due to gas evolution and the discharge reaction, the resulting layer may be more porous than the oxide layer formed during the solidification process. anodizing The general equations involved in the PEO process are:

$$2\ H_2O - 4\ e^- \rightarrow O_2\uparrow + 4\ H^+ \quad (1)$$

$$Me - ne^- \rightarrow Me^{n+} \quad (2)$$

$$x\ Me^{n+} + 3/2\ x\ n{\cdot}H_2O \rightarrow MexO_n\downarrow + x\ n\ H_3O^+ \quad (3)$$

$$2\ H^+ + 2\ e^- \rightarrow H_2\uparrow \quad (4)$$

$$Cat^{n+} + n\ e^- \rightarrow Cat^0\downarrow \quad (5)$$

where M is the metallic material required for the process, n is the number of electrons transferred, e is an electron, and Cat is a cation.

The article (Snizhko et al., 2007) reports that the Faradaic process is associated with traditional hard anodizing, but there have been cases where non-Faradaic phenomena were observed simultaneously with discharge reactions. It was later emphasized that the PEO process involves non-Faradaic processes such as thermal decomposition of water. Apart from these two processes, current PEO research mainly focuses on two hypotheses. Research is primarily being conducted to better understand the fundamentals of the PEO process, such as electrical discharge reactions, gas evolution (Snizhko et al., 2007), and acoustic emission (Arrabal et al., 2009; Boinet et al., 2005). The second assumption is different, such as the surface layer's resistance to corrosion and oxidation (Gu et al., 2011; Gu et al., 2012; Hwang et al., 2009; Barchiche et al., 2007), wear characteristics of the layer (Zhang et al., 2007; Yeshmanova et al., 2021), photocatalytic efficiency (Jiang et al., 2011; Kenzhaliyev et al., 2021; Yao et al., 2010), biological activity (Huang et al., 2005; Han et al., 2003) and thermal activity. and impact resistance (Clyne et al., 2019; Shokouhfar et al., 2012) regarding properties. All these assumptions are important for the emerging surface layer. General mechanisms in the PEO process: a) formation of an oxide layer at the interface of the metal and electrolyte, b) increase in the potential difference on both sides of the dielectric oxide layer; c) breakdown of the dielectric oxide layer (Lugovskoy et al; 2013). At the beginning of the oxidation process, there is an initial outward thickening of the oxide layer, followed by an inward thickening of the oxide layer (Darband et al., 2017).

The resulting oxide layer often has a solid crystalline structure because electrical discharges generate significant amounts of heat, leading to increased crystallization around the oxide layer (Wang et al., 2020). Surface layers treated with PEO have a higher level of porosity but are relatively more wear-resistant than anodized coatings (Clyne et al., 2019). Dielectric breakdown occurs between a thin oxide layer at the bottom of a deep pore in the coating. In the PEO process, high voltage and alternating current cause intense sparking due to microarc discharges, which leads to the formation of damaged oxide layers.

There are significant differences in the performance of PEO compared to the anodizing process. The layer formed as a result of anodization has a relatively uniform shape, and due to the low electrical conductivity of the oxide layer, the thickness of the resulting oxide layer is small. The resulting layer weakens the metal surface during anodization and limits its further growth (Fig. 1: Stages I-II). On the other hand, in the PEO process, high voltage causes intense sparking due to micro-discharge arcs that destroy the oxide layer (Fig. 1: stages I-III). High temperatures and pressures develop in the exhaust ducts, which cause complex phase transformation processes leading to the formation of a compact, thick and hard layer that is resistant to wear and corrosion. Despite the relatively high porosity of PEO layers, they can effectively protect the base metal from corrosion, since the pores formed during the discharge can be treated with molten oxides due to the high local temperature in the plasma discharge zone. Therefore, the surface layers of PEO do not allow aggressive environments to pass through.

The PEO process is influenced by various parameters such as the nature of the coating material, electrolyte components, current density, current type, voltage, frequency, duty cycle, additives, incorporated particles, coating time and operating temperature (Rapheal et al., 2016; Shokouhfar et al., 2012; Yerokhin et al., 2003; Li et al., 2013). Although this process is widely used for materials such as aluminum and its alloys (Yerokhin et al., 2003; Wielage et al., 2008; Patel et al., 2017; Loghman et al., 2018; Zhang et al., 2017) and

magnesium and its alloys (Narayanan et al., 2014; Lu et al., 2016; Apelfeld et al., 2017; Chen et al., 2018; Lu et al., 2018), recent research into PEO surface coatings has focused on other cladding metals such as titanium. (Luo et al., 2019; Han et al., 2018; Rokhian et al., 2018; Yavari et al., 2016; Jiang et al., 2016), tantalum (Wang et al., 2013; Gao et al., 2014; Rokosz et al., 2016; Zhao et al., 2017; Antonio et al., 2019), zirconium (Sandhyarani et al., 2014; Lu et al., 2015; Cengiz et al., 2017; Savushkina et al., 2017; Malayoglu et al., 2020), niobium and all their various alloys have been studied in (Rudnev et al., 2014; Stojadinović et al., 2016; Pereira et al., 2017; Pereira et al., 2018; Ge et al., 2019). Additionally, significant work on the modification of zinc using the PEO process has been reported by (Rocca et al., 2015; Stojadinović et al., 2016; Li et al., 2018; Yuan et al., 2018). Apart from the above-mentioned materials, several studies have been carried out with other rare metals such as hafnium (Stojadinović et al., 2017), beryllium (He et al., 2017) and brass (Cheng et al., 2020).

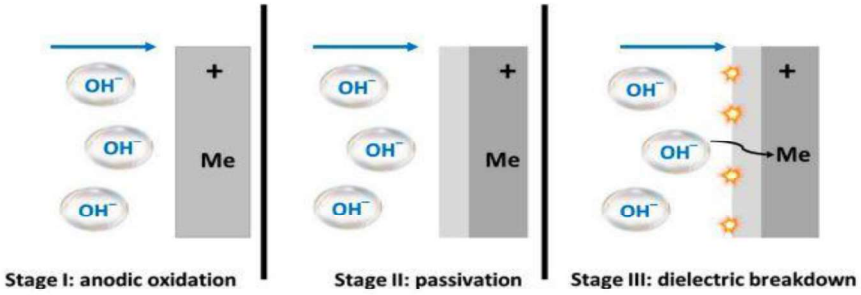

Figure 1. A schematic diagram explaining primary stages of an oxide layer generation in anodizing and PEO process (Yerokhin et al., 2003)

1.2. Processing conditions affecting the PEO process

In addition to the above parameters, there are other factors that affect the surface layer, such as the formation of gas bubbles, the development of soft plasma discharges in the late stages of the process, the emitted electromagnetic radiation, a phenomenon also known as galvoluminescence, plasma temperature, electrolyte in electrolyte when an electric field is applied, also known as electrophoresis. Mentioned in article (Kaseem et al., 2020) about the rapid movement of dispersed particles and the energy consumed in this process. The morphology, microstructure, and phase composition of the PEO layer ultimately determine the characteristics of the layer. Therefore, in the next section, we will briefly review studies analyzing the influence of technological parameters of PEO surface layers.

1.3. Action of electric current

The type of power used in the PEO process affects the morphology of the resulting surface layers, their structure, the rate of layer thickness growth, layer hardness, and porosity value (Denhavi et al., 2014). As mentioned earlier, the PEO process can use different electrical current modes: direct current and alternating current, as well as bipolar and unipolar current for specific applications. Although direct current can be used to form the PEO process, the process is more efficient when using alternating current. The use of direct current in applications requiring porous and thin surface layers is reported in (Khan et al., 2010). In addition, the constant current mode favors the formation of surface layers with a relatively low rate of oxide layer formation, which leads to the formation of highly porous structures. This current mode provides less control and less adjustable discharge characteristics, but if pulsed constant current mode is used, it allows better control of discharge duration and possibly reduced energy consumption (Khan et al., 2005; Jiang et al., 2010). Direct current is relatively cheaper and more convenient to use than alternating current. On the other hand, the advantage of using AC mode is that it stops the polarization of the electrode and helps control the process by interrupting the arc (Famiyeh et al., 2019). Bipolar pulsed current modes have been observed to produce taller and thicker coatings with higher corrosion resistance as they reduce the effects of high-intensity plasma discharges as well as high-temperature explosions when used in the PEO process (Denhavi et al., 2014; Hussein et al., 2011).

As for constant voltage modes, its effect on the PEO process with a zirconium (*Zr*) alloy in the presence of citric acid was studied (Stojadinović et al., 2014). They used optical emission spectroscopy (OES) to characterize microdischarges during PEO. The study showed that the optimal selection of experimental parameters, such as the type and volume of electrolyte, plays an important role in determining the

characteristics of the resulting surface layer. Other factors such as temperature and electron density have provided a more detailed understanding of the PEO process as well as the mechanisms involved.

Zhao et al. (2018) used direct current to improve the surface characteristics of several *Al-Zn-Mg-Mn-Zr* alloy samples in their research work. This process was characterized by the appearance of microdischarge sparks at four different stages. It was observed that in the first stage, the passivation film is formed under the action of a strong electric field, and in the remaining three stages, the passivation film is formed under the action of breakdown voltage. They found that the surface layer formed a thicker layer at lower current densities and with fewer internal defects. On the contrary, high current density had a detrimental effect on the composition and properties of the surface layer. (Sowa et al., 2018) studied the effect of direct current on the surface layer of pure *Zr* PEO in the presence of calcium acetate and calcium glycerol phosphate electrolytes. The process was carried out at voltages of 200, 300, and 400 V. At a voltage of 200 V, the appearance of the most corrosion-resistant surface layer without a porous structure was observed. This type of surface layer is ideal for biomedical equipment. When carrying out the process at 300 V and 400 V, in contrast to the 200 V process, a layer with less corrosion resistance was obtained. In addition, it was found that the thickness and roughness of the resulting layers increase with increasing stress. The influence of the electrolyte components on the surface characteristics was insignificant. Regardless of the parameters used, the pitting corrosion resistance of zirconium was found to improve after the application of PEO surface layers.

Another study (Akbar et al., 2017) analyzed the effect of the duty cycle on the surface layer thickness of bipolar direct current PEO. It was observed that the thickness of the surface layer decreases with increasing duty cycle and it was concluded that DC affects the surface layer of PEO differently and further research can be carried out to modify the surface layer.

Articles (Arrabal et al., 2009; Matykina et al., 2010; Guan et al., 2008; Matykina et al., 2009) write that PEO surface layers were applied to different metal coatings using different electrolytes under alternating current conditions. (Naeini et al., 2019) based on a research work investigated a biocompatible ceramic layer of TiO_2 nanoparticles and hydroxyapatite (HA) deposited on pure titanium (*Ti*) using a PEO surface layer. In the experiment, a titanium sample was used as an anode, and stainless steel was used as a cathode. Five different types of electrolytes with different molar concentrations were used in the experiments, as shown in table 1. Initially, PEO surface coating was carried out on Ti samples in the presence of electrolytes without the addition of HA nanoparticles. Later, HA nanoparticles were added to the samples via an electrolyte. It was observed that surface layers in a solution containing electrolytes 1, 3 and 4 lead to better binding of HA nanoparticles due to the pores formed during the PEO process.

Table 1. Composition and concentration of electrolytes used

Electrolyte	Composition	Electrolyte concentration (*M*)
1	NaH_2PO_4	0.030
	$Ca(CH_3COO)_2$	0.020
2	NaH_2PO_4	0.020
	$Ca(CH_3COO)_2$	0.013
	$NA_2(EDTA)$	0.120
3	$Ca(CH_3COO)_2$	0.055
	Na-Beta G	0.012
4	$Ca(H_2PO_4)_2$	0.020
	HMP	0.016
	$NA_2(EDTA)$	0.030
	$Ca(CH_3COO)_2$	0.028
5	$Ca(H_2PO_4)_2$	0.050
	$NA_2(EDTA)$	0.045
	$Ca(CH_3COO)_2$	0.0036

Among all the electrolytes, it was observed that 4 electrolytes give the greatest thickness of surface layers. Moreover, after reaching the breakdown voltage for all electrolytes, this led to a decrease in the thickness of the sample. This can be explained by the fact that local heat distribution and discharge generation in the PEO process affect the thickness of the sample (Aliasghari et al., 2016). It was also observed that the samples coated with HA nanoparticles showed less corrosion than the samples coated without HA

nanoparticles. From the results obtained in this study, it can be concluded that the addition of HA nanoparticles significantly improves the material properties of titanium samples.

In the PEO process carried out on alternating current, the formation of pores was observed during breakdown of the anode. These pores are regenerated by liquid oxides formed during the corresponding anodic pulse. In this case, the electrolyte near the sample is revived and the new oxide layers formed become homogeneous. Typically, the PEO process uses sinusoidal alternating voltages with a frequency of 50–60 Hz and a voltage of 100–600 V (Sah et al., 2012)[91].

It is assumed that PEO performed with alternating current goes through the following stages (Gao et al., 2014; Gu et al., 2011; Sah et al,m 2012):

(a) During the first anodic half-cycle, a barrier oxide layer forms at the interface between the metal and the electrolyte.

b) The potential difference on both sides of the oxide layer increases with increasing anodic half-cycle.

c) electric sparks occur when the dielectric layer is damaged. A new volume of electrolyte is injected into the metal surface during fracture until the voltage is sufficient to induce a new fracture state, resulting in penetration and expansion of the oxide layers.

d) during cathodic half-cycles, relaxation of the metal and oxide layer and partial reduction of oxidized samples occur.

(e) The formation and destruction of gas bubbles during the process affects the growth of the oxide layer.

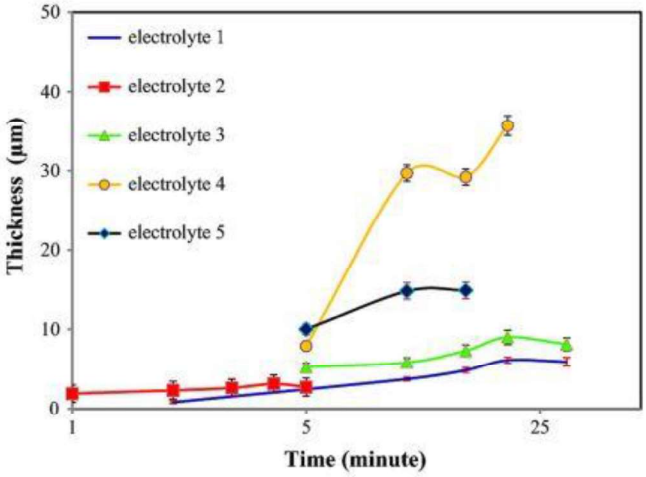

Figure 2. Time dependence of the thickness of the layer obtained from the electrolyte

To understand the importance of voltage and processing time characteristics associated with the PEO process, two studies are reported: (a) *AJ62 Mg* alloy using bipolar current mode and (b) *AM50 Mg* alloy operating in constant current mode (Chu et al., 2015). *AJ* alloys are magnesium-based casting alloys that provide optimum creep resistance at elevated temperatures. AM alloys containing aluminum and manganese, have good ductility and are used in the automotive industry for instrument panels, steering wheels and seat frames. There were four consecutive discharge periods for each study. Stage I: This stage is the initial phase of the PEO process where rapid electrochemical reactions occur in the resulting oxide film. Here the breakdown voltage has not yet been obtained. Stage II: At this stage, a decrease in the voltage level was observed, which was characterized by the appearance of several discharge sparks quickly moving along the surface of the sample. This phenomenon was characterized by a decrease in the rate of oxidation with increasing temperature in a process that was characterized by large numbers but slow discharge sparks. Stage IV: In this stage, the difference in stress rate was slower than in stage III. Here, intense discharges are formed in the form of relatively large and long-lasting sparks. In some cases, these powerful discharges can cause permanent damage to stage IV coatings.

1.4. Effects of electrolytes

The composition, nature (strong or weak) and concentration of electrolytes play an important role in determining the layer formed in the PEO process. Typically, the electrolytes used in the PEO process are

alkaline and weak. Electrolytes allow the movement of electrical charges to form a circuit and can regulate electrical conductivity as needed (Rogov et al., 2017). Aging of electrolytes is an important factor in the PEO process (Martin et al., 2015). In addition, the *pH* values of electrolytes play an important role in the PEO process, which can affect the microstructure and properties of the resulting layer.

In (Ghasemi et al., 2010), PEO surface layers were prepared on *AM50 Mg* alloys using *KOH* as an electrolyte with various additives such as silicate, phosphate and alumina, respectively. This alloy is widely used in automobiles, but its use is limited by low mechanical strength and corrosion resistance. The PEO process was found to produce the greatest silicate-based layer thickness of about 8 μm and the smallest alumina-based layer thickness of about 1 μm. In addition, it was found that the layer formed from these electrolytes has different phase components. In addition, PEO surface layers obtained in electrolytes with the same impurities but different concentrations may have different characteristics. It has been proven that increasing the electrolyte concentration increases the thickness of the total surface layers and affects its porosity.

In (Wang et al., 2020), the PEO process was carried out on *Al* 1060 alloy in the presence of three electrolytes (permeability values may vary), namely silicate, phosphate and a mixture of silicate and phosphate. This alloy has excellent electrical conductivity, corrosion resistance and is widely used in electrical and chemical industries. It has been observed that the breakdown voltage is 240 V for silicate system, 300 V for phosphate system and 280 V for mixed electrolytes. The fastest and largest layer thickness was observed for the silicate system, followed by the phosphate and finally the mixed electrolyte system. The influence of electrolytes on the roughness of the resulting surface layers was determined. The surface shape formed by the silicate coating showed the greatest deviation, followed by the phosphate electrolyte and then the mixed electrolyte.

(Shin et al., 2011) studied the effect of two different electrolytes on a *Ti* layer using the PEO method. The model is intended for biomedical research. The electrolytes used were potassium pyrophosphate ($K_4P_2O_7$) and potassium triphosphate (K_3PO_4), both of which are harmless to the human body. Both electrolytes have the same pH value. Experiments using the PEO process were carried out at room temperature to study the role of surface roughness and the structure of oxide films on titanium. These surface layers were used to further investigate the formation of biomimetic apatite in a simulated body fluid. According to the research results, it was noticed that $K_4P_2O_7$ forms crater-shaped microporous structures, which leads to an increase in surface roughness. The smaller pore size resulted in easier development of the surface layer of apatite. X-ray analysis of the same data showed that $K_4P_2O_7$ forms more phases, resulting in a higher growth rate of biomimetic apatite. Therefore, it can be concluded that $K_4P_2O_7$ was the best electrolyte for titanium PEO process for biomedical applications.

1.5. Nanocomposite layers

The introduction of nanoparticles is an effective way to improve the quality of the PEO process. The PEO process of these nanoparticles incorporated into the surface layer formation structure allows the creation of composite surface layers. Although a significant number of embedded nanoparticles enter the inner fragments of the surface layers, most of them remain diffusely distributed near the outer layer of the surface layers (Bahramian et al., 2011). As a result, the structure of the layer changes. Nanoparticles embedded in the structure of the formation of the surface layer not only improve its corrosion and tribological characteristics, but also improve adhesion and hardness to the underlying metal. These nanocomposite layers are used in the automotive, petrochemical, biomedical, marine and electronics industries. In the research work (Arrunnellajappan et al., 2018), α-Al_2O_3 and m-ZrO_2 nanoparticles were introduced into the *Al* alloy AA7075 by the PEO method in the presence of stearic acid, which led to the formation of nanocomposite layers. These nanoparticles were found to increase the thickness and corrosion resistance of the surface layer. The addition of stearic acid makes the coating hydrophobic in nature and further improves corrosion resistance. (Sharifi et al., 2016) used the processing of pure titanium PEO by adding α-Al_2O_3 nanoparticles along with the non-toxic corrosion inhibitor ketoconazole to produce dense nanocomposite surface layers. The presence of ketoconazole promoted the absorption of nanoparticles, made the layer denser and reduced its porosity. It was found that the hardness and wear resistance of the surface layer of the nanocomposite were also improved. (Sharifi et al., 2016) investigated the effect of cerium nanoparticles (CeO_2) on *AM50 Mg* alloy to develop an aluminate-based PEO method in their research work. It was found that the introduction of cerium reduces the porosity and roughness of the surface layer of the nanocomposite.

2. Mechanical properties of surface layers processed by the PEO method

2.1. Tribological attributes

PEO coatings are required for many surfaces that require slip or abrasion resistance. It has been established that the surface layers processed by the PEO method are firmly bonded to the underlying metal and have low hardness. As a result, the energy release rate of such layers is low. Although PEO surface coatings have a lower hardness, they are harder than anodized coatings. Here tribological studies play an important role for PEO treated surface layers and will be explained with several examples in the next section.

In (Qin et al., 2015), the PEO process was carried out on Ti_6Al_4V alloy with laser surface structure (LST) coated with MoS_2 solid oil. Different samples were considered for this process: untreated Ti_6Al_4V, LST treated Ti_6Al_4V, PEO treated Ti_6Al_4V, and a combined PEO treated Ti_6Al_4V and PEO treated Ti_6Al_4V sample. Under the same inlet conditions, the LST and PEO treated samples showed a higher coefficient of friction, while the untreated samples had a lower coefficient of friction. When examining the wear rate in the same experiment with the same input parameters, the untreated sample showed the highest wear rate, while the LST and PEO treated sample showed the lowest wear rate.

(Pezzato et al., 2018) investigated the tribological effect of PEO-treated surface layers with and without graphite nanoparticles on *AZ91 Mg* and *AZ80 Mg* alloys. Dry sliding tests were carried out on two alloys with and without graphite additives on a steel counter surface at two different processing times: 1 and 3 minutes, respectively. The coefficient of friction for *AZ91* with and without additives was highest at 1 minute of treatment. This was due to the abrasive interaction of the counter surface of the hard and rough PEO treated *AZ91* sample with the steel surface. On the other hand, for *AZ80* alloy with and without graphite, the highest friction coefficient was observed at a processing time of 3 minutes. In wear roughness depth analysis, both *AZ91* and *AZ80* with graphite showed the least scar formation.

2.2. Effect of fatigue load

The resistance to cyclic fatigue loading was affected by the development of cracks and the initial stage of their growth. Since these phenomena occur at the surface, it is very important to analyze what increases or decreases the resistance to these surface changes. Corrosion can also affect these surface development processes. PEO surface layers are often compressive in nature and have relatively low residual stresses. The loss of compressive stresses in the metal itself leads to deterioration in surface quality, which is undesirable. Therefore, it is important to pre-treat surfaces before carrying out the PEO process.

(Winter et al., 2016) performed a PEO process on *Al* 6082 alloy to understand the average stress sensitivity of the fatigue life of the alloy. 6082 *Al* is a medium strength alloy with excellent corrosion resistance used in vehicles. Previous studies have shown that PEO-treated aluminum alloys have lower wear resistance compared to uncoated alloys. As the coating thickness increases, the wear characteristics of the existing aluminum alloy PEO surface layers are further reduced. The decrease in fatigue strength may be due to the porosity of the oxide film, which initiates early crack propagation. Three different applied load ratios (R) of −1, 0.0, and 0.1, respectively, were used to study the fatigue behavior of the aluminum alloy. The applied load factor is defined as the ratio of the minimum and maximum loads taken into account during the fatigue loading process. During the experiment, the PEO process time was reduced to produce a thinner film, which reduced the negative impact on fatigue strength. The maximum stress that can be applied to a material without failure for a certain number of cycles is called its fatigue strength. After completion of the process, the fatigue strength of the PEO-treated samples decreased significantly under all three loading factors. It was observed that the PEO process neutralizes the effect of mean stress on the fatigue life of the layer. Other studies have also been noted that indicate a decrease in the fatigue life of other *Al* and *Mg* alloys (Klein et al., 2017; Dejun et al., 2015; Němcová et al., 2014). However, the fatigue life did not change in the PEO process carried out on Ti_6Al_4V alloy (Petomati et al., 2012). After the PEO process is completed, there are residual electrolytes in the packaging. If this residual electrolyte is not completely washed away, corrosion can occur. Therefore, you must be very careful while performing this process and check each step.

2.3. Residual stresses

The surface layer produced by the PEO process is restructured several times under the influence of microdischarges, so the residual stresses generated during this oxidation process are constantly decreasing in magnitude. In addition, the relatively low hardness of PEO layers does not allow high stresses to occur. But in a number of cases, literature studies mention high residual stresses (Dehnavi et al., 2014; Ao et al., 2019).

However, there are differences in these results. These high residual stress values were obtained from X-ray diffraction patterns. This method is difficult to apply in PEO layers, since the microstructure of the layer consists of very fine grains, different phases and it is possible to significantly change the microstructure of the layer. To account for this limitation, a new method called curvature measurement was used. Using this method, the overall stress level in PEO treated layers was found to be about 50 MPa for *Al* and 150 MPa for *Mg* (Dean et al., 2015).

Conclusion

The PEO process has been a standard metal surface treatment technology in many studies. Its use has increased significantly and it has many unique characteristics that set it apart from other facial treatments. This review helps to understand the mechanisms and discuss the processes involved in the process, the processing conditions affecting the process, the main characteristics of the process, the mechanical attributes of the process.

The articles mentioned here explain the effect of electric current on the surface layer treated with PEO on a modern model. The importance of electrolytes used in this process is discussed in detail. In addition, the types of additives that can be used in PEO processes are listed, as well as their functional properties. The interesting nanocomposite layers formed using the PEO process are another highlight of this resume.

Because PEO-treated layers change the microstructure, it reduces residual stresses and creates an overall more uniform surface layer. For a deeper understanding, it is necessary to describe the microstructural properties of the resulting surface layers. No less important is the study of the mechanical and tribological properties of the treated layers.

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Zeinura K. Abdimutalipova
Osh State University 723500, Osh, Kyrgyzstan
E-mail: 1986zeinura@gmail.com
ORCID ID 0000-0001-7425-5506

Abdikerim Y. Kurbanaliev
Osh State University 723500, Osh, Kyrgyzstan
E-mail: kurbanaliev@rambler.ru
ORCID ID 0000-0002-9204-8479

Numerical simulation of turbulent airflow in a room using the OpenFOAM package

Abstract. The results of numerical modeling of turbulent airflow in a room using the computational fluid dynamics approach to solve the Reynolds-averaged Navier-Stokes equation for a fluid are presented. First, a two-dimensional model was studied; the focus is on mesh refinement, the effect of mesh topology, and the influence of the turbulence model. The structured grid results were found to be in better agreement with available experimental measurements. Dimensionless velocities for various turbulence models are presented and compared: standard k-ε, standard k-ω, RNG k-ε, k-ω SST. The results explain that all turbulence models produce almost identical results.

Keywords: plain jet, turbulence models, RNG k-ε, k-ω SST, ventilation.

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Introduction

Air movement and the phenomenon of its transfer are very important characteristics of human thermal comfort. Speed is related to temperature distribution as well as turbulence levels. Thus, air velocity distribution plays a vital role in designing the interior condition of a room. This work is devoted to the study of the airflow model from the point of view of the distribution of speeds at different locations to compare the results of different turbulence models. Numerical simulations were carried out for the 2D model.

In recent years, when designing ventilation systems, computational fluid dynamics methods have increasingly been used, allowing for three-dimensional modeling of turbulent jet flows. In engineering practice, approaches that estimate flow parameters based on the numerical solution of Reynolds-averaged stationary or nonstationary Navier–Stokes equations have become widely used. Numerical simulations were carried out by solving Reynolds-averaged Navier-Stokes equations using OpenFOAM. In this research the results of a numerical simulation of turbulent air flow in a closed room using OpenFOAM.

Problem statement

The air flow in a room with dimensions of 3 m and 1 m, respectively, is considered. The geometry and computational mesh were created using the blockMesh utility in OpenFOAM. The pisoFoam solver was used for the simulations and post-processing was performed in Paraview.

The following turbulence models were used: Standard k-ε, Standard k-ω, RNG k-ε, k-ω SST. For this simulation, a 2D model of the room was used. On the front wall near the ceiling there is a natural ventilation slot with a slot height of h = 0.056H, and on the rear wall near the ground there is an open exit with a height of h = 0.16H. The Re number =5000 and depends on the inlet height, inlet velocity and ambient air conditions, so the flow is expected to have turbulent characteristics. Time-averaged results are confirmed by experimental results (Horikiri K et al., 2011; Akhmetov et al., 2021). The relationship between pressure and velocity was solved using the PISO algorithm (OpenFOAM 7.0 User's Guide, 2022). The time and turbulent terms were discretized using Eulerian and constrained linear schemes, respectively (OpenFOAM 7.0 User's Guide, 2022). Fig. 1 shows the number areas.

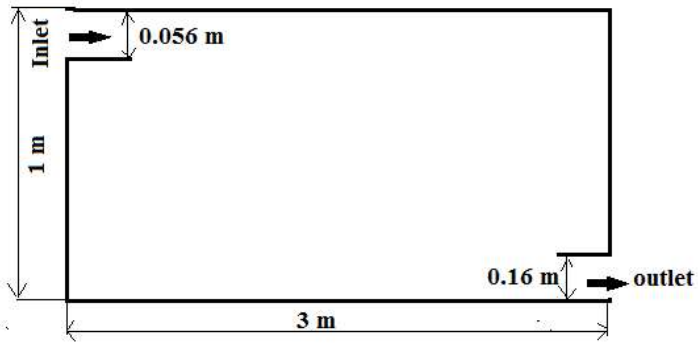

Figure 1. The geometry of the problem and boundaries of the domain

Initial and boundary conditions

We consider the isothermal movement of air described by a model of an incompressible fluid with constant physical properties: density ρ=1.23 kg/m^3, dynamic viscosity μ= 1.79·10^{-5} Pa·s. Air is supplied to the entrance to the room at a speed of 1.3 m/s and air circulation is created inside the room. Soft boundary conditions were specified at the output boundary. The remaining boundaries of the computational domain are solid walls on which no-slip conditions were specified. For our problem, the boundary conditions are determined by a zero pressure gradient normal to the wall - zeroGradient. At all boundaries of the computational domain, it is necessary to set boundary conditions for the main variables.

The computational domain is discretized using the control volume method. This data must be specified in the fvSchemes and fvSolution files located in the system folder. In the fvSchemes file, it is necessary to indicate the selected discretization schemes for all terms of equation (1), as well as describe interpolation schemes for calculating fluxes through the faces of control volumes. In this case, to solve the SLAE, the PISO algorithm is used, in which it is necessary to indicate the number of internal corrections for the velocity and pressure fields. Information about the boundary conditions used in this work, the methods of discretization of the systems of equations (1-19), and the solution of the systems of linear algebraic equations are given in Table 1, Table 2, and Table 3, respectively.

Table1. The boundary conditions used

Variable / Boundary	Velocity, m/s	Pressure, Pa	*k*, m2/s^2	ω, 1/s	ε, m^2/s^{-3}
Inlet	fixedValue; uniform (1.3 0 0);	zeroGradient	fixedValue; uniform 0.006308284;	fixedValue; $internalField;	fixedValue; uniform 0.020031953;
outlet	zeroGradient;	fixedValue; uniform 0;	zeroGradient	zeroGradient;	zeroGradient;
wall	noSlip;	zeroGradient	kqRWallFunction; uniform 0.006308284;	omegaWallFunction; $internalField;	epsilonWallFunction; uniform 0.020031953;
Front and rear	empty	empty	empty	empty	empty

Table 2. Discretization schemes used

The term	Approximation scheme in the OpenFOAM package	The order of accuracy of the scheme
Gradient	cellLimitedGausslinear 1	Second
Divergence	bounded Gauss limitedLinear 1;	Second

Laplacian	Gauss linear corrected;	Second
Interpolation	linear	First

Table3. Solvers of equations for basic variables

Variable	Scheme	Accuracy
Pressure	GAMG resolver using a smoothing agent GaussSeidel	1e-6
U, k, ε, omega	smoothSolver resolver using a smoothing agent symGaussSeidel	1e-5

Mathematical model

The numerical method used here is based on the solution of the averaged Reynolds Navier-Stokes equations. In tensor notation, the equation for incompressible fluid flows can be written as follows (Ferziger J H and Peric M):

$$\frac{\partial u_i}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial (u_i u_j)}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right) \quad (2)$$

Turbulence model

1. $k-\varepsilon$ model. The most popular model with two differential equations is the k-ε model proposed by (Chow, 1945) and further developed in the studies of (Launder-Jones,1972).

The equation for the kinetic energy of turbulence is:

$$\rho\frac{\partial k}{\partial t} + \rho\overline{u_j}\frac{\partial k}{\partial x_j} = \tau_{ij}\frac{\partial \overline{u_i}}{\partial x_j} - \rho\varepsilon + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] \quad (1)$$

Equation for specific dissipation rate:

$$\rho\frac{\partial \varepsilon}{\partial t} + \rho\overline{u_j}\frac{\partial \varepsilon}{\partial x_j} = c_{\varepsilon 1}\frac{\varepsilon}{k}\tau_{ij}\frac{\partial \overline{u_i}}{\partial x_j} - c_{\varepsilon 2}\frac{\varepsilon^2}{k} + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] \quad (2)$$

The kinematic eddy viscosity is calculated by the formula: $\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$ (3)

Turbulent Reynolds stresses (4)

$$\tau_{ij} = -\rho\overline{u_i' u_j'} = \rho\mu_t\left(\frac{\partial \overline{u_i}}{\partial x_j} - \frac{\partial \overline{u_j}}{\partial x_i}\right) - \frac{2}{3}\rho k\delta_{ij}$$

Model constants:

$c_{\varepsilon 1}$=1.44; $c_{\varepsilon 2}$ =1.92; C_μ =0.09; $\sigma_k = 1.0$; σ_ε=1.3.

2. $k-\omega$ model. Below is the basic two-layer model of (Menter, 1993):

The equation for the kinetic energy of turbulence is:

$$\rho\frac{\partial k}{\partial t} + \rho\overline{u_j}\frac{\partial k}{\partial x_j} = \tau_{ij}\frac{\partial \overline{u_i}}{\partial x_j} - \beta^*\rho k\omega + \frac{\partial}{\partial x_j}\left[(\mu + \sigma_k\mu_t)\frac{\partial k}{\partial x_j}\right] \quad (5)$$

Equation for specific dissipation rate:

$$\rho\frac{\partial\omega}{\partial t}+\rho\overline{u_j}\frac{\partial\omega}{\partial x_j}=\gamma\frac{\omega}{k}\tau_{ij}\frac{\overline{\partial u_i}}{\partial x_j}-\beta\rho\omega^2+\frac{\partial}{\partial x_j}\left[(\mu+\sigma_\omega\mu_t)\frac{\partial\omega}{\partial x_j}\right]+2(1-F_1)\rho\sigma_{\omega2}\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial\omega}{\partial x_j} \quad (6)$$

The dynamic eddy viscosity is calculated by the formula:

$$\mu_t=\rho\frac{k}{\omega} \quad (7)$$

Turbulent Reynolds stresses (8)

$$\tau_{ij}=-\rho\overline{u_i'u_j'}=\rho\mu_t\left(\frac{\partial\overline{u_i}}{\partial x_j}-\frac{\partial\overline{u_j}}{\partial x_i}\right)-\frac{2}{3}\rho k\delta_{ij}$$

$\beta^*=0.09;\quad \beta_1=0.075;\quad \sigma_{k1}=0.5;\quad \sigma_{\omega1}=0.5;$

3. $\boldsymbol{k-\omega\ SST}$ **model.** To summarize the model equations of the k-ω SST model are:

The equation for the kinetic energy of turbulence is:

$$\frac{\partial k}{\partial t}+u_j\frac{\partial k}{\partial x_j}=P_k-\beta^*k\omega+\frac{\partial}{\partial x_j}\left[(\nu+\sigma_k\nu_T)\frac{\partial k}{\partial x_j}\right] \quad (9)$$

Equation for specific dissipation rate:

$$\frac{\partial\omega}{\partial t}+u_j\frac{\partial\omega}{\partial x_j}=\alpha S^2-\beta\omega^2+\frac{\partial}{\partial x_j}\left[(\nu+\sigma_\omega\nu_T)\frac{\partial\omega}{\partial x_j}\right]+2(1-F_1)\sigma_{\omega2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial\omega}{\partial x_i} \quad (10)$$

Kinematic eddy viscosity:

$$\nu_T=\frac{\alpha_1 k}{\max(\alpha_1\omega,SF_2)} \quad (11)$$

The coefficients and additional ratios of the model are equal:

$$F_2=tanh\left[\left[max\left(\frac{2\sqrt{k}}{\beta^*\omega y},\frac{500\nu}{y^2\omega}\right)\right]^2\right] \quad (12)$$

$$P_k=min\left(\tau_{ij}\frac{\partial U_i}{\partial x_j},10\beta^*k\omega\right) \quad (13)$$

$$F_1=tanh\left\{\left\{min\left[max\left(\frac{\sqrt{k}}{\beta^*\omega y},\frac{500\nu}{y^2\omega}\right),\frac{4\sigma_{\omega2}k}{CD_{k\omega}y^2}\right]\right\}^4\right\} \quad (14)$$

$$CD_{k\omega}=max\left(2\rho\sigma_{\omega2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial\omega}{\partial x_i},10^{-10}\right) \quad (15)$$

$$\emptyset=\emptyset_1F_1+\emptyset_2(1-F_1) \quad (16)$$

$$\alpha_1=\frac{5}{9},\quad \alpha_2=0.44\quad \beta_1=\frac{3}{40},\quad \beta_2=0.0828 \quad (17)$$

$\beta^*=\frac{9}{100}, \sigma_{k1}=0.85\quad \sigma_{k2}=1\quad \sigma_{\omega1}=0.5\quad \sigma_{\omega2}=0.856$

4. RNG $\boldsymbol{k-\varepsilon}$ model. A more modern version of the k-ε model turbulence was proposed in works (Launder-Jones,1972; Menter, 1993). This model uses the same equations (1–2) as the standard k-ε turbulence model, but with different coefficients:

$C_\mu=0.085;\quad C_{\varepsilon1}=1.42;\quad \widetilde{C_{\varepsilon2}}=1.68;\quad \sigma_k=0.72;\quad \sigma_\varepsilon=0.72.$ (18)

$$C_{\varepsilon 2} = \widetilde{C_{\varepsilon 2}} + \frac{C_\mu \lambda^3 (1-\frac{\lambda}{\lambda_0})}{1+\beta\lambda^3}; \quad \lambda = \frac{k}{\varepsilon}\sqrt{2S_{ij}S_{ji}}; \quad \beta = 0.012; \quad \lambda_0 = 4.38 \tag{19}$$

Results and discussion

The structure of the flow in the room is shown in Fig. 2, which shows the velocity modulus fields in several sections of the room. As shown, the inlet flow is sucked into the chamber and curved toward the ground. The calculations determined the longitudinal velocity profile (u) along the vertical axis at two points x 1H and 2H, and a previous computational study was also performed by (Zuo and Chen, 2009).

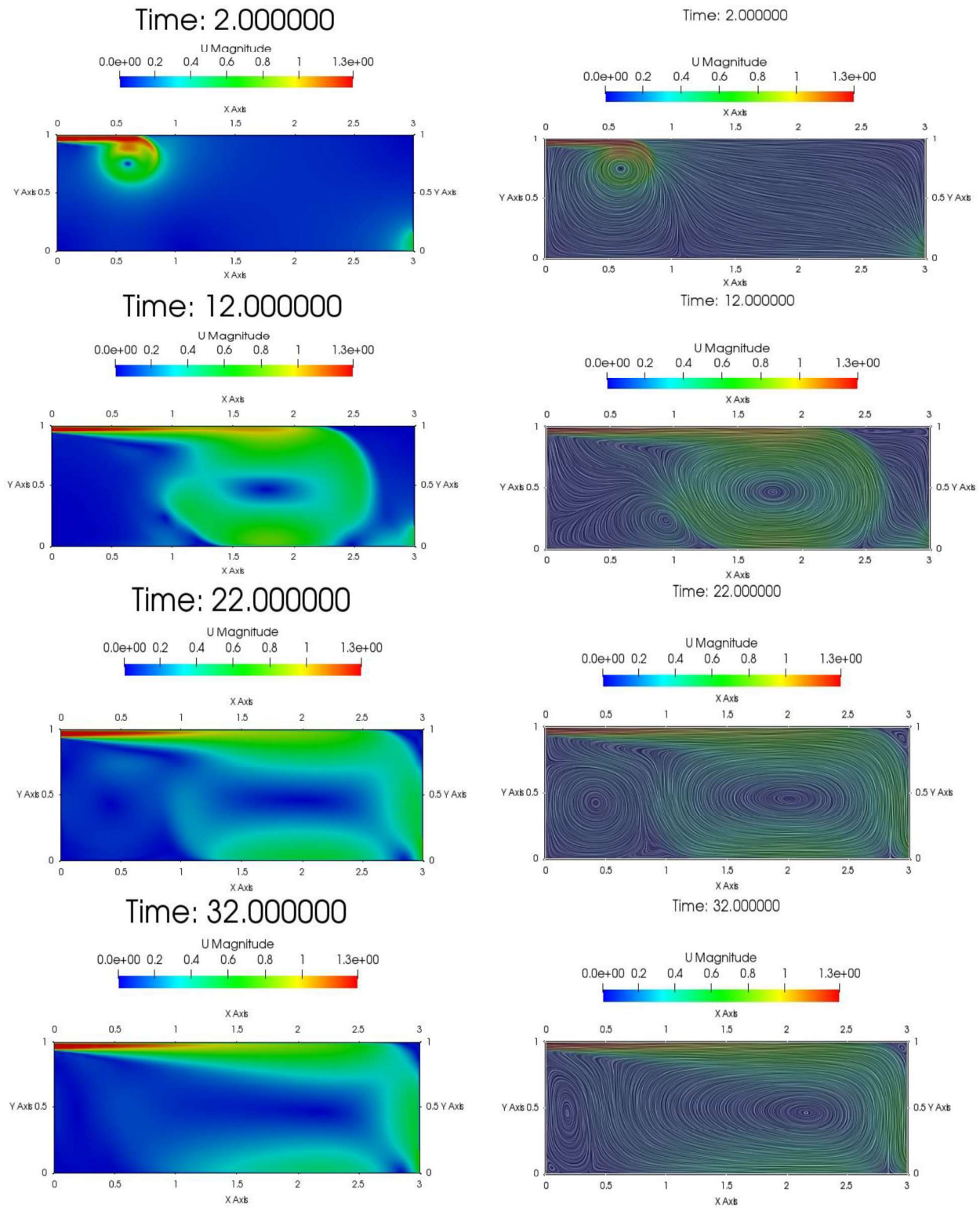

Figure 2. Longitudinal velocity profile (u) along the vertical axis

Near the ceiling, a wall-mounted turbulent air stream develops, which is almost symmetrical relative to the middle section of the room. As the jet propagates from the inlet to the opposite wall, the velocity value decreases by approximately half. After colliding with the opposite wall, the jet turns around and a secondary flow is formed in the lower part of the room with a speed of less than 0.1 m/s.

In ventilation, the entrance and exit are located in opposite side walls. The entrance is located in the upper left corner on the side wall at z = 6 m. The exit hole is in the lower right corner. Contaminated air is pumped out of the outlet at a uniform speed of 1 m/s.

As shown in Fig.3, all turbulence models give very close results to experimental data in a 2D model. Within these outputs, the standard k-w and SST results differ slightly from the other results.

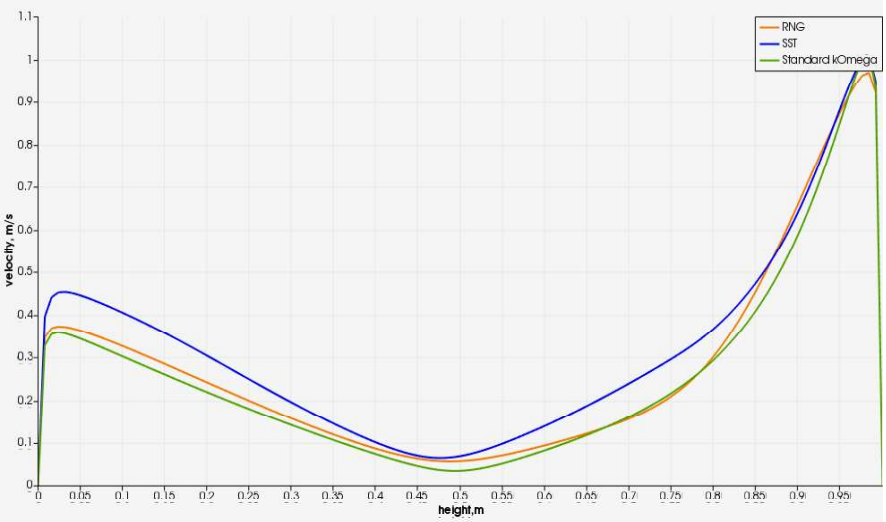

Figure 3. Dimensionless velocity distribution

Conclusions

Numerical modeling of turbulent air flow in a room was carried out using the OpenFOAM package and the presented results are in good agreement with available experimental measurements. Dimensionless velocities for different turbulence models are compared: Standard k-ε, standard k-ω, RNG k-ε, k-ω SST. The results explain that all turbulence models produce almost identical results.

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Y. Rakhmawati
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: yenirakhmawati.2021@student.uny.ac.id
https://orcid.org/0000-0001-6114-767X

S. Sugiman
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: sugiman@uny.ac.id
https://orcid.org/0000-0003-1931-7537

H. Retnawati
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: heri_retnawati@uny.ac.id
https://orcid.org/0000-0002-1792-5873

G.K. Kassymova
Abai Kazakh National Pedagogical University
050010, Dostyk ave., 13, Almaty, Kazakhstan
E-mail: g.kassymova@abaiuniversity.edu.kz
https://orcid.org/0000-0001-7004-3864

G. Kudyarova
Suleyman Demirel University, Almaty district,
Karasay region 040900, Kaskelen city, Abylai khan street, 1/1, Kazakhstan
E-mail: Gulnarakudyarova@gmail.com

Exploring Pre-service Teacher's Knowledge of Content and Teaching (KCT) and Computational Thinking: The Case of Addition and Subtraction

Abstract: This research discusses the knowledge of content and teaching (KCT) and computational thinking (CT) of pre-service elementary school teachers on student work results. How much do pre-service teachers deepen students' thinking about the concepts of addition and subtraction? This research aims to get an overview of pre-service teachers' thinking about KCT and CT so that the results can be used to determine educational policies for developing human resource capabilities in elementary schools. The subjects of this research were three pre-service teachers at elementary school that selected by purposive sampling. The criteria for pre-service teachers are those who have taken basic concepts of mathematics, mathematics education, and mathematics development. The subjects in the low, medium, and high categories from state universities with A accreditation in Yogyakarta, Indonesia. The type of research is a case study. The research instruments namely the results of elementary school students ' work about addition and subtraction, then interview instruments to give an idea of how deeply they think about the material. The KCT's findings are that pre-service teachers do not understand the Van De Walle concept of addition and subtraction, do not understand the prerequisites for addition and subtraction material, and pre-service teachers find unique ways of learning from students. In the CT component, there are two components that appear in them, namely pattern recognition and decomposition. An interesting finding was that pre-service teachers only learned about the Van de Walle technique after seeing the results of the work carried out by students. This means that previously they did not use those techniques at all. This picture shows that pre-service teachers' KCT and CT is still not optimal, so further, and in-depth research is needed to explore their understanding.

Keywords: knowledge of content and teaching (KCT), computational thinking, pre-service teacher, mathematics, addition and subtraction

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Introduction

Learning math is an interesting thing. Various thoughts both formally and informally can develop in math learning activities. Every student, especially elementary school students, has a level of thinking

according to their cognitive abilities. On the other hand, learning mathematics is a learning object that has a level of difficulty that is considered high (Arlinwibowo et al., 2020; Hafiz et al., 2017; Kooken et al., 2013). One proof is the PISA results in the field of mathematics of students in Indonesia which are still low (Chirkina et al., 2020). The PISA results show that students still lack reasoning and understanding skills.

Each student has diverse thoughts. This emphasizes the need for a teacher to convey a topic to students. This teacher's ability requires a mathematical situation, in creating a learning bridge for students (Muntazhimah & Ulfah, 2020). The focal point is the teacher's ability to design an appropriate contextual framework to build this knowledge (Niss, 2013; Rakhmawati & Mustadi, 2022). Mathematical didactics place students in appropriate learning situations. This theory was developed by Brousseau who built on the constructivist foundation of how humans can interact with the environment, and influence each other (Balacheff, 2016).

The acquisition of mathematical knowledge requires typical natural situations, and there is no natural scientific method for teaching mathematics (Balacheff, 2016; Oktay et al., 2021). This statement means that mathematics teaching has a social dimension, meaning that it can be influenced and has an influence on the social environment. The main study in mathematical didactics is how teachers examine the material in-depth and transform it into contextualized learning situations (Ariyanto et al., 2017; Gök, 2019; Suryadi, 2010).

The KCT domain has a fundamental urgency for prospective elementary school teachers. Ability in the KCT domain involves understanding various techniques and methods of effective numeracy thinking to be conveyed to students (Metz, 2018). In this domain, pre-service elementary school teachers can design problem-solving, reasoning, and application of numeracy concepts in everyday life. KCT is a combination of knowledge about teaching and knowledge about mathematics (Hill et al., 2008). Mastery of numeracy knowledge combined with strategies and techniques for teaching numeracy to students. At this stage, the role of KCT is closely related to CCK. Research (Chikiwa et al., 2019) proves that KCT is the focus of MKT development, and CCK is one of the domains that has a mutually influencing relationship with KCT. The KCT domain is strongly influenced by the teacher's abilities and knowledge. The KCT domain requires the teacher's ability to connect mathematical concepts and ideas with pedagogical approaches to produce meaningful and effective learning (Raiula & Vijaya Kumari, 2018).

KCT also includes the teacher's ability to identify common mistakes that students often make, relate numeracy concepts to real-world situations, design activities that encourage problem-solving, and provide constructive feedback to students. Ways to explore teachers' KCT in teaching are in various ways, for example, questionnaires containing questions that require teachers to organize the listed numeracy concepts or skills (rational counting, matching number symbols with dotted cards, and rote counting) and indicate the sequence of how they should be taught and then support their answers (Chikiwa et al., 2019; Koponen et al., 2019). How to measure KCT in numeracy for prospective teachers' students can use numeracy questions that contain problem-solving. Apart from that, it can be connected to questions related to numeracy teaching techniques for elementary school students.

Computational thinking (CT) is interpreted as a series of thinking patterns that provide representation, reasoning in various abstractions, and solving problems effectively (Gadanidis et al., 2017). CT can develop as a science related to programming languages on computers that work quickly. The essence of CT is the process of thinking quickly in solving a problem. Computational thinking is also seen as an approach to problem-solving that uses concepts and techniques from computer science to analysed and solve complex problems (Tedre & Denning, 2016). CT as a thinking process helps individuals deal with problems systematically and logically, by utilizing concepts such as abstraction, decomposition, pattern recognition, and algorithmic thinking (Wing, 2020).

CT in the context of the numeracy process refers to the application of principles and concepts from computing in solving mathematical problems. This involves structured, algorithmic, and logical thinking to analyze, solve, and model numeracy problems (Romero et al., 2017). It is believed that the role of computational thinking in numeracy learning activities can provide opportunities for individuals to improve their PISA scores (Niswar, 2021). The relationship between these two variables is that they have the same intersection in supporting and using higher-level thinking processes. In the process of implementing activities with Computational thinking, there are two ways, namely (1) presenting a classroom that has activities that specifically discuss the thinking skills being taught or (2) integrating thinking skills into existing lessons (Ye et al., 2023).

Learning related to addition and subtraction in elementary school students is very diverse. Students can learn according to the experience they have, or learning obtained at the previous stage (Castro et al., 2021). Students also have various problems, one of which is difficulty in understanding basic number operations (Baroody, 2006). Addition and subtraction 1-20 are basic materials. Students have an urgency to be able to understand this material so that in the future there will be no non-contextual terms in student learning activities. Terms that are often found in learning math are borrowing, and saving, even in Indonesian terms there is the word "owe". The term is deemed inappropriate for student learning in elementary school.

In this study, the addition and subtraction concepts used strategies developed by (Walle et al., 2018). Addition and subtraction can be framed into 3 activity structures. Based on the above series of addition and subtraction learning activities, four strategies can be used for students. These strategies include joining, separating, part-part-whole, and comparing. Joining can be interpreted as describing the initial process, modifiers, and results of combining. Separating is interpreted as the initial process, the change in the form of separating, and the result of the change. Part-part whole as a process from a combination then becomes a branch, or from a branch form to a whole form. In the comparison part, it is from a whole form and then compared in a smaller form.

The urgency of this research is the diverse abilities of students who have the potential to make new findings or ways in the mathematization process. This diverse student thinking needs to be explored in depth and become a potential for the development of the mathematics learning process in elementary schools (Suri & Herman, 2020). In addition, computational thinking is one of the competencies that must be possessed today. Computational thinking supports students' thinking patterns with various components (Wing, 2020). The purpose of computational thinking is to help students think mathematically, this mathematical process that allows students to learn.

The difference between this research and the previous research is that this research begins with the findings of a grade 2 student who has alternative thinking in working on subtraction problems. The student thought that, 12 - 4 can be produced by adding 2 as a unit with a pair of 4. The pair of 4 to become 10 is 6, so that the result can be obtained 2 + 6 = 8. Thus, 12 - 4 is 8. The student explained that he tried to find a pair of 10 to help him solve addition and subtraction problems. This student no longer uses fingers or borrowing and saving techniques. This data is used to measure KCT and CT from pre-service teachers for elementary schools.

Research Methods

This research used qualitative method with case study. The purpose of this research was to explore the central phenomenon on addition and subtraction material 1-20. The research instruments used were student grade 2 activity and interviews for pre-service teachers. The data collected in the form of learner work results and interview transcripts were analysed by retrospective analysis to find learning design conclusions based on the design obtained.

Research subjects were selected using purposive sampling with categories of low, medium, and high mathematical ability. Location at a state university with A accreditation in Yogyakarta, Indonesia. Pre-service teachers have taken courses in basic mathematical concepts, mathematics education, and mathematics development. This course is a prerequisite course before they dive into the practice of teaching elementary school mathematics. There are 3 students regardless of gender. Pre-service teachers try to explore the thinking of second grade students using answer sheets and student activities.

The research refers to mathematics learning using addition and subtraction materials 1-20 in elementary school students. The theory used refers to the concept of Van den Walle (Walle et al., 2018). Further calculations depend not only on the knowledge of composing numbers carefully and basic skills in flexible calculations, but also on insight into developing strategies, attitudes towards mathematics, and other pleasures in calculating (Heuvel-panhuizen, 2003).

The instrument for KCT uses 4 indicators from (Koponen et al., 2019) including 1) Know different teaching methods and styles; 2) familiar with educational trends; 3) Favor varied teaching methods; 4) Base teaching on students' ideas. The instruments for CT use from (Wing, 2020) instruments from which include decomposition, pattern finding, abstraction, and algorithms. Data analysis was carried out by analysing the pre-service teacher's answers by finding coding in the answers.

Result and Discussion

Result

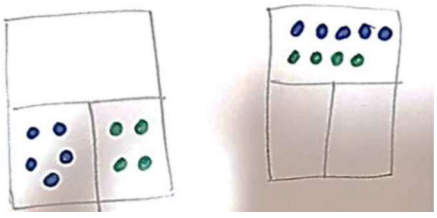
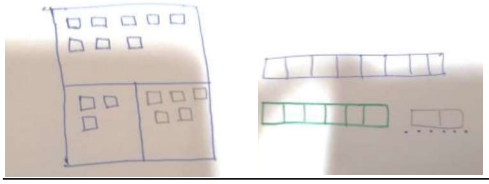
The results of this research are interviews with class 2 students' answers. There are 3 pre-service teachers with PST code 1 for the first pre-service teacher. PST 2 for the second Pre-service teacher. PST 3 for the third Pre-service teacher. From the class 2 students' worksheets, the abilities of pre-service teachers in KCT were explored. The research used 4 indicators from (KCT) by (Koponen et al., 2019) with the following results.

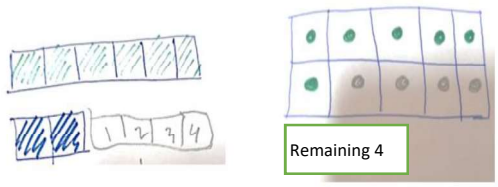
Table 1. Results from KCT interviews

No	Indicators	Questions	PST 1	PST 2	PST 3
1	Know different teaching methods and styles.	If asked to teach addition and subtraction 1-20, how would you do it?	"I will use concrete media available in the school environment. Apart from that, I will count backwards on my fingers."	"In the past, I was taught by counting backwards or on my fingers. Apart from that, I was taught by saving and borrowing techniques"	"I use concrete media and ask my students to draw pictures. If the numbers are large, I use the save and borrow technique."
2	familiar with the educational trends	Do you know any variations of mathematical thinking for teaching addition and subtraction 1-20?	"As far as I know, I counted on my fingers and my teacher used to memorize 1-10"	"I don't know many techniques about it, I also forgot how to learn that material when I was in elementary school"	"I don't know many ways, because in the past I only counted together with my classmates"
3	Favor varied teaching methods	Do you know the concept of Van de Wahle addition and subtraction which consists of 3 points?	"We've never learned about that"	"Sorry, we never knew. But I've seen the boxes in a 2nd grader's book."	"Never before, and just found out."
4	Base teaching on students' ideas	What are the prerequisite materials for teaching addition and subtraction?	"The prerequisite material for this case is that students must be able to count numbers, understand the concept of units and tens"	"Students of course already understand the concept of numbers, and know larger numbers are smaller. Or you can also learn about jumping numbers ".	"The right prerequisite material is writing numbers and counting. Apart from this answer, it is very important to have knowledge about pairs of 10.

These results illustrate pre-service teachers' thinking about KCT components. The results above are also supported by the results of a pre-service teacher study on the performance results of grade 2 elementary school students. These results are as follows in Table 2.

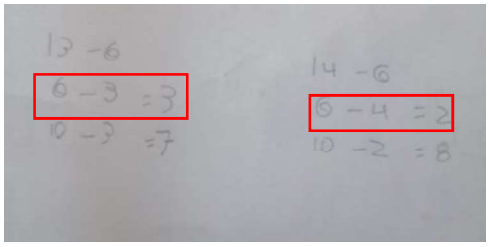
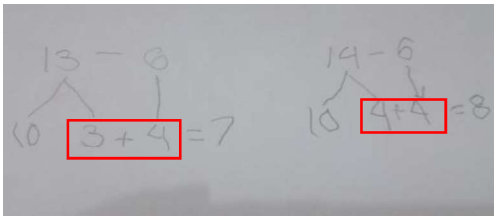
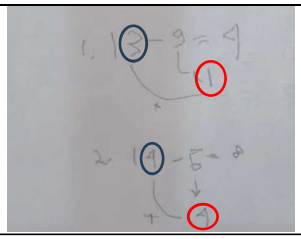
Table 2. Pre-service teachers' thinking on the basic concepts of addition and subtraction

The results of the work of grade 2 students	Results of pre-service teacher comments for elementary schools
	PST 1: "This student tries subtraction and addition techniques with columns of boxes accompanied by different colors." PST 2: "This student uses techniques like in the class 2 book." PST 3: "This student uses subtraction and addition thinking simultaneously. A dancing technique"
	PST 1: "The way it is presented is more unique with 2 different concepts." PST 2: "The first method is the same as student 1. The second method is for him to calculate the difference." PST 3: "This student's thinking is more varied, in 2 different

	ways"
	PST 1: "This student uses the technique of calculating the number of differences from the whole." PST 2: "This student's method is easier to read because of the symbols." PST 3: "This student counts differences, in 2 different ways. One with boxes and one with different colors."

These results illustrate the teacher's thinking in exploring students' answers. Apart from that, it shows the teacher's ability regarding the 3 methods of addition and subtraction presented by van de whale. In the answers above it can be seen that no one understands this concept. The next study is the technique for calculating students using their own methods and thoughts, namely in Table 3.

Table 3. Pre-service teachers' thinking on student counting techniques

	PST 1: "Wow, this student found a unique way by counting the units first. A different way, because so far I only counted on my fingers." PST 2: "So far I have been counting backwards. My teacher used to ask us to use our fingers or borrow a friend's fingers. This technique is new for me." PST 3: "After I observed him using the concept of ones and tens. This technique can replace the countdown technique that is taught a lot in schools."
	PST 1: "This student is more structured for students in the lower category." PST 2: "I prefer this technique, because it is more coherent. This child is more creative, and the method is easy to accept." PST 3: "It turns out that I have found many ways to count. If you look at it, it looks like the last number uses a pair of 10s."
	PST 1: "This student uses the same technique as before, but faster. I have never been taught that way." PST 2: "When we were at school, we never had this method. It turns out this technique is easier." PST 3: "This student thinks faster, from this it further proves the importance of knowledge of pairs of 10 for addition and subtraction material."

Discussion

Knowledge of Content and Teaching (KCT)

Pre-service teachers' content knowledge about the concepts of addition and subtraction is limited to the way they learned it when they were in school. The three research subjects understood how to add and subtract using the backward counting technique. Apart from that, the technique that is mastered is the storing and borrowing technique. Storing on addition and borrow on subtraction. The backward counting technique has a high error rate if a student does not master the sequence of forward and backward numbers. Sometimes students also make mistakes because they miss numbers (Desli, 2016; Wahyudi et al., 2018). Not only that, the concept of storing and borrowing is widely used by teachers in Indonesia and is difficult to eliminate. This concept uses a set of 10. Students in Indonesia are very familiar with this method, almost all schools only learn using this technique. These results are in accordance with research results which illustrate that students use a lot of storing and borrowing techniques (Sujarwo et al., 2020).

According to the three respondents, this was the first time they had seen the technique of working

with bond 10. It was very surprising that after learning basic concepts of mathematics, mathematics education and mathematics development, they did not know about this technique. There is something missing that this concept does not reach pre-service teachers. Looking at this fact, it can be found that pre-service teachers also do not know about this technique.

Not only that, for them Van de Walle's concepts, namely joining and separating, parts whole, and comparing, are not yet fully recognized. There were respondents who had seen the part-whole technique in books but did not know the name of the concept. The concept of joining and separating was not discussed much in these three responses. The concept of parts-whole is the concept most familiar to respondents. The concept of comparing has been recognized by showing the difference in numbers in the results of the third student's work.

Interestingly, these results are in accordance with research (Singh, 1998) that the van de whale concept for grade 2 elementary school students has not been explored well and students still do not use this technique much. However, this research was 15 years ago, when various technical developments should have occurred. It is impossible for past and present results to remain the same considering the highly developed student backgrounds, varied learning media, more qualified teachers, and the rapid development of the times. If so, the pre-service teacher's thinking is still the same as before. Because looking at the results, students have used various ways of thinking, but pre-service teachers don't know these techniques.

On the other hand, this research and research of (Robiansyah et al., 2018) found that elementary school students have unique mathematical thinking. Especially for the three respondents who had never encountered this method before. This adds to the significance of this research and is proof that pre-service teachers can learn directly from students' various thoughts and problem solving. This finding is important in that students directly bring adults into their thinking world. Not only do they receive a touch of learning from adult concepts, but students can now think according to the reasoning they have.

In analyzing stage 2 answers from the three elementary school students, many pre-service teachers were amazed by their way of thinking. These various mathematical process skills are important for elementary school students (Stigberg et al., 2022). This mathematical process forms mental mathematical thinking in students, which continues to grow with age and the amount of practice. These three students showed numeracy thinking that was different from that which had been studied by pre-service teachers.

The pre-service teachers try to recognize each student's technique. In the first student analysis, respondents had started to guess about the concepts used by the students. Student 1 uses the concept of subtraction in units. For example, in question 13-6, what is subtracted is 6-3 = 3, then 10 -3 = 7. The concept presented by the students was recognized by respondents with the answer that this technique requires reinforcement of the prerequisite learning about tens and ones. The relationship between ones and tens is very useful for learning addition and subtraction (Wilkie, 2014).

The second student analysis, the respondents looked more at the systematic structure of students' answers. In problem 13-6, 13 is first decomposed into 10 and 3. This student sees the pattern of the pair 10 of 6 being 4. The student adds these 2 patterns by taking a number that is not 10, namely 3 and 4 for a total of 7. This technique is recognized by students. Respondents as the technique most likely to be applied by grade 2 elementary school students. The response admitted that this method has a combination of a prerequisite understanding of counting 10 bills and the application of the concept of ones and tens. The third student's analysis was not much different from the second student's answer. These students were quicker to use the concepts of 10 bonds and place value. Thus, the third student calculates more quickly according to his abilities. The results of this research are in line with the results of research of (Khanby, 2018) which has proven the effect of bond 10 on the learning process of addition and subtraction.

KCT consists of knowledge about content and how to teach mathematics to students. If we look at the various results of pre-service teacher answers, it is found that coding includes never, don't know, and amazed. Haven't referred from the answer to van de walle's concept. Don't know refers to answers about mathematical thinking process techniques, especially on addition and subtraction material. Amazed, that is, the respondents were very amazed at the thinking skills presented by the students. This coding finding illustrates that the KCT of pre-service teachers is still not well described. It is a big reflection that this basic concept has not been mastered by pre-service teachers. The respondents have started training or

teaching practice at school. However, with these findings, it allows them to teach in the way they learned in the past. There is no development of mathematical thinking presented by teachers to students.

In discussing prerequisite material, pre-service teachers do not yet fully understand the material that students must master to master addition and subtraction operations. They only say that students must understand numbers in sequence. Prerequisite material includes the concept of forward and backward continuous numbers, the concept of ones and tens, filling in gaps, understanding the concept of skip numbers, and the concept of 10 bonds. If students master this prerequisite material, it will be easier for students to master addition and subtraction material (Afridayanti et al., 2022).

The fact is quite surprising that teachers' KCT for understanding prerequisite material is still not optimal. This can cause students in grades 1 and 2 to experience difficulties, especially in subtraction. Another surprising fact is that this method is a common technique abroad but is still something new for pre-service teachers here.

Computational Thinking

The patterns that pre-service teachers find are part of one of the thoughts of computational thinking. The various activities that pre-service teachers have done are one of the applications of computational thinking that is indirectly carried out by students. CT components are abstraction, llgorithmic, decomposition, and pattern recognition (Mota et al., 2016; Yongheng et al., 2020). In this study found in the research part of decomposition in pre-service teachers. Pre-service teachers can divide the problem into smaller solutions so that to get a solution. The method of decomposition found is that they understand the core of a big problem, then try to divide it into branches of solution. They found this when exploring students' thinking.

Pre-service teachers can also find patterns that are used when trying to explore how students work. This activity is an activity that refers to the CT component (Cansu, 2016; Kafai & Proctor, 2021). In these two components, pre-service teacher can rigidly explain the reasons underlying their thinking. When using the bond 10 technique with joining, pre-service teacher found a number pattern from student's thinking. The findings of this study prove that elementary school students can also process learning activities that refer to higher-order thinking. In line with that, the results of research (Romero et al., 2017; Varol & Farran, 2007) that elementary school students can also do learning activities with computing. Existing computations refer to math learning activities. The pattern of work carried out by grade 2 students has begun to be discovered by pre-service teachers which means that they fulfill one of the CT components.

The thinking of grade 2 elementary school students is in fact diverse even with the provision of the same milieu. In this research, the learning design uses vertical matematizazion. The mouth of this activity is that students can make generalizations in learning activities. The generalization obtained by students is that students find that pairs of 10 can be found in various ways. Diverse ways of learning students can produce one-way discoveries. Both students' thoughts and results are based on students' ability to illustrate the results of their thinking.

This is an interesting and new finding for pre-service teachers. They had never encountered this CT way of thinking before, and only discovered it after seeing these students work on questions about addition and subtraction with bond 10. The abstraction and algorithm components do not appear because these pre-service teachers do not work on the questions directly. Thus, these two CT components cannot be read properly. This component can be measured directly with a CT test for pre-service teachers.

Conclusion

This research produced findings about Knowledge of Content and Teaching (KCT) which includes understanding Van De Walle addition and subtraction, prerequisite material for addition and subtraction, and unique ways of thinking of students that can be used by pre-service teachers. The findings show that Van De Walle addition and subtraction are still new things for pre-service teachers, they have never known and used these concepts. The same results in mastering prerequisite material that they have not been able to explore. This shows that the condition of KCT pre-service teachers is still not encouraging.

Apart from that, the CT capability has not yet appeared. The CT that emerged from pre-service teachers was that they had found two components, namely pattern recognition and decomposition. An interesting result was that the pre-service teachers learned the thinking process from students' answers. They were amazed by the method presented by the students, even though this method was already widely used. This indicates that the KCT and CT of pre-service teachers is still not encouraging. However, by analysing students' answers, they can gain greater insight into teaching addition and subtraction.

These findings open new research with a wider range of respondents, resulting in more varied findings. KCT and CT has an important role in equipping pre-service teachers before serving and teaching. In this way, further research can be formed to develop human resources for pre-service elementary school teachers.

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Ahmad Gemeal
Central Metallurgical Research &Development Institute, Egypt
al-Faraby Kazakh National University, Kazakhstan
E-mail: agemeal@cmrdi.sci.eg; Gemil.Akhmad@kaznu.kz; Gemeal2000@mail.ru
ORCID ID 0000-0001-6663-2623

Crystal Plasticity Finite Element Method (CPFEM): state-of-the-art

Abstract: A brief discussion is given for crystal plasticity finite element method, reasons of its importance and its microscopic and macroscopic applications. Also, discussions were made for its primary engineering objectives and its further related applications. Chronological brief of evolution of its two legs: finite element method and crystal plasticity was also captured. Chronological brief of necessities and developments of new models was also tracked.

Keywords: Crystal plasticity, Twinning, Indentation, Multiphase steel, Anisotropy.

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Introduction

Why crystal plasticity finite-element method

Loading direction controls elastic plastic deformation of crystalline materials, i.e. mechanical anisotropy behavior dominates crystal behavior subjected to various mechanical loadings. The reasons for that are not only that elastic tensor is anisotropic, but also because the activation of crystallographic deformation mechanisms (dislocations, twins, martensitic transformations) is orientation dependent. Consequently, the associated mechanical phenomena such as shape change, crystallographic texture, strength, strain hardening, deformation-induced surface roughening and damage are all orientation dependent. This leads to an important result: the mechanical parameters of crystalline materials are tensor quantities (Roters, et al., 2010)).

This leads to two important facts. The first fact is that the uniaxial stress-strain curve, which is believed to have been practiced since Greek Procrustes or even before him thousands of years ago (Answers, 2023), is no longer enough to describe plastic deformation phenomena (Figure 1). The second fact is that plastic deformation influences crystallographic texture and its evolution during forming. Hence, integral anisotropy of polycrystals can be described by texture i.e. individual tensorial behavior of each grain and the orientation-dependent boundary conditions among the crystals can be used to describe integral plasticity.

Incorporating present knowledge of deformation physics (Curtin & Miller, 2003), (Arsenlis, Parks, Becker, & Bulatov, 2004) and (Vitek, Mrovec, & Bassani, 2004) into the computational tools of continuum mechanics (Zienkiewicz, 1967), (Zienkiewicz & Taylor, 2005) aiming to develop physically based advanced design methods that can be used in engineering application.

Early approaches in the West to describe anisotropic plasticity under simple boundary conditions have considered these aspects, such as, for instance, (Sachs, 1928), (Taylor, 1938), (Bishop & Hill, 1951), (Bishop & Hill, 1951) or (Kro¨ner, 1961) formulations.

Early approaches, in Russia, to the development of physics and physical chemistry plastic deformation was introduced by domestic scientists V.D. Kuznetsov, N.S. Kurnakov, N.N. Davidenko, A.A. Bochvar, S.I. Gubkin.

There were interactions between the two sides. Many of works of the following western scientists have been translated into Russian language: J. Alexander, J. Bishop, P. Bridgman, V. Bakofen, O. Goffman, V. Johnson, G. Sachs, Sh. Kobayashi, H. Kudo, A. Nadai, H. Pugh, E. Thomsen, R. Hill, K. Young, and other. Also, there were attention in the west about Russian efforts in this field. Proves that, the inclusion of Russia (that time called Soviet Union) and Russian language in related scientific associations since its early foundation, such as IDDRG (International Deep Drawing Research Group) since its early foundation in 1960 (BrDDRG, 2022).

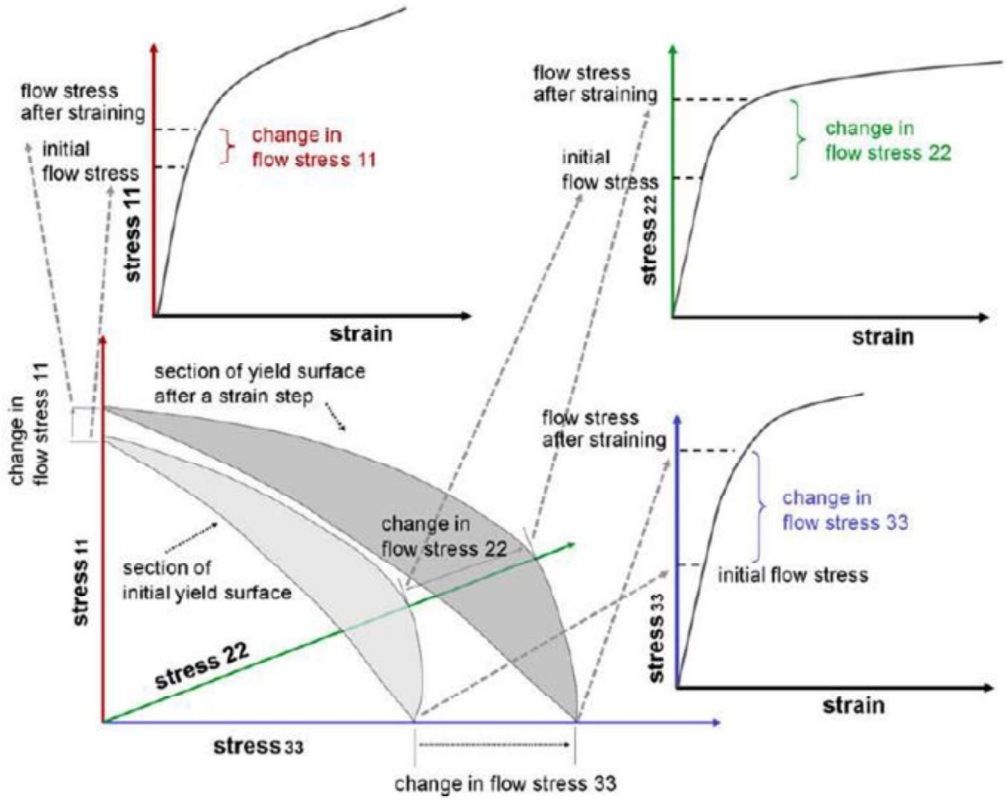

Figure 1. Flow stress and strain hardening of anisotropic materials are, merely, tensor quantities

In the development of the theory of plasticity, four can be distinguished:

1. **The first period:** Characteristic period was approximately from 1915 to 1945. The simplest ones have been solved problems based on general equations of plasticity theory for determining the strength of the most common metal forming operations (S.I. Gubkin, G. Sachs, E. Siebel, N.S. Petrov, L. Prandtl, E.P. Unksov, A.I. Tselikov).
2. **Second period:** (approximately from 1945 to 1960). Development of general approximate methods for solving problems related to determining deformation forces, tool loads and final forming. Engineering methods for analyzing mechanical engineering processes has been developed (S.I. Gubkin, G. Sachs, E. Siebel, I.M. Pavlov, E.A. Popov, V.S. Smirnov, M.V. Storozhev, E.P. Unksov), sliding line method (G. Genki, H. Geiringer, W. Prager, I.P. Renne, V.V. Sokolovsky, A.D. Tomlenov, R. Hill, L.A. Shofman), energy method (O.A. Ganago, V. Johnson, W.L. Kolmogorov, A.A. Pozdeev, I.Ya. Tarnovsky, E. Thomsen), method of resistance of metals to plastic deformation (G.A. Smirnov-Alyaev), visioplastic (Yu.N. Alekseev, E. Thomsen).
3. **Third period**: (approximately from 1960 to 1975). Development of methods used theoretical analysis of mechanical engineering processes by numerical methods and computers. The prerequisites have been created for the construction and analysis of models of metal forming processes that more fully take into account real conditions of deformation, and solving new problems in extreme shape change. Secondly, through the efforts of leading Scientists in Russia have created scientific schools, in particular:
    - Moscow (A.A. Ilyushin, N.N. Malinin, E.A. Popov, M.V. Storozhev, A.D. Tomlenov, E.P. Unksov, L.A. Shofman, V.T. Meshcherin, I.A. Noritsyn);

- Leningrad (V.S. Smirnov, G.A. Smirnov-Alyaev), Ural (O.A. Ganago, V.L. Kolmogorov, A.A. Pozdeev, A.A. Bogatov, I.Ya. Tarnovsky);
- Minsk (E.M. Makushok, V.P. Severdenko, V.M. Segal), Tula (I.P. Renne, L.A. Tolokonnikov, S.P. Yakovlev);
- Kharkov (Yu.N. Alekseev, E.F. Sharapov, V.A. Evstratov);
- Rostov (A.Z. Zhuravlev);
- Oryol (V.A. Golenkov).

4. **The fourth period:** (since approximately 1975). In this period, the works that deserve attention are those of G.D. Delya, E.I. Isachenkova, A.N. Levanova, V.L. Kol-mogorova, P.I. Polukhina, G.Ya. Guna, A.M. Galkina, G.A. Smirnova-Alyaeva, V.I. Uralsky, N.A. Chichenova, A.B. Kudrina. In them, the theoretical approach is based on experimental data, their statistical analysis, the use of new ideas about contact friction and material destruction, the role temperature, speed and mechanical deformation patterns.

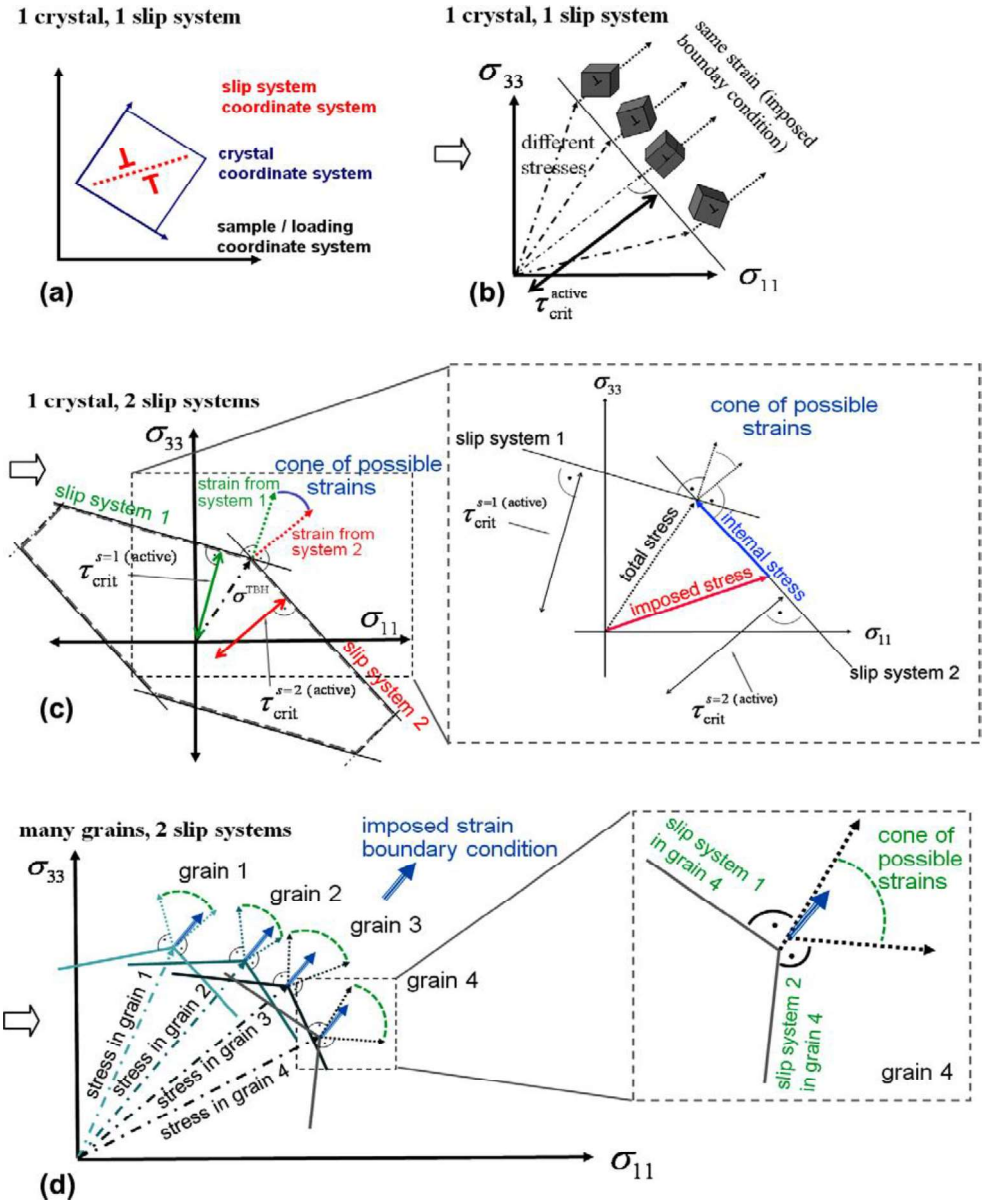

Figure 2. Schematically presented growing complexity of grain-scale mechanics with respect to the equilibrium of the forces and the compatibility of the displacements for different situations (a and b). Single slip problem in a single crystal presented in stress space (c). Part of a single-crystal yield surface with two slip systems (d). Multi-slip situation in a polycrystal where all different crystals must satisfy an assumed imposed strain in their respective yield corners. According to (Raabe, et al., 2002), (Raabe, Roters, Barlat, & Chen, 2004), different stresses in each crystal, τ_{critic}: critical shear stress, σ^{TBH}: Taylor–Bishop–Hill stress state (stress required to reach a yield corner), results from the situation of strain homogeneity.

However, the approaches of both Western and Russian scientists, in the first and second periods and to some extent third period, were neither designed for responding to complex internal or external boundary conditions nor considering explicitly the mechanical interactions among the crystals in a polycrystal (Figure 2). Instead, they are built on certain simplifying assumptions of strain or stress homogeneity to cope with the intricate interactions within a polycrystal.

For that reason, in the fourth period, enormous momentum was given to variational methods such as finite element approximations. These methods, which are referred to as crystal plasticity finite-element (CPFE) models, are based on the variational solution of the equilibrium of the forces and the compatibility of the displacements using a weak form of the principle of virtual work in a given finite-volume element.

The ability to solve crystal mechanical problems under complicated internal and/or external boundary conditions is one of CPFE main advantages. Since, it enables to tackle those boundary conditions that are imposed by inter- and intra-grain micromechanical interactions (

Figure **3**) (Sachtleber, Zhao, & Raabe, 2002), this aspect is not a mere computational advantage but is an inherent part of the physics of crystal mechanics. This is not only essential to study in-grain or grain cluster mechanical problems but also to better understand the often quite abrupt mechanical transitions at interfaces (Raabe, Sachtleber, Weiland, Scheele, & Zhao, 2003).

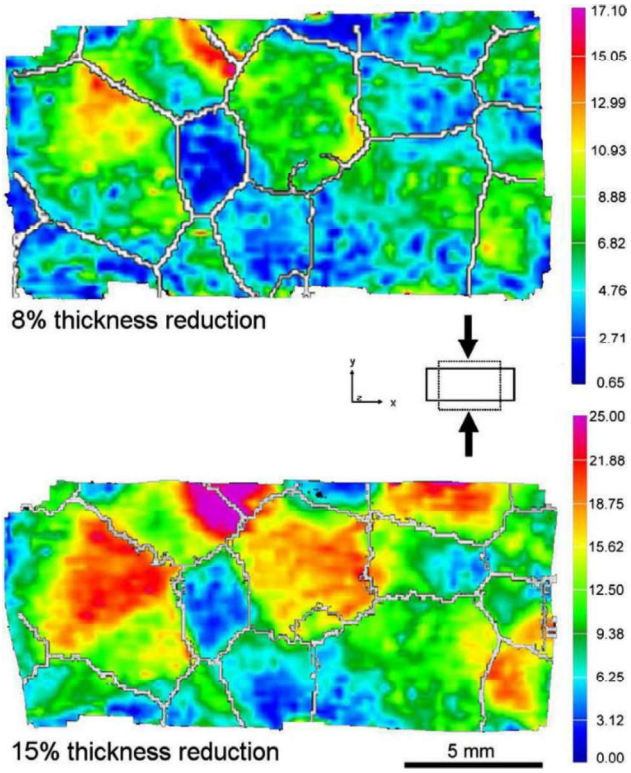

Figure 3. Experimental example of the heterogeneity of plastic deformation at the grain and subgrain scale using an aluminum polycrystal with large columnar grains (Sachtleber, Zhao, & Raabe, 2002). The equivalent strains differ across some of the grain boundaries by a factor of 4–5, giving evidence of the enormous orientation-dependent heterogeneity of plasticity even in pure metals. The images show the distribution of the accumulated von Mises equivalent strain in a specimen after 8% and 15% plane strain sample thickness reduction (the deformation is given in % of $\Delta d/d$, where d is the sample extension along compression direction). The experiment was conducted in a lubricated channel–die set-up. The strains were determined using digital image correlation. The high-angle grain boundaries indicated by white lines were taken from electron backscatter diffraction microtexture measurements.

CPFE methods have several advantages. Firstly, they, efficiently, deal with complicated boundary conditions. Secondly, they also offer, at the elementary shear system level, great flexibility with respect to including various constitutive formulations for plastic flow and hardening. The constitutive flow laws that were suggested during the last decades have gradually developed from empirical viscoplastic formulations (Rice, 1971) (Asaro & Rice, 1977) into physics-based multiscale internal-variable models of plasticity, including a variety of size-dependent effects and interface mechanisms (Arsenlis, Parks, Becker, & Bulatov, 2004), (Arsenlis

& Parks, 1999), (Arsenlis & Parks, 1999), (Evers, Brekelmans, & Geers, 2004). The CPFE method has matured into a whole family of constitutive and numerical formulations that has been applied to a broad variety of crystal mechanical problems (**Table 1**). This is the accumulation of works since it was firstly introduced by (Peirce, Asaro, & Needleman, 1982).

1.2. Aspects of crystal plasticity finite-element method

1. **Handling various dyadic kinematics mechanisms:** CPFE approach can handle various dyadic kinematics mechanisms such as dislocation, martensite formation (Thamburaja & Iwamoto, 2001), (Lan, Xiao, Li, & Li, 2005), shear band formation (e.g. in glassy matter) (Anand & Sun, 2005), mechanical twinning (Kalidindi S. R., 1998), (Staroselsky & Anand, 1998), (Marketz W. T., et al., 2002), (Salem, Kalidindi, & Semiatin) and superplastic grain boundary shear (Wei & Anand, 2004), (Wei, Su, & Anand, 2006). This means that a type of deformation mechanism (e.g. dislocation slip) may occur at some material point while in another point several mechanisms (e.g. dislocations and twins) may appear together;

Table 1. Examples for different applications of the CPFE method

Application of the CPFE method	Reference
Surface roughening, roping, ridging, thin film mechanics	(Becker, 1998), (Raabe, Sachtleber, Weiland, Scheele, & Zhao, 2003), (Zhao, Radovitzky, & Cuitino, 2004), (Yue, 2005), (Siska, Forest, & Gumbsch, 2007), (Zhao, Ramesh, Raabe, Cuitino, & Radovitzky, 2008)
Grain boundary mechanics, grain interaction, grain size effects, strain gradient effects, non-local formulations, interface mechanics, superplasticity, Hall–Petch behaviour, strain gradient effects	(Wei & Anand, 2004), (Fu, Benson, & Meyers, 2004), (Evers, Brekelmans, & Geers, 2004), (Evers, Brekelmans, & Geers, 2004), (Diard, Leclercq, Rousselier, & Cailletaud, 2005), (Bate & Hutchinson, 2005), (Wei, Su, & Anand, 2006), (Murphy, Cuddy, Harewood, Connolley, & McHugh, 2006), (Deka, Joseph, Ghosh, & Mills, 2006), (Ma, Roters, & Raabe, 2006) (Ma, Roters, & Raabe, 2006), (Gurtin, Anand, & Lele, 2007), (Venkatramani, Ghosh, & Mills, 2007), (Okumura, Higashi, Sumida, & Ohno, 2007), (Gerken & Dawson, 2007), (Counts, Braginsky, Battaile, & Holm, 2008), (Gerken & Dawson, 2008), (Kuroda & Tvergaard, 2008), (Bitzek, Derlet, Anderson, & Van Swygenhoven, 2008), (Borg, Niordson, Kysar, & Kysar, 2008), (Li, et al., 2009)
Creep, high temperature deformation, diffusion mechanisms	(McHugh & Mohrmann, 1997), (Balasubramanian & Anand, 2002), (Hasija, Ghosh, Mills, & Joseph, 2003), (Bower & Wininger, 2004), (Venkatramani, Ghosh, & Mills, 2007), (Agarwal, Briant, Krajewski, Bower, & Taleff, 2007), (Venkataramani, Kirane, & Ghosh, 2008), (Xu, Yonezu, Yue, & Chen, 2009)
Dislocation-based constitutive modelling	(Marketz & Fischer, 1994), (Arsenlis & Parks, 1999), (Arsenlis & Parks, 2002), (Evers, Parks, Brekelmans, & Geers, 2002), (Arsenlis & Tang, 2003), (Arsenlis, Parks, Becker, & Bulatov, 2004), (Evers, Brekelmans, & Geers, 2004), (Cheong & Busso, 2004), (Evers, Brekelmans, & Geers, 2004), (Ma & Roters, 2004), (Ma, Roters, & Raabe, 2006), (Ma, Roters, & Raabe, 2006), (McDowell, 2008)
Martensite mechanics, phase transformation, shape memory	(Marketz & Fischer, 1994), (Marketz & Fischer, 1995), (Tomita & Iwamoto, 1995), (Diani, Sabar, & Berveiller, 1995), (Diani & Parks, 1998), (Cherkaoui, Berveiller, & Sabar, 1998), (Cherkaoui, Berveiller, & Lemoine, 2000), (Thamburaja & Anand, 2001), (Tomita & Iwamoto, 2001), (Govindjee & Miehe, 2001) (Anand & Gurtin, 2003), (Turteltaub & Suiker, 2005), (Thamburaja, 2005), (Lan, Xiao, Li, & Li, 2005), (Turteltaub & Suiker, 2006), (Geers & Kouznetsova, 2007), (Tjahjanto, Turteltaub, & Suiker, 2008)
In-grain texture, grain-scale mechanics, non-uniform	(Sarma, Radhakrishnan, & Zacharia, 1998), (Forest, 1998), (Bhattacharyya, El-Danaf, Kalidindi, & Doherty, 2001), (Raabe, Sachtleber,

deformation, grain-scale mechanics, mesoscale	Zhao, Roters, & Zaefferer, 2001), (Miller & Turner, 2001), (Raabe, Zhao, Park, & Roters, 2002), (Sachtleber, Zhao, & Raabe, 2002), (Kim & Oh, 2003), (Clarke, Humphreys, & Bate, 2003), (Choi, 2003), (Zaefferer, Kuo, Zhao, Winning, & Raabe, 2003), (Erieau & Rey, 2004), (Sarma & Radhakrishnan, 2004), (Roters, Wang, Kuo, & Raabe, 2004), (Kim, Kim, & Oh, 2006), (Murphy, Cuddy, Harewood, Connolley, & McHugh, 2006)], (daFonseca, Oliver, Bate, & Withers, 2006), (You, Connolley, McHugh, & Motz, 2006), (Musienko, et al., 2007), (Han & Dawson, 2007), (Zhao, Ramesh, Raabe, Cuitino, & Radovitzky, 2008), (Zhang, Bower, Mishra, & Boyle, 2009)
Texture evolution, texture stability, anisotropy, in-grain texture formation	(Mika & Dawson, 1999), (Miehe, Schro¨der, & Schotte, 1999), (Kalidindi S. R., 2001), (Balasubramanian & Anand, 2002), (Van Houtte, Delannay, & Kalidindi, 2002) (Delannay, Kalidindi, & Van Houtte, 2002), (Raabe, Zhao, & Mao, 2002), (Bate & An, 2004), (Raabe, Zhao, & Roters, 2004), (Li, Van Houtte, & Kalidindi, 2004), (Sarma & Radhakrishnan, 2004), (Anand, 2004), (Roters, Jeon-Haurand, & Raabe, 2005), (Van Houtte, Van Bael, Seefeldt, & Delannay, 2005), (Li, Kalidindi, & Beyerlein, 2005), (Van Houtte, Kanjarla, Van Bael, Seefeldt, & Delannay, 2006), (Delannay, Jacques, & Kalidindi, 2006), (Tang, Zhang, Chen, & Deng, 2006), (Tikhovskiy, Raabe, & Roters, 2006), (Lee, Wang, & Anderson, 2007), (Tikhovskiy, Raabe, & Roters, 2007), (Mayeur, McDowell, & Neu, 2008), (Delannay, Melchior, Signorelli, Remacle, & Kuwabara, 2009)
Forming, deep drawing, cup drawing, process modelling, spring-back, earing, anisotropy, wire drawing, extrusion, design, fretting	(Zhao, Mao, Roters, & Raabe, 2004), (Tugcu, Neale, Wu, & Inal, 2004), (Delannay, Beringhier, Chastel, & Loge, 2005), (Raabe, Wang, & Roters, 2005), (Dick & Cailletaud, 2006), (Delannay, Jacques, & Kalidindi, 2006), (Tikhovskiy, Raabe, & Roters, 2007), (Chen, Lee, & To, 2007), (Raabe, 2007), (Nakamachi, Tam, & Morimoto, 2007), (Ocenasek, Rodriguez Ripoll, Weygand, & Riedel, 2007), (Tikhovskiy, Raabe, & Roters, 2007), (Li, Donohue, & Kalidindi, 2008), (Mayeur, McDowell, & Neu, 2008), (Li, Donohue, & Kalidindi, 2008), (Li, et al., 2008), (Zhuang, Wang, Cao, Lin, & Hart, 2008), (Delannay, Melchior, Signorelli, Remacle, & Kuwabara, 2009), (Zamiri, Bieler, & Pourboghrat, 2009)
Crystal plasticity and recrystallization	(Bate P. , 1999), (Raabe & Becker, 2000), (Raabe, 2000), (Radhakrishnan, Sarma, Weiland, & Baggethun, 2002), (Raabe, 2002), (Takaki, Yamanaka, Higa, & Tomita, 2007), (Raabe, 2007), (Semiatin, Weaver, Goetz, Thomas J., & Turner, 2007), (Zambaldi, Roters, Raabe, & Glatzel, 2007), (Loge, et al., 2008)
Deformation twinning	(Kalidindi S. R., 1998), (Staroselsky & Anand, 1998), (Marketz W. T., et al., 2002), (Staroselskya & Anand, 2003), (Marketz, Fischer, & Clemens, 2003), (Salem, Kalidindi, & Semiatin, Strain hardening due to, 2005)
Nanoindentation, pillar testing, micro-scale deformation, micro-bending, testing	(Wang, Raabe, Klu¨ber, & Roters, 2004), (Zaafarani, Raabe, Singh, Roters, & Zaefferer, 2006), (You, Connolley, McHugh, & Motz, 2006), (Raabe, Ma, & Roters, 2007), (Casals, Ocenasek, & Alcala, 2007), (Zaafarani, Raabe, Roters, & Zaefferer, 2008), (Alcala, Casals, & Ocenasek, 2008), (Weber, Schestakow, Roters, & Raabe, 2008), (Xu, Yonezu, Yue, & Chen, 2009), (Demir, Raabe, Zaafarani, & Zaefferer, 2009)
Numerical aspects, FE shape effects, mesh dependence, texture discretization, accuracy, robust integration methods	(Miehe, 1996), (Bachu & Kalidindi, 1998), (Harewood & McHugh, 2006), (Kuchnicki, Cuitino, & Radovitzky, 2006), (Amirkhizi & Nemat-Nasser, 2007), (Harewood & McHugh, 2007), (Melchior & Delannay, 2006), (Zhao, Kuchnicki, Radovitzky, & Cuitin˜o, 2007), (Li, Yang, & Sun, 2008), (Ritz & Dawson, 2009), (Barton, et al., 2001), (Gerken & Dawson, 2007)

Damage, cyclic loading, void growth, fatigue	(Bruzzi, McHugh, O'Rourke, & Linder, 2001), (Turkmen, Dawson, & Miller, 2002), (Turkmen, Loge, Dawson, & Miller, 2003), (Kysar, Gan , & Mendez-Arzuza, 2005), (Sinha & Ghosh, 2006), (Potirniche, Hearndon, Horstemeyer, & Ling, 2006), (Zhang, Zhang, & McDowell, 2007), (Cheong, Smillie, & Knowles, 2007), (Dunne, Walker, & Rugg, 2007), (Liu, Zhang, Tang, & Du, 2007), (Kumar, et al., 2008), (Patil, Narasimhan , Biswas, & Mishra, 2008), (Watanabe, Terada, deSouza, & Peric, 2008), (McDowell, 2008), (Mayama, Sasaki, & Kuroda M., 2008), (Borg, Niordson, Kysar, & Kysar, 2008), (Bieler , et al., 2009)
Multiphase mechanics	(Hartig & Mecking, 2005), (Tjahjanto, Roters, & Eisenlohr, 2007), (Mayeur, McDowell, & Neu, 2008), (Inal, Simha, & Mishra, 2008) (Vogler & Clayton, 2008)

2. **Sub-models necessity:** Complexity in the latter case arises from the necessity of sub-models to describe the evolving fractions (e.g. of the twinned volume) and the interaction between various mechanisms at the same field point (Figure 4);
3. **Complexity increase:** Martensite or twins may, after their formation, undergo:
   - Further plastic deformation;
   - Create accommodation strains related to volume changes;
4. **Interactions implementation:** The user of CPFE can not only implement these shear mechanisms, but also their interactions;
5. **Local homogenization rules:** The resulting complexity requires the formulation of local homogenization rules (Raabe, et al., 2002), (Raabe & Roters, 2004);
6. **Close connection:** CPFE method includes close connection between shape change, rotation and geometrically necessary dislocations (GNDs) (Nye, 1953), (Kroner, 1958), (Ashby, 1970), (Kroner, 1981);
7. **Constitutive laws implementation:** This allows implementing constitutive laws that treat mechanical size effects in conjunction with local orientation gradients (Ma, Roters, & Raabe, 2006);
8. **Size-dependent plasticity modeling:** This point is relevant to size-dependent plasticity modeling, as the polarized portions of dislocation arrays (which are often conceptually treated as GNDs), such as anticipated in many size effects models, must necessarily coincide with orientation gradients (Nye, 1953);
9. **High Resolution Measurements:** Nowadays, it is possible to measure, precisely and in 2D and 3D high resolution measurements, such lattice rotations. This leads to the possibility of testing corresponding models (Larson, et al., 2002), (Kuo, Zaefferer, Zhao, Winning, & Raabe, 2003), (Zaefferer, Kuo, Zhao, Winning, & Raabe, 2003), (Roters, Wang, Kuo, & Raabe, 2004), (Zaafarani, Raabe, Singh, Roters, & Zaefferer, 2006), (Zaefferer, Wright, & Raabe, 2008), (Demir, Raabe, Zaafarani, & Zaefferer, 2009).
10. **Homogenization schemes:** Appropriate homogenization schemes are required within a CPFE model. That is because a larger number of crystals and/or phases must be considered in each representative volume element mapped at a FE integration point.
11. **Numerical aspects:** Numerical aspects also deserve attention. CPFE formulations can be either fully integrated into FE codes or implemented as user-defined subroutines into commercially available solvers. The latter case is important because engineering applications are often tackled using commercial platforms. The use of standard solvers also helps to make CPFE methods accessible to a broader community.
12. **Mesh and the integration procedures**: They also play a significant role in CPFE simulations.

The possibility of using CPFE modelling in both microscopic and macroscopic scales is another advantage (Raabe, et al., 2002).

1.2.1 Microscopic applications of CPFE

1. Inter- and intra-grain mechanics, damage initiation, mechanics at interfaces, simulation of micromechanical experiments (e.g. indentation, pillar compression, beam bending);
2. Prediction of local lattice curvatures and mechanical size effects (Table 1);

3. CPFE simulations for experimental boundary conditions in small-scale material testing. In such testing, it is difficult to control and/or monitor experimental boundary conditions and sometimes it is difficult to interpret experimental results without corresponding CPFE simulations. It allows the experimentalist to simulate the effects of details in the contact and boundary conditions;
4. Engineering design of grain scaled parts, e.g. microelectromechanical systems (MEMS), bonding wires and pillars, stents, and practically all materials in electronic components. Design of such parts increasingly requires consideration of grain-scale crystalline anisotropy.

1.2.1 Macroscopic applications of CPFE

Primary engineering objectives of CPFE applications in macroscopic forming simulations are the prediction of:

1. The precise material shape after forming;
2. Thickness distribution;
3. Material failure;
4. Optimization of material flow (Kraska, Doig, Tikhomirov , Raabe, & Roters, 2009);
5. Elastic spring-back;
6. Forming limits (Nakamachi, Xie, & Harimoto, 2001), (Xie & Nakamachi, 2002);
7. Texture evolution (Zhao, Mao, Roters, & Raabe, 2001), (Zhao, Mao, Roters, & Raabe, 2004), (Raabe, Wang, & Roters, 2005);
8. Mechanical properties of the formed part.

Further related applications occur in:

1. Virtual mechanical laboratory (Kraska, Doig, Tikhomirov , Raabe, & Roters, 2009);
2. Press layout;
3. Tool design;
4. Surface properties (Table 1);
   - Macroscopic (e.g. wrinkling);
   - Microstructural (e.g. roping, ridging, orange peel) mechanisms that influence the surface topography (Raabe, Sachtleber, Weiland, Scheele, & Zhao, 2003), (Becker, 1998), (Zhao, Radovitzky, & Cuitino, 2004).

2. Chronological brief

2.1. Finite Element (FE):

1. The first FE simulation was performed by Courant in 1943 [218].
2. The breakthrough of the method came with the publication of "The Finite Element Method in Structural and Continuum Mechanics" by (Zienkiewicz, 1967).
3. The three succeeding volumes (Zienkiewicz & Taylor, 2005), (Zienkiewicz, Taylor, & Zhu, 2005), (Zienkiewicz, Taylor, & Nithiarasu, 2005) are considered the most important monographs in the field to date.

2.2 Crystal Plasticity (CP)

1. Despite that, it has been known since 1934 (Taylor, 1934), (Orowan, 1934), (Polanyi, 1934) that crystalline materials deform plastically by the slip of dislocations on discrete slip systems, for a long-time continuum mechanical FE simulation used isotropic material models;
2. The first CPFE simulations were performed by (Peirce, Asaro, & Needleman, 1982). Due to computational restrictions they used a simplified set-up of two symmetric slip systems in order to study the tensile behavior of a single crystal;
3. These simulations were later extended to a polycrystalline arrangement by (Harren, De`ve, & Asaro, 1988), (Harren & Asaro, 1989) using a 2D setup with two or three slip systems;
4. In 1991 Becker was the first to perform simulations based on the 12 slip systems of a face-centered cubic (fcc) crystal. Using a 3D model for the crystallographic degrees of freedom, he simulated channel–die deformation of a columnar polycrystal aggregate (Becker, 1991) and of a single crystal (Becker, Butler, Hu, & Lalli, 1991);
5. In the field of direct or one-to-one crystal plasticity models numerous grain- and subgrain scale problems have been tackled using meshes with sub grain resolutions and, in part, complex 2D and 3D grain arrangements (Sachtleber, Zhao, & Raabe, 2002), (Siska, Forest, & Gumbsch, 2007), (Mika & Dawson, 1998), (Sarma & Dawson , 1996), (Sarma, Radhakrishnan, & Zacharia,

1998), (Beaudoin, Mecking, & Kocks, 1996), (Bachu & Kalidindi, 1998), (Zhao, Kuchnicki, Radovitzky, & Cuitin˜o, 2007);

6. On the macroscopic side, homogenization schemes were developed for the application of the CPFE method to large-scale forming operations. In this case the main problem was the correct representation of the (statistical) crystallographic texture of the material in the CPFE mesh. This can be achieved in different ways using, for example, texture components (Zhao, Mao, Roters, & Raabe, 2001), (Raabe & Roters, 2004) or direct sampling of single orientations from the orientation distribution function (ODF) (Melchior & Delannay, 2006), (To´th & Van Houtte, 1992), (Eisenlohr & Roters, 2008).

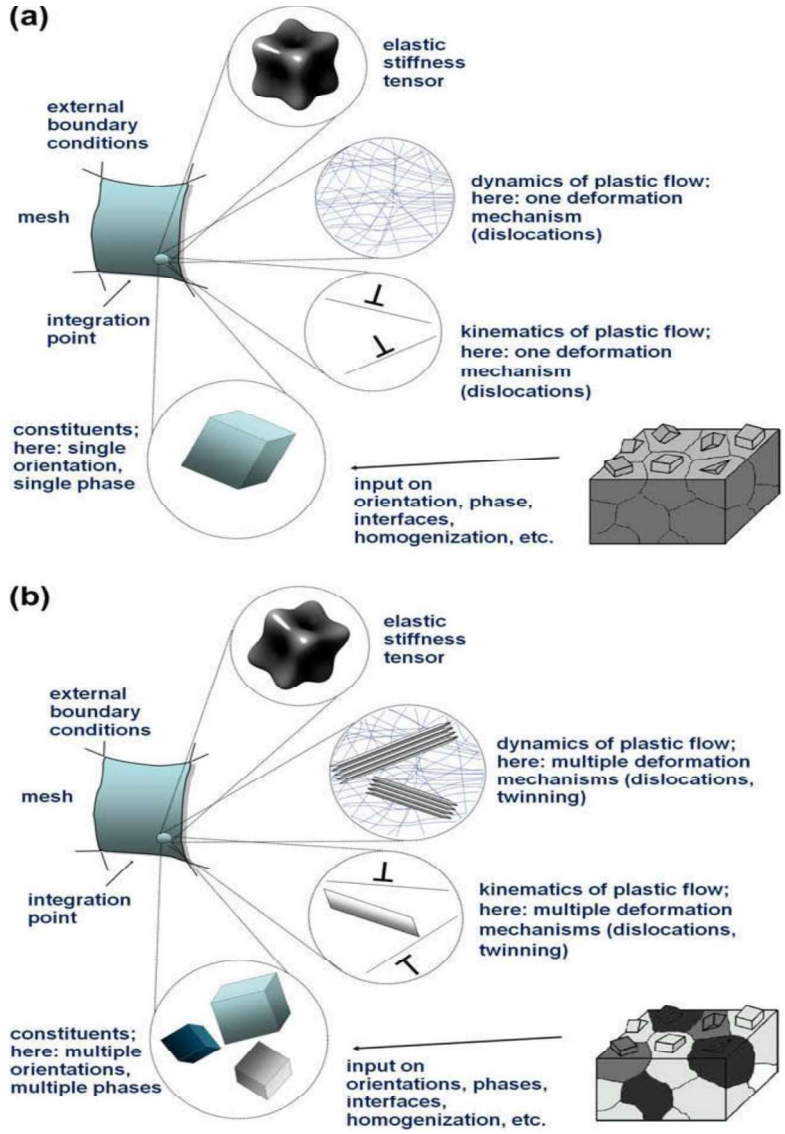

Figure 4. Schematic presentation of the conceptual ingredients in CPFE simulations. (a) Example of a case with one type of deformation mechanism (lattice dislocations) and one phase. (b) Example of a case with various deformation mechanisms, phases, orientations and homogenization schemes at the same integration point.

2.3 New Models

Phenomenological strain gradient theories were developed by (Fleck, Muller, Ashby, & Hutchinson, 1994), (Fleck & Hutchinson, 1997.), and (Nix & Gao, 1998). Using these theories, size effects can be introduced into CPFE frameworks. Also, because strain gradients can be associated with GNDs, new internal-variable constitutive formulations were developed that incorporate dislocation densities as physically based state variables (Arsenlis & Parks, 2002), (Arsenlis & Parks, 1999), (Arsenlis & Parks, 2002), (Ma, Roters, & Raabe, 2006), (Ma, Roters, & Raabe, 2006), (Gao & Huang, 2003) instead of strain measures, which were often used in phenomenological formulations.

Additional metallurgical mechanisms can be incorporated due to those most recent class of constitutive models. Mechanisms such as grain boundary mechanics (Ma, Roters, & Raabe, 2006), (Ma, Roters, & Raabe, 2006) or damage initiation (Bieler , et al., 2009) into the constitutive description. Concerning additional deformation mechanisms such as those that occur in TWIP or TRIP steels, extended CPFE formulations have been suggested by (Kalidindi S. R., 2001), (Kalidindi S. R., 1998), (Salem, Kalidindi, & Semiatin, 2005), (Staroselskya & Anand, 2003).

Conclusions

CPFEM is a powerful tool for modelling a wide range of mechanical problems in material sciences and engineering. Its applications vary between various microscopic and macroscopic applications. Tracking its chronological evolution showed that it had to wait until enough evolutions is reached in its two main legs: finite element method and crystal plasticity. Only after enough evolution for each of them and after their mixing together, evolution of new models became possible. Those new models severely needed due to various advances in material science and engineering.

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Ilya Chumanov
Federal State Autonomous Educational Institution of Higher Education "South Ural State University (national research university)", Russia
E-mail: chumanoviv@susu.ru
ORCID ID 0000-0003-0433-1846

Andrey Anikeev
Federal State Autonomous Educational Institution of Higher Education "South Ural State University (national research university)", Russia
E-mail: anikeevan@susu.ru
ORCID ID 0000-0002-9278-6404

Vadim Sedukhin
Federal State Autonomous Educational Institution of Higher Education "South Ural State University (national research university)", Russia
E-mail: sedukhinvv@susu.ru
ORCID ID 0000-0002-6356-4351

On the feasibility of producing locally modified metallic materials with controlled gradient of properties

Abstract: Metallurgy and engineering endeavours to develop and implement advanced technologies to save metal and create new metallic materials with improved characteristics. These scientific and technological activities include improvements to existing materials as well as the development of new materials by various methods. One such method is the creation of iron-based materials with a gradient of properties along the cross-section, obtained by locally modifying a given volume of the formed billet by filling the structure with heat-resistant, high-strength, dispersed phases. This paper describes the course and results of a number of experiments on the formation of a gradient of properties in steel castings of various compositions, and analyses the results of experiments on the creation of such materials.

Keywords: metal melts; dispersed particles; centrifugal casting; dispersed hardening; microstructure; properties.

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Introduction

Traditionally, the increase of mechanical properties of used steels and alloys in ferrous metallurgy is achieved by introducing a significant amount of alloying elements into the composition of the metal (base - iron) or alloy. At present, the existing grade compositions are more than sufficient to solve most of the current industrial problems. At the same time, the analysis of the cost market for alloying elements has shown that the prices are increasing every year. For this reason, one of the main objectives of the study is to develop a theoretical and practical basis for the development of technology for obtaining metals that meet the specific requirements of the existing industry, and at the same time having a relatively low cost. The solution to this problem is the rational design of steels by providing the necessary properties only to those amounts of metal that are subjected to specific effects, which is achieved by using a small amount of properly selected ultradisperse powders (Brown, 2014; Camagu, 2020; Parashivamurthy, 2014; Sobula, 2017; Zhang, 2015), and their location in specified volumes - on the working surface or in other volumes of the product that need specific properties. In other words, this can be characterised as the creation of materials with a controlled gradient of properties (Fernandes, 2017; El-Hadad, 2011; Kiviö, 2016; Watanabe, 2009, 2017).

At present, heterogeneity of properties in the volume of metals is achieved in several ways:

- by assembling different grades of steel into a single "package" and rolling, forging or explosion welding it;

- forming cavities in steel and filling them with other material;

- creating "frames" that hold materials with different properties in one product;

- suspension exogenous or endogenous casting.

All these methods have significant disadvantages:

- there is no physical-chemical interaction between dissimilar materials. Even in the case of rolling a "package" (or explosive welding) in an inert atmosphere or vacuum, delamination is observed due to the presence of oxide films. The lack of interaction between dissimilar materials increases the likelihood of failure at the interface, making them less suitable for use in structures, machines and mechanisms. In addition, these materials do not fulfil the requirements for the properties of structural materials, i.e. it is difficult to join separate parts by welding (due to their different weldability);

- production is not technological: firstly, separate layers of materials are formed and only then joined together. The joining requires specific expensive equipment: it is difficult to create a vacuum in the rolling mill to deform the "package"; explosion welding requires separate special chambers, the use of explosives and highly qualified, trained personnel with the appropriate tolerances;

- if the mechanical "frames" holding materials with different properties in one product are destroyed, the whole product is destroyed;

- the application of existing methods of exogenous or endogenous suspension moulding is impossible because there are no mechanisms for controlling the distribution of introduced or formed particles. As a consequence, it is impossible to achieve accurate prediction of the resulting properties in different volumes, which is especially important in materials where layers must have different properties (e.g., alternating viscous and solid layers).

In the present paper, the authors present variants of the method of suspension exogenous casting during metal casting on a centrifugal casting machine in order to obtain locally modified metallic materials with a controlled gradient of properties.

Research Method

In the absence of mechanisms to control the distribution of introduced or generated particles, the authors propose to utilize the density difference between the metal to be hardened and the dispersed particles to be introduced. In a static, stationary melt (for example, in an ingot or in a ladle), due to the difference in density, particles whose density is greater than that of the metal to be hardened move downwards (under the action of gravity), and particles with lower density - move in the direction opposite to gravity - to the top of the ingot or melt.

To control the distribution of particles in the volume it is proposed to apply centrifugal force, which can be used when using a centrifugal casting machine for casting melt and obtaining cylindrical billets. If the density of the dispersed particles in the melt is different from the density of the melt itself, a force will act on the particle that does not balance its centrifugal force and gravity. This creates conditions for the particle to move in or out of the workpiece. When the particle comes in contact with the forming crystallization front, it may be anchored there or continue to move, depending on the forces acting on it.

This method involves the interaction of dispersed carbide particles with metal melts, and the variety of particles and steels makes it possible to obtain an almost infinite number of combinations of variations in material properties.

A number of experiments with different particles and steels have been carried out by a team of authors:

1. particles carbide of tungsten and silicon in various amounts into steel 1020 and steel 1030 (Anikeev, 2016);

2. particles carbide of tungsten and boron in various amounts into nickel and chromium alloyed steel 20 (up to 5 %);

3. particles carbide of tungsten and titanium, yttrium oxide into steel 1020 (Anikeev, 2016);

4. particles carbide of tungsten and titanium in steel AISI 420 (Chumanov, 2017);

5. particles carbide of tungsten and titanium in steel AISI 321 (Chumanov, 2022).

Each series of experiments resulted in cylindrical castings containing different amounts of particles individually and in combinations. For the uniformity of the study, a research methodology was developed, including the study of changes in the structures and properties of multifunctional composite materials. All the obtained blanks were investigated according to the following standards:

- the macrostructure of the samples was examined for voids, friability, shrinkage, air bubbles, delaminations, cracks and other defects using the naked eye and a magnifying glass. To assess the size change of different crystalline regions, the samples were scanned with high resolution on an Epson scanner after etching. The obtained panoramic images of the crystal structure were downloaded into a computer and processed using the image analysis software "Thixomet", version "Pro". During the analysis, the panoramic images were compiled into a single image of the surface of the entire sample, after which the length of the macrostructure zones was measured using the built-in tool;

- microstructure of the obtained samples is examined for changes in the size of dendritic cells by measuring the length of chords on the outer and inner volumes of the blanks, as well as in the centre (½ of the radius). The uniformity of distribution of ultradisperse particles in the structure is also evaluated by counting the number per unit area in accordance with GOST 5639, as well as changes in the chemical and morphological composition of inclusions;

- tests of mechanical properties included tensile tests according to GOST 1497-84, Charpy tests (GOST 9454-84), hardness was measured by Rockwell method according to ISO 6508-86, DIN 50103 and ASTM E18-74 standards, GOST 9013-059. Tests of all mechanical properties are also carried out from three horizons of the billet (from the outside, ½ of the billet radius, inner edge).

Results and Conclusions

1. Titanium and boron carbide, yttrium oxide has low wettability indices with carbonaceous melts and almost do not interact with melts: individual particles are in the structure of castings, but their concentration is residually low. This is confirmed by a slight increase in the concentration of titanium and boron in the castings (traces). When titanium is added to steel, the wettability of titanium carbide increases, probably due to a decrease in surface tension.

2. Changing the chemical composition of the studied steels (within the limits of the experiments) in order to reduce the values of surface tension, practically did not affect the change of wettability of boron carbide and yttrium oxide.

3. Dispersed particles of tungsten carbide, regardless of the chemical composition of steel, affect the macro - and microstructure of the obtained blanks. When examining the macrostructure, the alignment of the structure along the cross-section, the elimination of clear boundaries of crystallization zones, and a decrease in the length of the dendritic crystals zone are observed. The greatest influence on the structure is exerted by tungsten carbide particles fed in the amount of more than 3%.

4. The study of microstructure of samples with tungsten carbide shows that the size of dendritic cells in carbon steels decreases as the amount of introduced dispersed particles increases. In the samples without particles, the cell size ranges from 156 to 48 micrometers (in the inner and outer layers of the billets, respectively). The addition of tungsten carbide above 2.4% in the sample mass leads to a decrease in cell size from 25.5 to 15.5 micrometers (in the inner and outer layers of the billets, respectively).

5. When adding dispersed particles of tungsten carbide up to 0.5%, no significant changes in the macro- and microstructure of the samples are observed, changes occur only in the outer areas of the blanks, where the size of dendritic cells decreases by 15-20% compared to the samples without particles.

6. When introducing dispersed particles in a volume exceeding 2.4% of the mass of the investigated sample, it is observed that there is no increase in the concentration of particles in the surface volumes. Instead, there is an expansion of the zone with high concentration of carbides from the outer part of the sample to its inner part.

7. The concentration of 4-6 ultradisperse particles per square micrometre in the metal structure allows to increase (in comparison with comparison samples without particles) the strength of various steel grades in the range from 20 to 38 %, impact toughness - from 15 to 26 %, hardness - from 15 to 35 % and abrasive wear resistance - from 25 to 36 %. This concentration corresponds to the introduction of 2.4 % of ultrafine particles from the weight of the billet.

8. Due to the high cost of carbides (especially tungsten) it is reasonable to use the method of disperse hardening in centrifugal casting to obtain workpieces weighing more than 20 kg. This allows saving significantly on alloying elements, forming the required properties only on the outer surface layers of the formed billet. When the mass (and, accordingly, dimensions) of the workpiece to be hardened increases, the feasibility of the method will increase due to the scale factor.

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Ilya Chumanov
Federal State Autonomous Educational Institution of Higher Education "South Ural State University (national research university)", Russia
E-mail: chumanoviv@susu.ru
ORCID ID 0000-0003-0433-1846

Andrey Anikeev
Federal State Autonomous Educational Institution of Higher Education "South Ural State University (national research university)", Russia
E-mail: anikeevan@susu.ru
ORCID ID 0000-0002-9278-6404

Dmitry Sergeev
Federal State Autonomous Educational Institution of Higher Education "South Ural State University (national research university)", Russia
E-mail: sergeevdv@susu.ru
ORCID ID 0000-0001-6051-4917

About economic efficiency of electroslag refining process of iron-rich raw material

Abstract: The question of efficiency of use of metalized pellets for production of consumable electrodes subjected to electroslag remelting process in order to obtain metal pure in phosphorus and impurities of non-ferrous metals is considered. Analytical estimation of the processes occurring during the interaction "pellet - ligature" has been made, which allowed to obtain optimal parameters for the formation of consumable electrode from ligature and metallized pellets. The experimental estimation of temperature interval of pellets preheating 300...500 °C was carried out. The optimum temperature of pellets preheating is determined, which is 400 °C. The obtained prototypes are investigated and it is established that pellet preheating up to 400 °C allows to obtain fusion of pellet surface layers with ligature. The technology of formation of expendable electrodes from metalized pellets by pouring liquid ligature into a special liner with a polystyrene rod pre-installed in it has been developed.

Keywords: iron, raw material, slag, refining process, costs of production.

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Introduction

At present, considerable experience has been accumulated in the direct production of iron and its use in steelmaking, bypassing the blast furnace process. The increased interest in the products of direct reduction is explained by their guaranteed purity in terms of the content of impurities of non-ferrous metals, as well as sulfur and phosphorus, which allows to significantly reduce the duration of the refining period of melting and increase the mechanical characteristics of steel (Lyalyuk et al., 2018; Zhunussova et al., 2023).

More than 75% of reduced iron is smelted in electric furnaces. Continuous loading of metalized pellets, which are more transportable than scrap, into the furnace allows to significantly increase the productivity of electric furnaces. This is achieved due to the absence of time losses for pelletizing and increased transformer power utilization due to high stable power consumption. However, the conventional methods do not allow to fully utilize the advantages of pure virgin pellets.

The costs of production of metalized raw materials significantly exceed the costs of scrap metal (3...8 times). Therefore, more than 60% of the cost of metal in the structure of metal production cost is metalized pellets. Costs are reduced as a result of increased production of metalized pellets when the entire complex of shaft furnaces is put into commercial operation and the technology of their production is fully mastered at the Oskol Electrometallurgical Plant (OEMP).

Currently, this method has been tested and implemented on an experimental industrial scale at some machine-building plants, where ingots weighing up to 650 kg of die and roll steel are produced. The melting technology includes continuous supply of all necessary components to the mold, extraction of ingot from the mold in the course of melting and drainage of excess slag (Nikitchenko et al., 2018).

The presence of iron oxides in slag, metal contact with furnace lining during the smelting process and with the air atmosphere during discharge and casting, introduction of deoxidizers leads to contamination of steel with non-metallic inclusions and gases. Increasing the purity of metal through the use of synthetic slags and vacuumization, as well as the use of refining remelting significantly increase the cost of steel (Kerimov & Shakhov, 2020).

In this regard, studies on the development of new processes for steel production by one-stage transformation of direct iron reduction products into homogeneous ingots are of particular interest (Puzakov et al., 2020). Such technologies are casting on continuous casting machines and in special molds, which allow to obtain electrodes with a good surface and less shrinkage.

Research Method

Economic efficiency of mastering the process of electroslag remelting of metallized raw materials is determined by comparing current, specific capital and reduced costs for the production of rolling rolls on the compared variants of technology from tool alloy steel type 60Х2СМФ for rolls of cold rolling mills in the conditions of OEMP.

Industrial development of the new technology of production of rolling rolls from ESSP metal in comparison with ESSP in the conditions of metallurgical production provides cost savings in the field of metallurgical production. This is due to the 10 - 15% excess of cost savings on technological operations excluded from the technological scheme of production (operations for the manufacture of consumable electrodes) (Bersenev et al., 2018).

Metalized pellets are one of the varieties of sponge iron, which is a product of direct reduction of iron carried out in the solid phase. Sponge iron pellets are distinguished from other types of sponge iron by the spherical shape of the particles, which is inherited from the raw material used - iron ore pellets. If chunks of rich iron ore are used as raw material, the end product of direct reduction will be lumpy sponge iron. In a number of processes, powdered iron ore concentrates are used as raw materials.

At present, economical processes of direct reduction of iron, which allow using solid fuel cheaper than natural gas, are being widely developed all over the world. Works on direct reduction of iron with gasification of hard coal and subsequent gas reduction of iron are underway. Much attention is paid to liquid-phase direct reduction processes, which provide for production of relatively small portions of pig iron using cheap small lump ore and low-grade coals as raw materials, including non-coking coals.

Одним из главных показателей качества металлизованных окатышей является степень One of the main indicators of the quality of metallized pellets is the degree of metallization, i.e. the ratio of metallic iron content to the total iron content. Pellets suitable for processing into steel should have a metallization degree of 85...97%.

The phosphorus content in metallized pellets is usually in the range of 0.010...0.030 %, and sulfur - 0.030...0.070 % (when using solid reducing agents, the sulfur content can be much higher) (Titov, 2018).

Metalized pellets are used for steelmaking in electric arc furnaces, as well as (very limitedly) for steelmaking in oxygen converters and low-frequency induction furnaces. Electric arc smelting accounts for the bulk of steels smelted using metallized pellets. The content of pellets in the charge is 50 % and more, while in oxygen converter smelting this indicator does not exceed 25...30 %. The quality of mass consumption steels produced using metalized pellets in electric arc furnace, converter or induction furnace meets the requirements. Smelting of steel in an electric arc furnace using metalized pellets differs significantly from scrap smelting, first of all, by the melting period. When smelting metalized pellets there is a real danger of destruction of furnace slopes by aggressive waste rock slag. To create a flux from acid waste rock it is necessary to introduce lime, which leads to an increase in energy consumption for slag melting. Processes of additional reduction of iron oxides by excess carbon, occurring during the melting of metallized pellets, are associated with the release of carbon monoxide and lead to the boiling of slag, there is a possibility of slag emissions. The content of pellets in the charge over 20...30 % complicates melting and significantly worsens the process performance. The mentioned peculiarities of metallized pellets smelting cause the search for ways to create a

more economical than electric arc furnace unit for processing of metallized raw materials into steel, capable to work on the charge of 100% sponge iron (Bersenev et al., 2021).

One of the tempting directions in the search for the technology of 100% conversion of metallized raw materials is the application of electroslag process for smelting. Works on electroslag smelting of sponge iron are being carried out on a wide front. It should be immediately stipulated that none of the works today has not passed the stage of pilot testing, and many of them are at the stage of laboratory studies.

The main working medium for melting metalized pellets is the slag bath. It is a generator of heat, thanks to which the melting of raw materials takes place. Pellets are fed into the slag bath at a temperature higher than their melting point. And despite the fact that the density of slag, as a rule, is somewhat lower or close to the density of metalized pellets, the latter, falling into the slag, do not sink and melt in the layer of slag (the density of real liquid slag at 1673 K is within 2.5 ... 3.15 t/m3). This circumstance, typical for classical electroslag remelting and quite unusual for steelmaking process, is of great importance: in the slag bath there is melting of charge, waste rock is separated from pellets, iron oxides pass into slag; practically all metallurgical reactions take place in it. Metal droplets falling into the metal bath already have the final chemical composition. Thus, the use of metallized pellets is very relevant for the production of consumable electrodes for electroslag remelting.

Research Results

The method of obtaining consumable electrodes for electroslag remelting, which consists in feeding metalized pellets into a mold and filling the mold with molten metal, was used for manufacturing electrodes. As a mold used a liner, in which installed in the center of the polystyrene rod with a diameter equal to 1/3 of the diameter of the liner, poured pre-dried at a temperature of 2000C for 4 hours. Then the molten metal was fed into the liner by siphon pouring from below in the volume of 1:3 vol.% to the volume of pellets, after the end of the crystallization process, the finished electrode is extracted.

The use of a polystyrene rod in the center of the liner allowed the pellets to be initially restrained from collapsing as the metal was poured in, and also ensured that the metalized pellets were densely impregnated as the liner was filled due to polystyrene combustion and filling of the liner with liquid metal.

The use of metallized pellets as a solid metallic phase makes it possible to obtain an electrode having a dense core evenly surrounded by pellets, which are joined to the core by impregnation of the latter with the poured metal. The material obtained as a result of further electroslag remelting has a low content of harmful gases, impurities of non-ferrous metals, which are not removed in the course of electroslag remelting.

Samples were cut out of the obtained ingots and examined on the electron microscope JEM 2100. On the basis of the obtained phase chemical composition we can conclude that the pellet is slightly melted, as evidenced by the increase in the carbon content in the boundary zone, relative to its content in the ligature. In turn, the pellet melting provides a strong bond with the ligature, and thus the required mechanical strength of the combined electrode for its further electroslag remelting.

The experiments were carried out at different temperature regimes of pellets heating, in the range from 200° C to 800 °C. For the experiments of pouring the pellet with the volume of ligature we used metallized pellets produced by OAO "Oskol Electrometallurgical Plant", the degree of metallization of which reaches 96.1 %, and as a ligature - soft iron.

Conclusions

When the pellets were preheated to temperatures of 600 and 800 °C, the ingots showed cavities around the pellet, which were formed due to CO release when the pellet was in contact with the liquid melt. Also, significant secondary oxidation prevented the alloying of the ligature and the metal component of the pellet, which contributed to its pitting when preparing the sample for microscopic analysis. When pellets were preheated to temperatures of 200 and 400 °C, as well as without preheating, no violations of ingot macrostructure were detected. The experiments have shown that the mechanical strength of the electrode, due to the fusion of the metal component with the ligature, is ensured by preheating the pellets to temperatures of 200 - 400 °C.

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Alan Rifqi Kamal
Department of Educational Research
and Evaluation, Graduate School,
Yogyakarta State University (UNY), Indonesia
E-mail: alanrifqi.2021@student.uny.ac.id

Edi Istiyono
Department of Educational Research
and Evaluation, Graduate School,
Yogyakarta State University (UNY), Indonesia
E-mail: edi_istiyono_uny@yahoo.co.id

Analysis of numeracy ability test item characteristics grade VIII students with mixed model item response theory (IRT) approach

Abstract: Basic knowledge of mathematics is essential for solving problems contextually. Mathematics has a function for the development of the ability to calculate, measure, find, and use mathematical formulas that can provide students with an understanding of concepts related to life phenomena. One ability that is synonymous with understanding problems contextually is numeracy ability. Numeration has a main focus, namely the ability of students to formulate, apply, and be able to interpret mathematics in various contexts that include mathematical reasoning and using mathematical concepts, methods, facts, and auxiliary media, explaining, and predicting phenomena in everyday life. This study aims to determine the construct of numeracy ability test instruments for class VIII public junior high school students in Pekalongan Regency, determine the quality of numeracy ability test instruments for class VIII public junior high school students in Pekalongan Regency, and determine the numeracy ability profile of class VIII public junior high school students in Pekalongan Regency. This research method approaches quantitatively by developing instruments using CFA and IRT mixed models. This research was conducted at the junior high school level within the scope of the education office of Pekalongan Regency, Central Java Province, by taking 6 schools as samples. Content validity using Aiken V and Cronbach Alpha reliability as well as item characteristics with mixed IRT and descriptive analysis. The results of this study, namely (1) Construction of numeracy ability instruments for grade VIII State Junior High School students, which are related to the content of algebra, numbers, geometry, and measurement, as well as data and uncertainty. In addition, using personal, socio-cultural, and scientific contexts, using cognitive levels of understanding, application, and reasoning, (2) The quality of numeracy ability instruments is declared valid and reliable, and in construct validity all items are fit as seen from the *Loading Factor Standardized Solution* value of more than 0.3 and *p-value* < 0.05 and the reliability of the high category and the estimated characteristics of the items show that the question items are included in the category both in terms of difficulty, and (3) The numeracy ability of junior high school students in Pekalongan Regency shows that there are 36 students out of 599 students classified as proficient with a percentage of 6%, 139 students out of 599 students classified as proficient with a percentage of 23%, 390 students out of 599 students classified as basic with a percentage of 65%, and 34 students out of 599 students classified as needing special intervention with a percentage of 6%.

Keywords: Item Characteristics, Numeracy Ability, Mixed Model Item Response Theory (IRT).

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Introduction

Learning mathematics is not just about understanding concepts and theorems in mathematics, but students must be able to use logical reasoning to be able to solve problems or predict phenomena. Teacher involvement has an important role in achieving the success of the learning process. Teachers have a role in helping students to understand mathematical concepts. In this process students can use mathematics in solving contextual problems in accordance with mathematical concepts (OECD, 2019). Mathematics has a close relationship with everyday life problems, especially in terms of the ability to calculate, measure, and find patterns.

This is in line with the objectives of mathematics learning as outlined in the Regulation of the Minister of Education and Culture of the Republic of Indonesia Number 21 of 2016 concerning Content Standards for Primary and Secondary Education, namely: 1) understanding mathematical concepts, describing the relationship between mathematical concepts and applying concepts flexibly, accurately, efficiently, and precisely in solving problems, 2) utilizing reasoning patterns of nature from mathematics, develop or manipulate mathematics in making general conclusions from an event, formulating evidence, or describing the results of mathematical thoughts and statements, 3) solving problems including determining known elements, assembling mathematical solving models, processing mathematical models, and providing appropriate solutions, and 4) communicating the results of thoughts or ideas with diagrams, tables, symbols, or other supporting media in order to clarify problems or circumstances. Basic skills for students need to exist so that the goals of national education are achieved. The basic ability to learn mathematics is closely related to numeracy ability.

The Ministry of Education and Culture (Kemendikbud) is very concerned about the urgency of numeracy ability. This can be seen from Indonesia's participation in *the Program for International Student Assessment* (PISA) driven by the *Organization for Economic Cooperation and Development* (OECD) which measures mathematical literacy skills which shows the results of PISA rankings obtained by Indonesia from 2003 to 2018; Indonesia ranked 38 out of 40 OECD member countries in 2003, Indonesia ranked 50 out of 57 OECD member countries in 2006, Indonesia ranked 61 out of 65 OECD member countries in 2009, Indonesia ranked 64 out of 65 OECD member countries in 2012, Indonesia ranked 69 out of 76 OECD member countries in 2015, Indonesia ranked 72 out of 78 OECD member countries in 2018 (OECD, 2019). These results show that there is still low mathematical literacy ability in Indonesia.

Basic knowledge of mathematics is essential for solving problems contextually. Mathematics has a function for the development of the ability to calculate, measure, find, and use mathematical formulas that can provide students with an understanding of concepts related to life phenomena (Megawati &; Sutarto, 2021). Learning mathematics is not just about understanding concepts, but can apply concepts that have been understood to solve problems. One ability that is synonymous with understanding problems contextually is numeracy ability.

Numeration means the ability of students to use their reasoning. Numeration has a main focus, namely the ability of students to formulate, apply, and be able to interpret mathematics into various contexts that include mathematical reasoning and use mathematical concepts, methods, facts, auxiliary media, explain, and predict phenomena in everyday life (Puspaningtyas &; Ulfa, 2020). It is important for students to understand numeracy which can later help students understand the role or benefits of mathematics in everyday life.

Numeracy ability is the ability or ability of students in terms of utilizing various kinds of numbers, diagrams, tables, symbols, or other supporting media that have a connection with mathematics to solve contextual problems and solve the information presented then be able to interpret the results of the analysis to predict and make decisions. More concisely, revealed (Ministry of Education and Culture, 2020), numeracy ability is the ability to think using concepts, procedures, facts, and mathematical media to solve everyday problems in various types of contexts. Numeration has a meaning as the ability of students to understand and use their mathematical knowledge in explaining phenomena, solving problems, or determining decisions in everyday life. This is in accordance with research conducted by (Braak &; Størksen, 2021) which explains that mathematical numeracy skills based on experience, discovery, experiments, or observations that have been made are still developing cumulatively. In everyday life we very often encounter phenomena related to numeracy skills such as when shopping, calculating height or weight, determining drug doses, regulating diet and nutrition, and many more related to student numeracy.

The Indonesian government considers the importance of numeracy skills for students to train students' reasoning in daily activities. This is done by replacing the UN by the Ministry of Education and Culture per 2021 to the Minimum Competency Assessment (AKM) in order to prepare students who have skills in the 21st century will be carried out a fundamental competency assessment to measure the ability to reason using mathematics or numeracy (Ministry of Education and Culture, 2020). Numeracy skills need to be possessed by students as a fundamental ability to be able to apply mathematical concepts in everyday life.

In order to find out the results of numeracy that is able to explain students' abilities according to their conditions, an accurate measuring instrument is needed. Assessment in mathematics subjects is used to measure students' numeracy abilities related to students' basic knowledge, namely the ability to apply, and process the understanding of mathematical concepts into the phenomena obtained which are divided into 4

main points, namely numbers, algebra, measurement and geometry, as well as data and uncertainty (Ministry of Education and Culture, 2020). In order to find out students' numeracy skills, measuring instruments in the form of test instruments are needed as a way of collecting data. Instruments used to collect information through student answers as evidence of learning outcomes which then the results are used to determine student characteristics (Istiyono, 2020; Retnawati, 2016). In this case it is necessary to use a measurement model called *Item Response Theory* (IRT).

Item Response Theory (IRT) is widely used in test analysis in educational, psychological, and using probabilistic models (Gunawan *et al*, 2020; Mardapi, 2017). The mathematical model means that students have the opportunity to answer question items correctly depending on student abilities and item characteristics (Retnawati, 2014). This means that students who have high abilities will have a greater chance of answering questions correctly than students who have low abilities. In addition, there are three assumptions that must be met in *Item Response Theory (*IRT): (1) unidimensional, meaning that each question item measures only one ability, (2) local independence, meaning that there is no correlation between test taker responses to different questions, and (3) invariant, meaning that the characteristics of question items do not depend on the distribution of test taker ability parameters and the parameters that characterize test takers do not depend on the characteristics of question items (Hambleton, Swaminathan, & Rogers, 1991). This means that the results obtained will provide the same ability even though the questions are done by students who are less smart and smart or students from the lower middle class and students from the upper middle class will not give different student ability results.

The *Item Response Theory* (IRT) approach in this study was used to analyze and measure individual abilities in answering numeracy ability test questions. The IRT approach makes it possible to gain a deeper understanding of the level of numeracy ability of students. IRT makes it possible to measure numeracy ability more accurately than other traditional ones. The expected IRT model must have the following characteristics: (1) the characteristics of the question item do not depend on the group of test takers to whom the question item is subjected, (2) the score that describes the test taker's ability does not depend on *the test, (3) the model is expressed in the level of the* question item, not in the test level, (4) the level model does not require parallel tests to calculate the reliability coefficient, and (5) the model provides an accurate measure of each ability score (Hambleton, Swaminathan, & Rogers, 1991). The results of the IRT analysis can be used to design more targeted educational interventions. The IRT approach is able to identify students who need extra help and what types of assistance are most effective in improving numeracy skills. Based on the explanation above, it is necessary to analyze numeracy ability test items. This study has objectives, namely (1) to know the construct of numeracy ability test instruments for class VIII public junior high school students in Pekalongan Regency, (2) to know the quality of numeracy ability test instruments for class VIII public junior high school students in Pekalongan Regency, (3) to know the numeracy ability profile of class VIII public junior high school students in Pekalongan Regency.

Research Method

***Types of Research*.** This study used a quantitative approach by developing student numeracy ability test instruments. The purpose of this study was to see the characteristics of numeracy ability test items. The steps for developing test instruments adopted from (Istiyono, 2020) consist of eleven steps, namely 1) Determining the purpose of the test instrument, 2) Determining the competencies and materials to be tested, 3) Compiling the test item distribution matrix, 4) Compiling the test instrument *blueprint,* 5) Writing and designing test items, 6) Compiling scoring rubrics, 7) Validity of test instrument items, 8) Revision of test items, 9) Assembling instruments, 10) Carrying out test trials, and 11) Taking measurements with the main test instruments.

***Time and Place of Research*.** This research was carried out at the junior high school level within the scope of the education office of Pekalongan Regency, Central Java Province. Data sampling will be carried out from April to June 2023.

***Data, Instruments, and Data Collection Techniques*.** Data collection in this study was using test instruments. The test instrument is in the form of a student numeracy ability test done by students. This test has the purpose of determining numeracy ability. Test questions are questions with indicators contained in AKM.

***Data Analysis*.** Content validity is obtained by rational analysis of test content based on *expert judgment* (Allen & Yen, 1979). Content validity consists of advanced validity and logical validity (Allen &; Yen,

1979). Content validity has a *judgemental nature* where the results of the analysis are based on rational judgment from *experts*. Here we will see to what extent the agreement of experts can be proven empirically. Numeracy ability test instrument test data are analyzed to find evidence of construct validity, reliability, and item characteristics. Proof of construct validation is done with *Confirmatory Factor Analysis* (CFA) with the help of *R program software*. Construct validity is used to see or describe the extent to which instrument-measuring theories are used (Allen & Yen, 1979).

Reliability is an important aspect that can show the reliability of a measuring instrument. An instrument is said to be reliable if the instrument can be consistent in measuring a latent variable. High-reliability results will minimize the error rate in measurement (Retnawati, 2016). Reliability estimation can use construct reliability, where estimation can be done after proving construct validity through CFA when it has obtained a suitable model or *fit* model (Retnawati, 2016). Reliability after CFA analysis is classically reliability with *Alpha Cronbach*.

The trial of the student numeracy ability test instrument will produce student response data after working on the question items to be given. The data obtained will be analyzed using IRT modeling procedures for dichotomus and polytomus scores. The procedure carried out is testing IRT assumptions which then proceed to estimating question items and capabilities with a two-parameter logistical model.

Results and Discussion

Content Validity. *Expert judgment* provides a quantitative assessment of each item related to the instrument developed. *Expert judgement* gives a score of 1–5. The scores obtained are then analyzed using Aiken's V formula. Based on the validation process that has been carried out on the developed numeracy ability instrument, it can be seen in Table 1.

Table 1. Results of Numeracy Ability Content Validity Analysis

Items	V Aiken	Decision	Items	V Aiken	Decision
Men_1	0,7917	Valid	PGK_1	0,9167	Valid
Men_2	0,9167	Valid	PGK_2	0,8333	Valid
Men_3	0,8333	Valid	PGK_3	0,7917	Valid
Men_4	0,8333	Valid	PGK_4	0,8750	Valid
Men_5	0,8750	Valid	PGK_5	0,8333	Valid
PG_1	0,8333	Valid	PGK_6	0,9583	Valid
PG_2	0,7917	Valid	PGK_7	0,8333	Valid
PG_3	0,7917	Valid	PGK_8	0,8750	Valid
PG_4	0,7917	Valid	PGK_9	0,8333	Valid
PG_5	0,7917	Valid	PGK_10	0,8750	Valid
PG_6	0,9167	Valid	IS_1	0,8333	Valid
PG_7	0,8333	Valid	IS_2	0,8750	Valid
PG_8	0,9583	Valid	IS_3	0,8750	Valid
PG_9	0,8750	Valid	IS_4	0,7917	Valid
PG_10	0,9167	Valid	IS_5	0,8750	Valid
PG_11	0,9167	Valid	U_1	0,9583	Valid
PG_12	0,8750	Valid	U_2	0,9167	Valid
PG_13	0,8333	Valid	U_3	0,9167	Valid
PG_14	0,9583	Valid	U_4	0,9167	Valid
PG_15	0,9167	Valid	U_5	0,9167	Valid

Based on the content validation analysis with the Aiken V formula assisted by the R program can be seen in Appendix 3b and the category rating is 5 with a significance level of 0.029, the numeracy instrument is declared analytically valid if the Aiken V value. $\geq 0,79$ The results of the analysis can be seen in Table 10, it can be concluded that all items developed in a total of 40 items are classified as good with details of 5 matching items (Men), 15 multiple-choice items (PG), 10 complex multiple-choice items (PGK), 5 short-fill items (IS), and 5 description items (U). There were no missing items, but based on research considerations only 20 question items were used in conducting the trial. The selected items are items that represent aspects of numeracy,

namely algebra, numbers, geometry, and measurement, as well as data and uncertainty so for each aspect there are items that represent.

Construct Validity and Reliability. The final results of the construct validation analysis of numeracy ability were measured by 20 items, but of the 20 items there were items that were merged into one so that the CFA analysis for numeracy ability involved 12 items. The merged question items are question items that have similarities in terms of item indicators, namely 4 items for algebraic aspects, 2 items for number aspects, 2 items for geometry and measurement aspects, and four items for data and uncertainty aspects. Figure 1 presents a hypothetical visualization of a converse measurement model for numeracy ability.

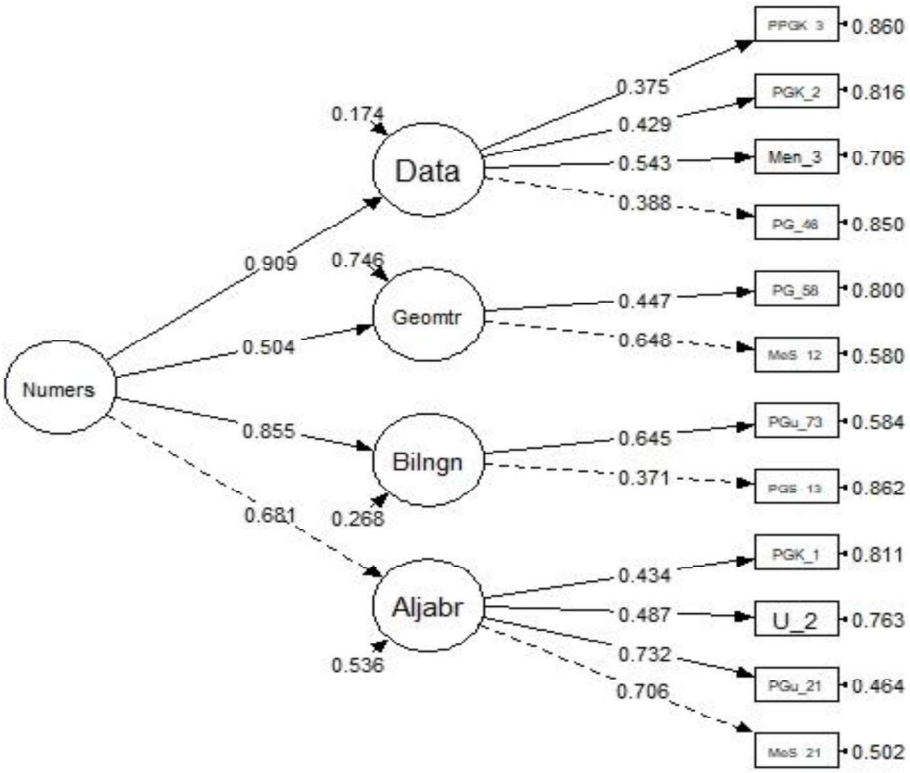

Figure 1. *Loading Factor Standardized Solution* Numeration

Based on empirical data, it will be seen how the model fits, the value of the loding factor, and the *t-value (*p-value). The compatibility of the numeracy ability measurement model is seen through the *chi-square (*p-value) value *of 0.05 and RMSEA (*Root Mean Square Error of Approximation) *< 0.08.* The value of the loding factor can be seen through a hypothetical model after CFA analysis as shown in Figure 1. Numeracy construct measurement model fit evaluation is a second-order CFA measurement model with four latent constructs, namely algebraic construct, number construct, geometric and measurement construct, and data construct and uncertainty. The fit of this measurement model is characterized by *chi-square* values = 64.766 with df = 50 *and p-value* = 0.078, and RMSEA values = 0.032. Based on the results of the evaluation of the suitability of the measurement model, it can be concluded that the empirical data obtained as a whole shows a match with the hypothetical model of measuring numeracy ability.

The load result *of the Loading Factor Standardized Solution first order for all items shows good convergent validity by considering* the Loading Factor Standardized Solution *and* the t-value *(*p-value). The results of the *Loading Factor Standardized Solution* analysis have been more than 0.3 and a significant factor load characterized by a *p-value* smaller than the maximum value p = 0.05 which has been set as a significance criterion. This means that they have good convergent validity, i.e. MeuS_21, PGu_21, U_2, and PGK_1 items for Algebraic constructs, PGuS_13 and PGu_73 items for Number constructs, MeuS_12 and PG_58 items for Geometry and Measurement constructs, and PG_46, Men_3, PGK_2, and PPGK_33 items for Data and Uncertainty constructs. The most dominant to less dominant aspects are Data and Uncertainty, Numbers, Algebra, and Geometry and Measurement. The dominant aspect can be seen from the results of the *second-order Loading Factor Standardized Solution*.

The next construct measurement model of numeracy ability is construct reliability using *Cronbach*'s Alpha in CFA to help measure the internal consistency of a set of measurable variables that contribute to latent factors. In simple terms*, Cronbach's Alpha value* is also considered a unidimensional index, which measures the extent to which a test measures a single factor (Gregory, 2000: 85). This means that reliability estimation using *Cronbach's Alpha is* able to provide information about the extent to which variables are measured in the CFA model. The latent variable of numeracy ability provides high construct reliability, namely the value of *Alpha Cronbach* (α) = 0.708.

Table 2. Eigenvalues Value Unidimensional Analysis

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	3,088	15,439	15,439
2	1,449	7,246	22,685
3	1,256	6,282	28,967
4	1,200	6,001	34,968
5	1,126	5,631	40,599
6	1,083	5,414	46,014
7	1,021	5,105	51,119
8	0,959	4,796	55,915
9	0,944	4,719	60,633
10	0,924	4,621	65,255
11	0,898	4,492	69,746
12	0,825	4,123	73,869
13	0,775	3,876	77,745
14	0,756	3,780	81,525
15	0,731	3,653	85,178
16	0,705	3,525	88,703
17	0,668	3,340	92,044
18	0,570	2,849	94,892
19	0,564	2,818	97,710
20	0,458	2,290	100,000

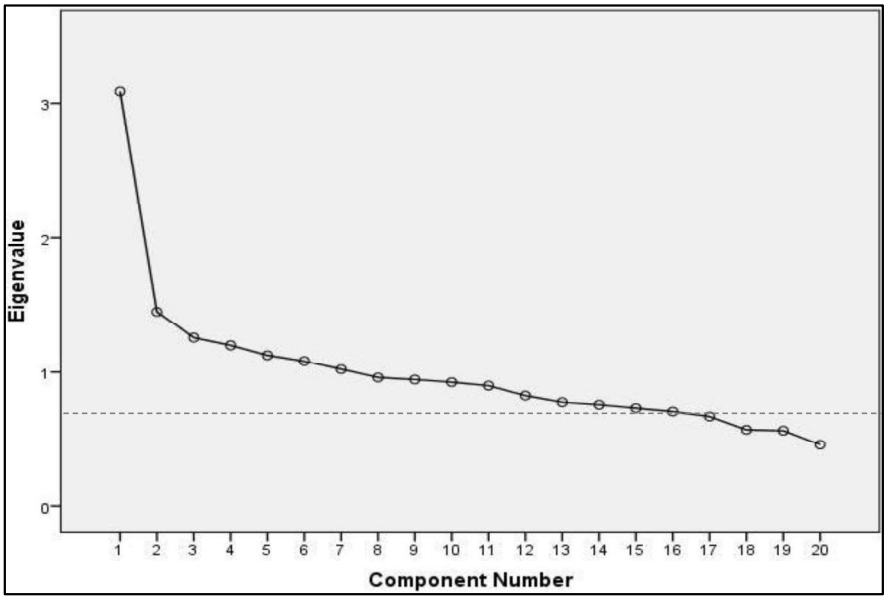

Figure 2. Unidimensional Scree Plot

Grain Characteristics. Unidimensional assumptions can be proven through construct validity using EFA which can be seen through the *Total Variance Explained Table, the* results of analysis using SPSS 23 are presented in Table 2 and *the Scree Plot* in Figure 2. Table 2 explains that there are 7 factors formed, but there

is one dominant factor, namely the first factor with *an eigenvalue* of more than 1, which is 3.088 as shown in Table 2. The number *of components* formed is 7 factors that can explain the variance of 51.119%. This explains that the numeracy ability instrument developed is able to distinguish student ability variances by 51.119%.

The proof of this unidimensional assumption is reinforced *by the scree plot* where it is proven that there is only one steep that is most dominant, namely the steep produced by the first factor. The *scree plot* graph looks from the first component/factor to the second component/factor steeply and from the second component/factor the graph is already sloping. This shows that there is one dominant factor, namely the numeracy ability of students. The resulting *screen plot* graph is shown in Figure 2.

Based on Figure 9, the chart shows a steep plot screen *chart pattern on* the first factor and starting to ramp up on the second factor, and so on. This proves that there is only one factor or factor that is dominant in the numeracy ability test instrument device is numeracy. The assumption of local independence can be fulfilled if the proof of unidimensional assumptions is also fulfilled (Mars, 2010 in Retnawati, 2014: 8). This means that if the unidimensional assumption is met, then automatically the assumption of local independence will also be fulfilled. This is because these two concepts are equivalent or equivalent (Lord, 1980; Lord & Novick, 1968 in Hambleton, Swaminathan, & Rogers., 1991: 11). The results of the unidimensional assumption test have been met, so automatically the assumption of local independence has also been fulfilled.

The third assumption test of *Item Response Theory* is the invariance of item parameters and capability parameters. Item parameter invariance means that item parameters will not affect/change if done by different groups of students while ability parameter invariance means that students' abilities will not be affected due to taking tests that have different levels of difficulty (Retnawati, 2014: 3). The assumption of invariance will be proven using the Rasch estimation model because it only considers the estimated difficulty of the item.

Proof of item invariance is carried out by dividing respondents into two groups, namely the male student group and the female student group. The next step is to estimate the difficulty of the item for the male student group and the item difficulty estimation for the female student group. Proof of the assumption of buitr invariance with the help of the program R generated *scatter plot* as in Figure 3.

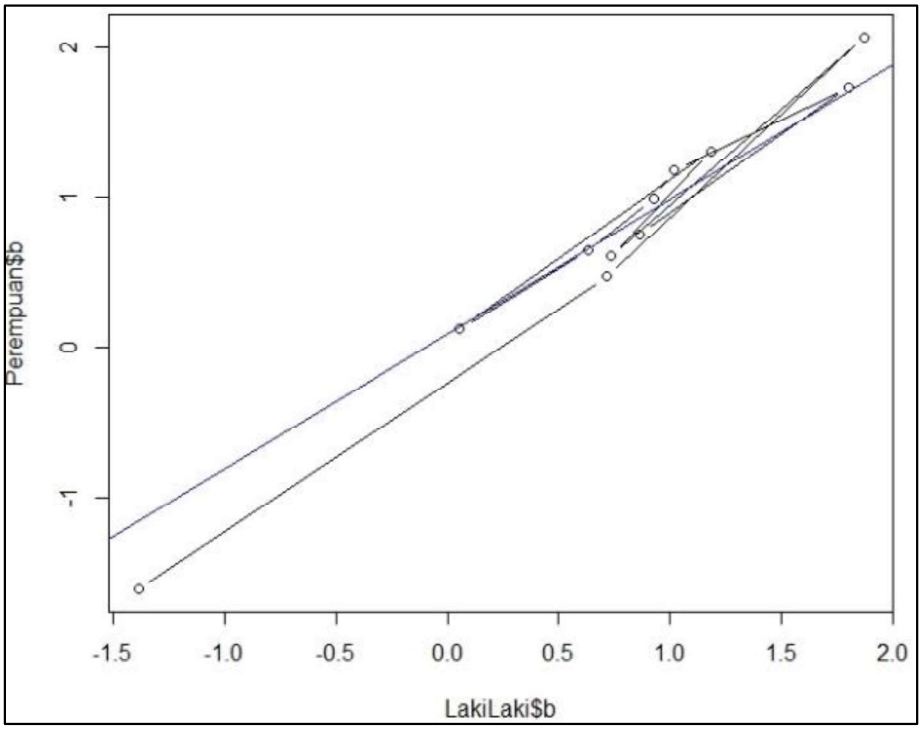

Figure 3. Item Parameter Invariance

Based on the *scatter plot* in Figure 3, it can be seen that there is no variation in the level of difficulty based on sex in the numeracy ability instrument. This proves that the level of difficulty estimated based on the group of men is almost the same as the level of difficulty estimated based on the group of women. This can be seen from the scores of male and female students are around a straight line, meaning that gender does not affect the variance of student scores in doing numeracy ability test instruments.

Analysis of item characteristics is carried out with the help of the R program. Dichotomus and polytomus data in the R program can be analyzed simultaneously. Dichotomus data were analyzed using the Rasch/1PL IRT model, while polytomus data were analyzed using the *Partial Credit Model* (PCM) model. This item characteristic analysis only looks at the difficulty level of the item so it uses a mixed model of the Rasch/1PL model and *the Partial Credit Model* (PCM) model.

The results of the analysis using the R program will produce item parameter estimates (difficulty level), model fit estimates (*fit model*), *Item Characteristic Curve* (ICC), *IFF,* SEM, and capability estimates. The data analyzed at this stage contained 20 items that had been proven valid in content and construct, namely 8 multiple-choice items, 3 short-fill items, 3 matchmaking items, 3 complex multiple-choice items, and 3 description items.

IRT analysis begins by looking at the *fit* model which means that the item is in accordance with the model used or the item can consistently function normally in making measurements according to the model used. The results of the model fit analysis are used to eliminate items that do not match the model used. Items that do not fit or do not fit indicate that there is a respondent's misconception of the item being tested. The fit model test *is* not suitable if it is based on *chi square values* because it will tend to reject if the sample is large (Hooper, Couglan, &; Mullen, 2008: 57). The *chi square* value is very sensitive to the sample size. The *chi square value will increase and lead to model rejection, if the number of samples is above 200 then* the chi square value will continue to rise so that there is a tendency to reject the null hypothesis (Haryono, 2016: 66). Model fit tests in addition to using *chi square* values can also be done by looking at the *infit value* to see the quality of items (Fisher, 2007: 1095).

The decision-making criterion for model fit using *infit is if* the infit value has a value ranging from 0.77 to 1.30 (Fisher, 2007: 1095). The study of infit decision criteria *is reinforced by (Keeves &; Alagumalai, 1999: 36) stating that the suitability of the model follows the rule that* the Item Characteristic Curve *(ICC) will be flat if* the *infit* value for the item is greater than 1.30 or less than 0.77. This, reinforced by (Adams & Khoo, 1996: 30) the item will be said to match or *fit* with the model used if the *infit value* ranges from 0.77 to 1.30. The results of the R-program-assisted model fit analysis can be seen in Table 3.

Table 3. Numeration Capability Model Fit Analysis Results

Items	Infit	Fit Model	Items	Infit	Fit Model
1	1,024	Fit	11	0,958	Fit
2	0,898	Fit	12	0,991	Fit
3	0,991	Fit	13	0,919	Fit
4	0,952	Fit	14	0,929	Fit
5	0,997	Fit	15	0,951	Fit
6	0,972	Fit	16	0,956	Fit
7	0,986	Fit	17	1,034	Fit
8	1,009	Fit	18	0,879	Fit
9	0,864	Fit	19	0,894	Fit
10	0,937	Fit	20	0,955	Fit

Based on Table 3, overall it can be seen from the *infit* value it can be concluded that the overall items used, namely 20 items analyzed using a mixture of Rasch and PCM models, it is proven that 20 items match or fit the model and can be used at the measurement stage.

The estimated parameter analyzed in this study is the difficulty level of the item (b). Test items can be tied well if the difficulty level of the item is in the interval -2.0 to 2.0 logit scale (Hambleton &; Swaminathan, 1985: 36). The characteristic curve of item 3 can be seen in Figure 4 of the items analyzed with a mixed model.

Dichotomous data is applied to the Rasch model with the parameter of the analyzed item is the difficulty level (b) and for the Rasch model the difference power parameter of all items is considered the same, namely 1 which affects all ICCs having the same slope. Analysis of item parameter estimation with the help of the R program for item parameter data from the analysis of the Rasch/1PL mixed model and the *Partial Credit Model* (PCM) model is presented in Table 4.

Based on Table 4, we can see the estimated parameters of the Rasch/1PL mixed model and the *Partial Credit Model* (PCM) model. The interpretation of the item characteristic curve for the dichotomus data in

Figure 12 is that the minimum probability required of the student answering correctly from an item is 50% or 0.5. Suppose that the PG_3 item for a dichotomous item such as Figure 4, the difficulty level can be estimated

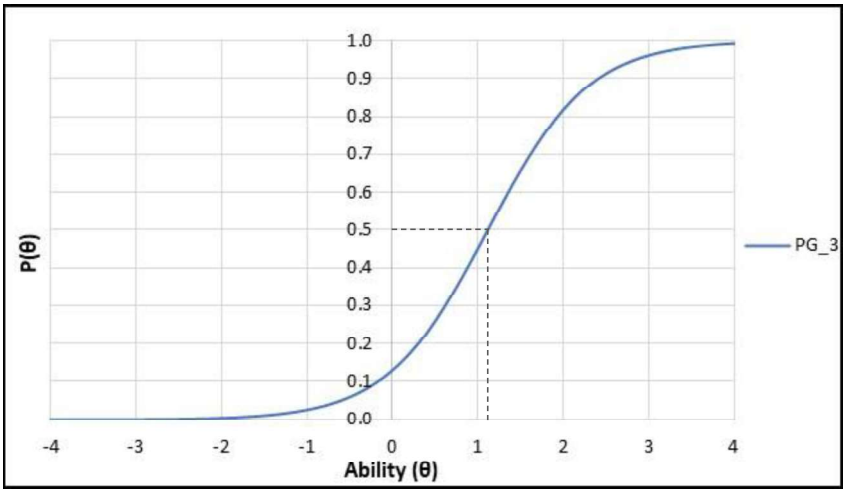

Figure 4. Item Characteristic Curve (ICC) Dichotomus Item PG_3

Table 4. Item Characteristic *Curve* (ICC) Numeration Capability

Items	***a***	***b***	b_1	b_2	**IRF**
PG_1	1,000	0,794	NA	NA	0,794
PG_2	1,000	1,762	NA	NA	1,762
PG_3	1,000	1,114	NA	NA	1,114
PG_4	1,000	0,962	NA	NA	0,962
PG_5	1,000	0,642	NA	NA	0,642
PG_6	1,000	0,100	NA	NA	0,100
PG_7	1,000	1,257	NA	NA	1,257
PG_8	1,000	0,658	NA	NA	0,658
IS_1	1,000	1,985	NA	NA	1,985
IS_2	1,000	0,565	NA	NA	0,565
IS_3	1,000	-1,519	NA	NA	-1,519
Men_1	1,000	NA	-2,147	1,685	-0,231
Men_2	1,000	NA	-1,360	0,531	-0,415
Men_3	1,000	NA	-1,291	1,328	0,018
PGK_1	1,000	NA	-0,626	-0,018	-0,322
PGK_2	1,000	NA	-0,589	0,811	0,111
PGK_3	1,000	NA	-1,505	0,737	-0,384
U_1	1,000	NA	-1,733	1,638	-0,047
U_2	1,000	NA	-0,254	0,139	-0,057
U_3	1,000	NA	-0,997	1,324	0,163

by drawing a straight line from P (θ) at a probability value of 0.5 to the right until it meets the curve, then drawn a straight line down which is the ability of (θ) 1.114. This means that it takes 1.114 abilities to correctly answer PG_3 item with a probability of 50%.

The interpretation of the item characteristic curve for the polytomus data in Figure 5 was analyzed using PCM which means that a high category score indicates greater ability than a lower score. This means that increasing the score requires certain abilities with a *threshold* or minimum ability or *step* parameter applies $b_1 < b_2 < b_3 < \ldots < b_n$. PCM analysis considers each category as a parameter step that students must pass to reach the correct answer. Polytomus curves will show the intersection between curves which are often referred to *as step* parameters and also as minimum opportunities and abilities (Saepuzaman *et al*, 2022:

273). Items with polytomus scores for numeracy instruments using 3 categories, namely 0, 1, and 2, will produce the step parameter $(b_1 < b_2)$.

Figure 5. Item Characteristic Curve (ICC) Polytomus Item Men_3

Table 4 shows that all polytomus items show b_1 and b_2 are increasing sequentially. The interpretation of the item characteristic curve for polytomus data will be given an example of Men_3 item as in Figure 5 showing the difficulty index of the step parameter shown through the intersection of the curve. For example, the intersection point between P1 and P2 represents the minimum opportunity and ability or can be said to be the first step parameter (δ) and the *intersection point between P2 and P3 represents the minimum opportunity and ability or can be said to be the* second step b_1 parameter (b_2). Figure 5 shows that the *step* 1 parameter is -1.291 and *the step* 2 parameter is 1.328. This means that students have a chance to score 1 if they have a minimum ability of -1.291, less than -1.296 then the greatest chance of getting a score of 0. In addition, the chance to get a score of 2 students must have a minimum ability of 1,328.

The item difficulty range for dichotomus data and polytomus data will be viewed through IRF to determine the difficulty level location index. IRF analysis is useful for looking at a single index for polytomus items (Ali, Chang, & Anderson, 2015: 2). Rasch/1PL mixed model and *Partial Credit Model (PCM*) model, so it is necessary to know the single index of difficulty level in PCM.

IRF has a more precise basis for representing the difficulty of the polytomus item as a whole. A single index using IRF also considers the item information function. Each test item has its own IRF value. The use of IRF can provide accurate information for each item. IRF can also be used to determine the difficulty level of an item, as well as IRF hypothetically has values ranging from $-\infty$ up to $+\infty$ (Gregory, 2000: 108). An item can be good if it has an item difficulty value ranging between -2 and +2 (Hambleton, Swaminathan, & Rogers, 1991). If viewed from the IRF results, it can be concluded that all items have a good level of difficulty.

The ability estimates of 599 students obtained from *the* R program output are presented on a logit scale between -4.0 to 4.0 Appendix 7e. The categorization of students' numeracy abilities is carried out using the normal distribution. The results of estimating student ability will be converted first into standard scores because they are closely related to follow-up actions in numeracy assessment. The logit scale resulting from the estimated ability to use MLE will first be converted into a scale of 0 to 100 for easy interpretation. The conversion results will be divided into four categories suggested by the Pusmenjar of the Ministry of Education and Culture, namely Proficient, Cakap, Basic, and Need Special Intervention (Ministry of Education and Culture, 2020: 29). The results of estimating students' numeracy ability after conversion can be seen in Table 5.

Table 5. Estimation of Student Numeracy Ability

Estimation Numeration Ability	**Category**	**Sum**	**(%)**
$X \geq \overline{x} + 1,5SB$	Skillful	36	6
$\overline{x} \leq X < \overline{x} + 1,5SB$	Clever	139	23
$\overline{x} - 1,5SB \leq X < \overline{x}$	Basis	390	65
$X \leq \overline{x} - 1,5SB$	Need Special Intervention	34	6
Sum		**599**	**100**

Based on Table 5, it shows that the numeracy ability of junior high school students in Pekalongan Regency ranges from 26.1605 to 77.5433 with an ideal average of 51.8519. The numeracy ability of junior high school students in Pekalongan Regency shows that there are 36 students out of 599 students classified as proficient with a percentage of 6%, 139 students out of 599 students classified as proficient with a percentage of 23%, 390 students out of 599 students classified as basic with a percentage of 65%, and 34 students out of 599 students classified as needing special intervention with a percentage of 6%.

The validity and reliability of instruments based on the IRT approach can be seen through the value of the information function and the *Standard Error of Measurement* (SEM). The function of measurement result information is very important in suckling instruments. The information obtained can be used to select items or can provide information regarding the strength of the item in measuring latent capabilities to be used according to its measurement purpose. In addition, through the results of the information function can also be known *Standard Error of Measurement* (SEM) or errors in measurement. The SEM value can be obtained from the inverse square root of the information function. The curves of the information function and SEM will intersect each other as shown in Figure 6.

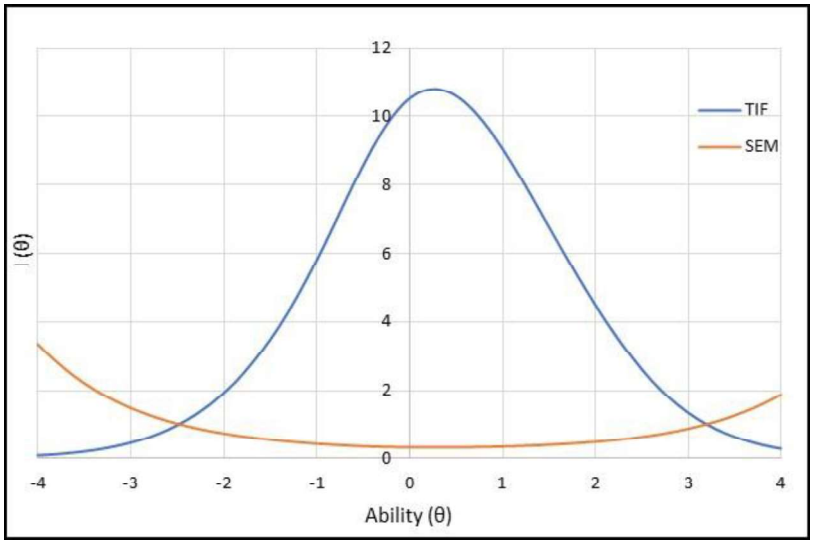

Figure 6. Information Function Curves and SEM

Based on Figure 6, the maximum value of the numeracy ability test information function is 10.503 (θ) at 0.0 and SEM at 0.308. A good or reliable test instrument when the *Total Information Function* (TIF) value is $\geq$ 10 according to Hambleton (in Wiberg, 2004). This means that the instruments used include good and reliable instruments to measure students' numeracy abilities based on the results of the R program analysis. In addition, there is an intersection of information function curves and SEM intersecting at θ = -2.4 and 3.2 which means that the instrument is very suitable or will provide accurate information or greater than Standard *Error Measurement* (SEM) from the left intersection to the right intersection or it can be said that the numeracy ability instrument will be reliable and provide accurate information if given to students who have the ability =

θ -2.4 to = θ 3.2. This range shows that the numeracy ability instrument is able to measure students' abilities with a fairly wide range.

Conclusion

Based on the results of the analysis, it can be concluded that the construction of numeracy ability instruments for grade VIII State Junior High School students, is related to the content of algebra, numbers, geometry, and measurement, as well as data and uncertainty. In addition, it uses personal, socio-cultural, and scientific contexts, using cognitive levels of understanding, application, and reasoning. The quality of the numeracy ability instrument is declared valid and reliable, and the construct validity of all items is fit as seen from the *Loading Factor Standardized Solution* value of more than 0.3 and *p-value* < 0.05 as well as high category reliability and estimated item characteristics show that the question items are included in the category both in terms of difficulty. The numeracy ability of junior high school students in Pekalongan Regency shows that there are 36 students out of 599 students classified as proficient with a percentage of 6%, 139 students out of 599 students classified as proficient with a percentage of 23%, 390 students out of 599 students classified as basic with a percentage of 65%, and 34 students out of 599 students classified as needing special intervention with a percentage of 6%.

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Ihda Mutimmatul Fitriyah
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: ihdamutimmatul.2021@student.uny.ac.id

Heri Retnawati
Yogyakarta State University (Universitas Negeri Yogyakarta), Jl. Colombo No. 1, Indonesia
E-mail: heri_retnawati@uny.ac.id
https://orcid.org/0000-0002-1792-5873

Analysis of the distractor of the multiple-choice test using classical test theory (CTT) and item response theory (IRT)

Abstract: This study aimed to analyzed the functional distractor based on the results of the multiple-choice test using CTT and IRT. Data obtained mathematics test at one of the junior high schools (grade 7) in Sidoarjo in the 2021-2022 academic year. The test consists of 20 items, which are a collection of questions that have been standardized in the school curriculum. One hundred examinees attending this mathematics test. The analysis used Iteman 4.3 software for analysis distractor using CTT, and R program for analysis pseudo-guessing's parameter using 3PL IRT model. The result showed that all items have distractors well function it (Prop. > 0,05) in CTT. Meanwhile, with IRT, 8 of the 20 questions were not good because the pseudo-guessing index was > 0.25. The result of this study provided important information for future study to examine the ability estimate when a test's fixed feature is the item-specific characteristic utilized for pseudo-guessing.

Keywords: Distractor, Pseudo-guessing, classical test theory, item response theory.

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Introduction

Multiple choice tests are the most popular test of educational assessment. According to Bolt et al. (2020), multiple-choice tests become a mainstay in an assessment system despite their known limitations. It can happen because multiple-choice tests are easy to score, and offer increased accuracy, reliability, and objectiveness in the assessment process (Becker & Johnston, 1999; Romm et al., 2019; Suseno, 2017; Tangianu et al., 2018; Tarrant & Ware, 2012; Walstad & Becker, 1994; Stepanova et al., 2018). Rodriguez (2016) revealed multiple-choice tests are efficient to administer and take a relatively short time when used for research. Then, Gierl et al. (2017) stated that the most effective, long-lasting, and economical form of assessment is a multiple-choice test.

Multiple choice tests are often used to measure a person's cognitive abilities (Carretta & Ree, 2018; Edwards et al., 2012), both in formative assessment or summative assessment, as well as in school, college, or general such as civil servant selection. Siegfried and Wuttke (2019) also reported that the multiple-choice format is most widely used in college to measure students' cognitive performance. Gierl et al. (2017) revealed that the application of multiple-choice tests for international assessment is PISA and Trends in International Mathematics and Science Study (TIMSS). Therefore, apart from being a popular form of questioning on a national and international scale, multiple-choice tests are also a mainstay in various contexts.

Based on the construct, multiple-choice items consist of a main question (stem) and a set of answer choices (Papenberg & Musch, 2017; Arlinwibowo et al., 2020). In a set of answer choices, there is a correct answer and the others function as distractors, with the number of distractors intended being one or more. A multiple-choice item can be said to be of high quality if the distractors function well (Papenberg & Musch,

2017). Then, Sajjad et al. (2020) stated that at least 5% of good distractors are selected by the total number of examinees.

In the implementation of multiple-choice tests, teachers often ignore the importance of distractors because constructing them is not easy. Gierl et al. (2017) stated that it took a long time to develop distractors. However, there are still many teachers who choose to use multiple-choice tests. The research results by Efrina et al. (2021), found that teachers prefer to create easy distractors and deviate far from the correct answer option with the aim that students will find it easy to answer questions correctly. Apart from that, teachers should avoid creating difficult distractions because it will make the questions difficult for students to solve. The problems above indicate that there needs to be a habit of self-education to be able to carry out multiple-choice tests by paying attention to the function of distractors.

The function of distractors on a multiple-choice item can be estimated by analyzing the characteristics item. Analysis characteristics items can be carried out using two approaches, namely the classical approach (classical test theory) or the item response theory approach. Classical test theory (CTT) is a theory with a simple mathematical model that shows the relationship between observed scores, actual scores, and measurement error (Mardapi, 2012). CTT is applied in estimating reliability, level of difficulty, discrimination index, distractor function, and measurement error (Retnawati, 2017). CTT is considered widely used because it does not require a large number of respondents (more than 100) and is easy to understand and apply (Argianti & Retnawati, 2020). Setiawati et al. (2023) revealed that for more than 20 years, CTT has been the mainstay standard in the development of psychological tests. Even though there are several advantages to CTT, there are things that make it have limitations.

The CTT limitations can be demonstrated in that actual scores are highly dependent on measurements, and test results cannot be compared. Observed scores and actual scores change depending on the level of difficulty and assessment, so both are very dependent on the results of the student's characteristics being measured, where the observed score is the only score that can be seen while the actual score and measurement error are latent (Otaya et al., 2020). Given these limitations, an item response theory (IRT) approach was applied to overcome the limitations of CTT. IRT is widely used in education, research, and psychological measurement practice (Cai et al., 2023). In IRT, the latent trait being measured is called ability (Bahar et al., 2021; Hambleton & Swaminathan, 1985). There must be several equation models involved in the interaction between ability and item parameters. The process of estimating item parameters and abilities can be done directly through the use of the Bayes technique or the maximum likelihood method (Retnawati, 2017).

Item parameters in IRT can be estimated if statistically the model used statisfied the assumptions (Hambleton & Swaminathan, 1985; Santoso et al., 2022). The assumptions are namely unidimensional, local independence, and parameter invariance. This must be fulfilled if an IRT analysis is to be carried out. If the assumptions not statisfied, then the analysis carried out is CTT. Fulfillment of the assumptions is based on the quality of the instrument being tested; therefore, a test developer must have good knowledge so that the questions produced are also good in terms of content quality.

IRT models can be classified in different ways according to the number of response categories. such as Rasch, 1 Parameter Logistic Model (1PL), 2PL, 3PL, and 4PL for dichotomous data; Nominal Response Model (NRM), Partial Credit Model (PCM), Generalized Partial Credit Model (GPCM), and Graded Response Model (GRM) for polytomous data (Can Aybek, 2023). Meanwhile, the item parameters resulting from IRT analysis are namely level of difficulty (b), discrimination (a), pseudo-guess (c), and others. Both CTT and IRT analysis can estimate the functioning of distractors; in IRT, it is called pseudo-guessing, where pseudo-guessing's parameter represents the probability of examinees whose abilities are at a low level to be able to answer item i correctly.

The results of research by Huriaty (2016), which analyzed the characteristics of junior high school mathematics tests in the form of multiple-choice questions using IRT 3PL, In the analysis, the Bilog program was assisted, but the 3PL analysis was carried out directly without testing assumptions. The pseudo-guessing estimation results show that the items tested all have good pseudo-guessing indices. Starting from this research, this research will expand and complete previous studies, where the focus of this research is only on distractor parameters whose results want to be synthesized using two approaches, namely CTT and IRT. For IRT, before it is carried out, it is ensured that the assumption test has been met. Meanwhile, for CTT, use the Iteman Program. Thus, this study aims to analyze distractor parameters in multiple-choice tests using CTT and IRT.

Research Methods

***Design and data source*.** This research is a descriptive study with a quantitative approach. The data source is the results of the grade 7 th mathematics test at one of the junior high schools in Sidoarjo in the 2021-2022 academic year. The test consists of 20 items, which are a collection of questions that have been standardized in the school curriculum. School have their own references regarding materials for each semester, they still look at the core competencies-basic competencies (KI-KD) that have been set by the government. These questions consist of 6 items on integers and fractions, 7 items on sets, and 7 items on ratios of two quantities and comparisons. The research was carried out online with the Zoom meetings via Google Form, directly supervised by the mathematic's teacher. A total of 100 students attending this mathematics test.

Data analysis. In accordance with its purpose, this study analyzed the functional distractor based on the results of the mathematics multiple choice test using CTT and IRT. Therefore, data analysis was generally carried out in several stages. First, for CTT, the distractor estimated using Iteman Program (version 4.3), where the results are obtained by looking at the proportion column. Second, the IRT model assumption can fulfill three criteria. They include unidimensional, local independence, and parameter invariance (Retnawati, 2014). Third, estimated the pseudo-guessing parameter (c) with the model fit IRT between 3-PL and 4-PL model. It was used because of its dichotomous scoring, which consists of two categories: the correct answer with a score of 1 and the incorrect answer with a score of 0 (Isnani et al., 2019), also both of that models pseudo-guessing's parameter are estimated. To help analyzed the data, the R program was utilized with the 'mirt' package. The R syntax that we used to estimate under IRT model is available in Appendix 1.

Research Findings and Discussion

***Findings*.** In this section, we report the main findings of this study, namely the distractor of the items based on the estimation using CTT and 3-PL IRT model.

Findings of the Distractor in CTT Approach. In this study, the mathematics multiple choice test used consisted of four options, so that there was one option as the correct answer and three other options as distractors. A distractor is said to function well if it is selected by at least 5% of examinees (see Table 1), and if it does not meet these criteria, then the distractor needs to be revised (Sajjad et al., 2020).

Table 1. Result for The Distractor's Estimation Using Iteman

Item Number	Options			
	A	B	C	D
	Prop.	Prop.	Prop.	Prop.
Item 01	0,1	0,13	0,71*	0,06
Item 02	0,3	0,53*	0,11	0,06
Item 03	0,15	0,45*	0,21	0,19
Item 04	0,15	0,19	0,15	0,51*
Item 05	0,1	0,32*	0,5	0,08
Item 06	0,28	0,2	0,45*	0,07
Item 07	0,1	0,35*	0,47	0,08
Item 08	0,11	0,13	0,66*	0,1
Item 09	0,19	0,14	0,51*	0,16
Item 10	0,09	0,16	0,42	0,33*
Item 11	0,15	0,45*	0,35	0,05
Item 12	0,42*	0,23	0,23	0,12
Item 13	0,28*	0,26	0,18	0,28
Item 14	0,16	0,26	0,45	0,13*
Item 15	0,22*	0,34	0,27	0,17
Item 16	0,1	0,15	0,66*	0,09
Item 17	0,17	0,42	0,24*	0,17
Item 18	0,5*	0,25	0,18	0,07
Item 19	0,09	0,33*	0,4	0,18
Item 20	0,52*	0,21	0,18	0,09

*The correct anwer

Table 1 shows that the distractors from the 20 question items have an answer proportion of 5% to 47%. This is in accordance with the criteria for distractor functioning, namely that distractors are said to function well if they have a minimum proportion of 5%. The distraction, which has a proportion of 5%, is only in one question item, namely item 11.

Findings of the Analysis of IRT Model Assumptions. The first assumptions that has to be statisfied in IRT is the assumption of unidimensional which requires that the mathematics multiple choice test only measure one dominant factor. This can be demonstrated through factor analysis and principal components by considering the eigen value, total variance explained, and the scree plot. The factor analysis can be carried out if qualify the sample adequacy by The Kaiser-Meyer-Olkin (KMO) more than 0,5. The KMO of the mathematics multiple choice test (KMO = 0,540) showed that the sample size has statisfied adequacy for factor analysis. The eigen value for the principal component of 3,038 with the explained variance 15,191%. Scree plot (see Figure 1) shows that there is a steepness from the principal component to two components, for more component it starts to slope, indicates that test is unidimensional.

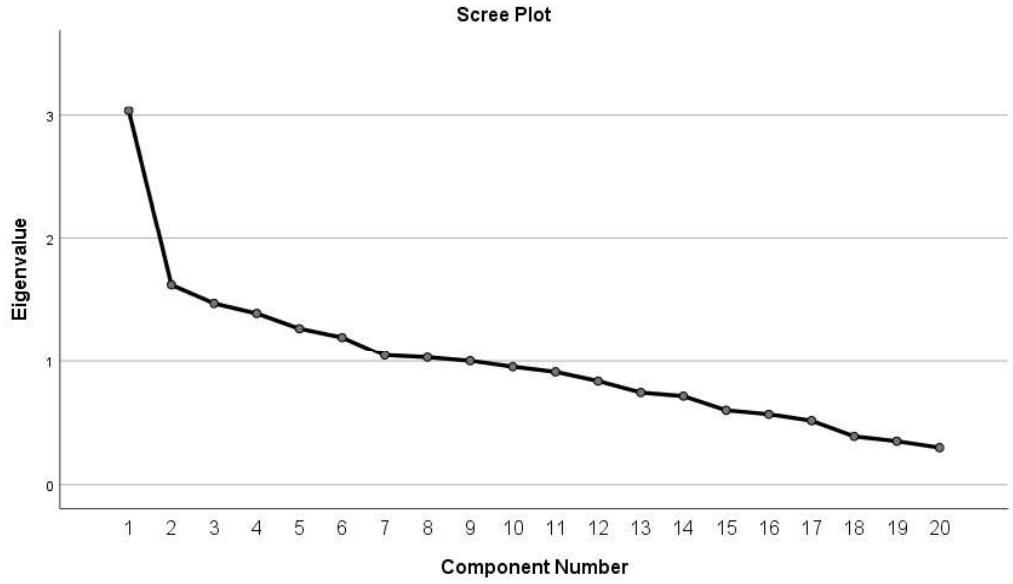

Figure 1. Scree Plot for Unidimensional Assumption

The second assumptions underlying IRT is local independence. This assumption requires that the student's response to an item is independent of his response to other items. Retnawati (2014) stated that local independence automatically fulfilled if the unidimensional assumption is statisfied. Cause the unidimensional assumption test has been proven, so the independence local assumption has also statisfied. The last IRT assumption that we need to show that is parameter invariance. There are two parameters need to prove, namely the item parameter and the person parameter.

The item's parameter invariance is proven by estimating item difficulty for students who take the test by being grouped into two different subgroups based on an even absence and an odd absence. Meanwhile, the person's parameter invariance is proven by estimating student's ability from a subset of items in odd order and a subset of items in even order. The scatter gram showing the distribution of the estimated results for each item's parameter invariance and person's parameter invariance (see Figure 2 and Figure 3). Retnawati (2014) stated that there are dots on a scatter gram (approaches the line that passes through the origin with a gradient of 1). It can be assumed that the item parameters and person parameter are invariance.

Based on Figure 2 and Figure 3, each data has a position relatively close to the line that passes through the origin with a gradient of 1, so that the item parameters and person parameters are invariant. Based on the results above, the three IRT assumptions have been statisfied, so the estimation of item parameters can be continued with 3PL model.

Findings of the Pseudo-guessing's Parameter in IRT Approach. First, determine the fit model between 3PL and 4PL, because both of that model the pseudo-guessing's parameter can be estimated. Basically, model fit can be determined by estimating examinees patterns to the items (Zi Yan & Heene, 2021). Determining the

model fit in this research used Akaike's Information Criterion (AIC), Sample size Adjusted BIC (SABIC), and Bayesian Information Criterion (BIC) values (see Table 2). Data fit the model if these three values are smaller than other IRT models (Djidu et al., 2022).

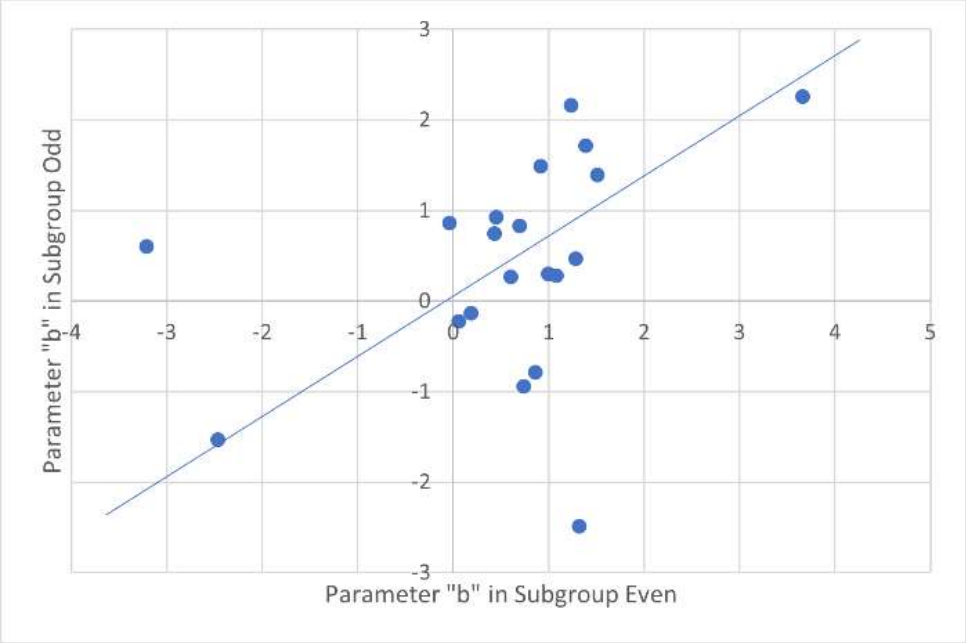

Figure 2. The Scattergram Showing the Distribution of Item Difficulty Estimated from a Subset of Students in Even Absences and Odd Absences

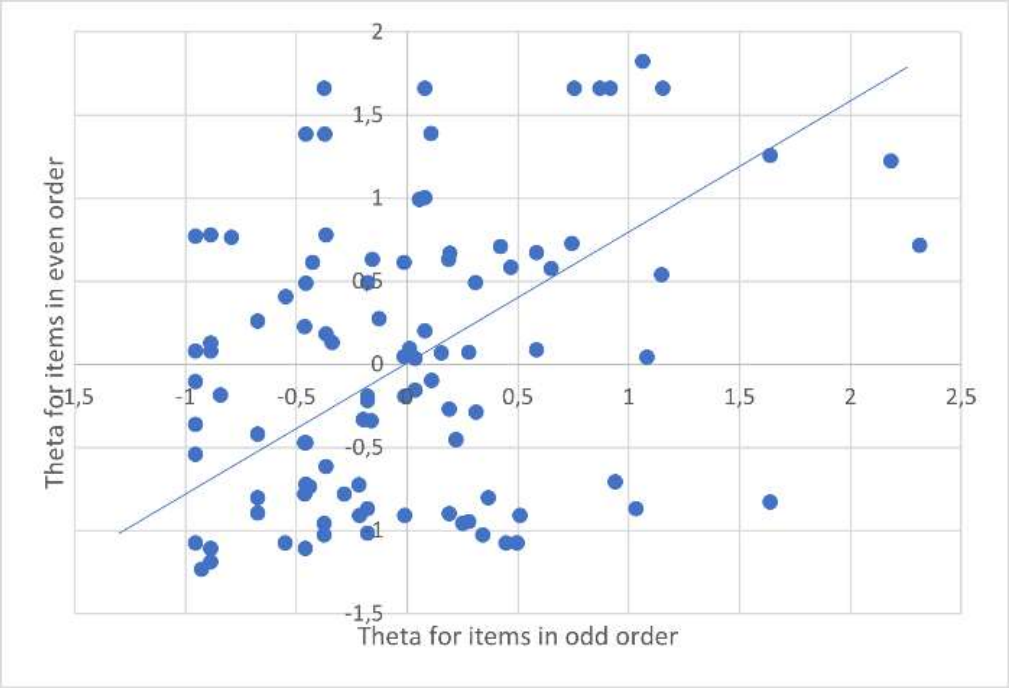

Figure 3. The Scattergram Showing the Distribution of Student's Abilities Estimated from a Subset of Items in Odd Order and Even Order

Table 2. The Model Fit Estimation from The Result of The Mathematics Multiple Choice Test

IRT Model	AIC	SABIC	BIC
3-PL	2520,779	2487,594	2677,089
4-PL	2539,497	2495,250	2747,910

Table 2 shows that the AIC, SABIC, and BIC of 3PL model smaller than 4PL model. It concludes that 3PL model used for further analysis. 3PL model produces three parameters that can be estimated, namely discrimination (a), difficulty (b), and pseudo-guessing (c). Because this research focuses on pseudo-guessing's parameter, so the estimation results shows in Figure 4 and Table 3.

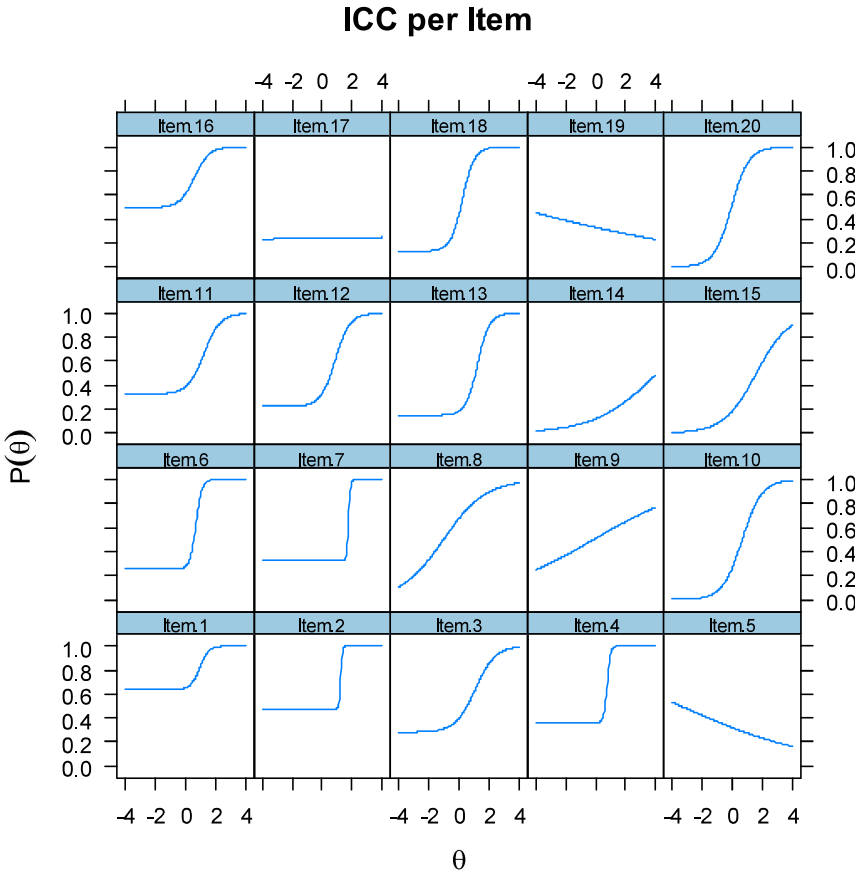

Figure 4. Item Characteristics Curve from The Items

Table 3. The Pseudo-guessing's Parameter Using 3-PL Model Analysis

Item Number	Pseudo-guessing's Parameter	Item Number	Pseudo-guessing's Parameter
Item 01	0,636	Item 11	0,327
Item 02	0,474	Item 12	0,222
Item 03	0,280	Item 13	0,150
Item 04	0,361	Item 14	0,000
Item 05	0,000	Item 15	0,000
Item 06	0,252	Item 16	0,494
Item 07	0,326	Item 17	0,006
Item 08	0,001	Item 18	0,132
Item 09	0,001	Item 19	0,034
Item 10	0,000	Item 20	0,002

Pseudo-guessing's parameter represents the probability of examinees whose abilities are at a low level to be able to answer item i correctly, or the lower asymptote of the ICC of item i. According to Allen & Yen (1979), the pseudo-guessing index is no more than 1/k (*k* being the number of options). Because in this test the number of options is 4, so the apparent pseudo-guessing index is expected to be no more than 0,250. Table 3 shows that the pseudo-guessing index is in the range of 0,000 to 0,634. Eight items (item 01, item 02, item 03, item 04, item 06, item 07, item 11, and item 16) have a pseudo-guessing index of more than 0,250. This indicates that an examinee who has an ability of 0 has a chance of answering correctly (each of the eight items) above 0,250. These results show that the eight items not in good criteria and need to be corrected for the

distractor options. Because the criteria for a good item is that examinees with an ability of 0 should have a chance of guessing the answer correctly with a low value, namely below 0,250, Meanwhile, the other 12 questions already have a pseudo-guessing index of more than 0.250.

Research Discussions

Multiple choice test might be regarded as a popular item types in educational assessment. However, in a test with multiple choice items, some examinees may guess a correct answer (guessing effect). The findings of this study reveal that identifying distractor function can be estimated using two approaches (CTT or IRT). Estimation using IRT can be analyzed if three assumptions have been statisfied, if it is not been statisfied so estimated using CTT. Estimating the effectiveness of distractors with CTT uses the proportion of examinees who answered correctly out of the total examinee for each distractor option. Estimation using this approach is very profitable because it can be identified which distractor options are less functional, so that improvements are only made to the problematic distractor options. This is in line with Fiska et al. (2021) which stated that the effectiveness of the distractor functions in determining the effectiveness of the distractor in carrying out its measuring function and distinguishing between students who understand the concept and those who do not understand the concept. The estimation results show that students do not fully understand the concepts of the mathematics material being tested. In the IRT approach, distractors are termed pseudo-guessing's parameters. Students guess the answer and are correct; in IRT, this is a problem, especially for students with zero (0) ability who should have difficulty guessing the correct option. In contrast to the estimates obtained with CTT, in this IRT, eight of the 20 questions had a pseudo-guessing index below the criterion. This needs to be reviewed again with the existence of these eight questions, so it is indicated that the eight questions have easy difficulty or that distracting options were made at a low level without considering what errors could occur when students choose distracting options. This study was limited to analysis the distractor using two approaches namely CTT and IRT. Furthermore, other item parameters are not estimated, so it cannot be generalized whether the items tested are items with good characteristics or not. Further study, it is recommended to compare the ability estimation when the pseudo-guessing's parameter is item-specific and it is a fixed characteristic of a test. And also, for future research must carry out distractor's analysis on mathematics test with the material is general, so that the result can be generalized.

Conclusion

The findings of this study provide that there is an unfunctional distractors of the mathematics multiple choice test using 3PL IRT model, but for CTT all the distractors have a good function. These findings confirm that between CTT and IRT have a different results estimation but both of these can be used to identify which items must be repaired for get more qualified items of mathematics multiple choice test. For further study, it is recommended to compare the ability estimation when the pseudo-guessing's parameter is item-specific and it is a fixed characteristic of a test. And also, for future research must carry out distractor's analysis on mathematics test with the material is general, so that the result can be generalized.

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Rina Safitri
Graduate Program
Universitas Negeri Yogyakarta, Indonesia
E-mail: rinasafitri455@gmail.com
ORCID ID 0000-0003-0003-8474

Rugaya Tuanaya
Graduate Program
Universitas Negeri Yogyakarta, Indonesia
E-mail: rugayatuanaya.2021@student.uny.ac.id
ORCID ID 0000-0002-1010-7026

Syahri Ramadan
Graduate Program
Universitas Negeri Yogyakarta, Indonesia
E-mail: syahriramadhan@uny.ac.id
ORCID ID 0000-0001-9801-0861

Heri Retnawati
Mathematics and Science Faculty
Universitas Negeri Yogyakarta, Indonesia
E-mail: heri_retnawati@uny.ac.id
ORCID ID 0000-0002-1792-5873

Trends and Network Analysis of Data Literacy in Various Fields: Bibliometric Analysis

Abstract: Data literacy has emerged as a key aspect in meeting the challenges of the evolving digital age. However, existing bibliometric analyses related to this topic are scarce. To fill the gap, this study uses a bibliometric approach to conduct a comprehensive review spanning nearly seven decades in order to assess the research landscape, progress, and emerging trends in data literacy. This article presents a new review of scientific production through an in-depth bibliometric analysis of the Scopus database using two software packages namely VOSviewer and RStudio. The article presents a synthesis of 2896 peer-reviewed articles from 1956 to 2023. Using keyword and co-occurrence analyses to identify key trends and relationships in research on this topic. Researchers highlighted the most researched concepts and the most important relationships between different publications. The analysis process was conducted by presenting the publication time, disciplinary area, scientific publications on data literacy, prolific authors, most cited publications, productive scientific countries, and keyword co-occurrence analysis on this topic.

Keywords: Bibliometrics, data literacy, scientific research.

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Introduction

One of the basic literacies supporting the 21st century is data literacy (Pratama et al., 2020; Kassymova et al., 2019). Data literacy has emerged as a key aspect in facing the challenges of the evolving digital era. Data literacy includes the ability to collect data (Zhang et al., 2019; Stepanova et al., 2018), understand data (Carlson et al., 2013), explain data (Swan et al., 2013), identify, interpret, and implement data (Mandinach & Gummer, 2013), communicate and evaluate data (Huang et al., 2022), use data (Prado & Marzal, 2013), analyze data (Dichev & Dicheva, 2017), and manage data (Li et al., 2019).

According to Venture Beat (2014) in Gray et al. (2018) data literacy will be the most important new skill of the 21st Century and refers to the development of capacities and technologies to help companies, countries, and citizens make the most of their data. Some argue that "competence in finding, manipulating, managing and interpreting data" should be "an integral aspect of every business function and activity" (Harris, 2012). Others warn of a data literacy deficit and predict a shortage of millions of "data-savvy managers and analysts" (Manyika et al., 2011). It can be concluded that effective data literacy is not only an important skill in the world of business and science, but has also penetrated into many other fields, including education, health, technology, and the general public. Data literacy is also a new addition to the growing group of literacies such as numerical literacy, statistical literacy, and IT literacy (Frank et al., 2016).

Interest in data literacy is also shared by many in the public sector and civil society. A report from the UN advocates "global data literacy" to catalyze a "data revolution" for sustainable development (Independent Expert Advisory Group on a Data Revolution for Sustainable Development, 2014). Data literacy is seen as something that enables "change agents" to advance progress toward "the future we want." Data literacy is the intersection of statistical literacy, information literacy, and technical skills for working with data. Research literature on data literacy has experienced rapid growth over the past few decades. From 1956 to 2023, a significant period in technological development and increased access to data, research on data literacy has been in the spotlight in various fields of knowledge.

Research trends in data literacy cover various aspects, including innovative learning methods, evaluation of data literacy levels, the role of data literacy in decision-making, and the relationship of data literacy with technological developments such as Artificial Intelligence (AI) and extensive data analysis. In addition to research trends, the analysis of collaboration networks is also a focus of this bibliometric study. Researchers in various disciplines and institutions have collaborated to explore a deeper understanding of data literacy. Collaboration network analysis will help identify who is involved in data literacy research, how cooperation between researchers evolves, and how research contributions cross disciplinary boundaries.

Bibliometrics is a statistical method of analyzing publications (Phoong et al., 2022; Wang et al., 2021; Zhang et al., 2019). Bibliometrics is the basis for determining the most popular and most significant publications in a particular field (Sa'ed H. Zyoud et al., 2023). Bibliometrics is a research method that has complete information by combining science, mathematics, and statistics in analyzing knowledge quantitatively (Zhang et al., 2019). So, bibliometrics is a statistical method that contains information related to publications used to analyze publications in a particular field.

According to Abouzid et al. (2021), bibliometric research is an important method in analyzing qualitatively and quantitatively publications on certain subjects. According to S. H. Zyoud et al. (2017), in bibliometric research, data analysis is carried out using qualitative and quantitative indices such as publication year, affiliation, document type, country name, subject category, journal name, publisher language, collaboration, and citation pattern.

Over the years, bibliometrics has evolved and become common in analyzing and mapping concepts and knowledge published in many fields (Rana & Pragati, 2022; Zupic & Čater, 2015). Along with information and communication technology, research on data literacy has undergone significant development. Researchers from various disciplines have contributed to understanding the concept of data literacy, effective teaching strategies, and the impact of data literacy in various contexts. Through this bibliometric analysis, it is possible to understand recent developments in data literacy, identify vulnerabilities, and map trends that can guide further development in data literacy. As such, this analysis can provide valuable insights into how we can improve the understanding and use of data literacy in various fields in the future.

This study aims to explore the development of scientific literature related to data literacy over the period 1956 - 2023 and provide a comprehensive overview of trends and collaboration networks in data literacy. With a better understanding of research contributions and collaborative relationships among researchers, we can design strategic measures to face challenges and opportunities related to data literacy in the future.

Research Method

This research is a type of research with bibliometric analysis. Bibliometric analysis is applied to quantitatively measure and analyze certain indicators in the published literature in a particular domain and to generate knowledge maps based on large databases (Hung, 2012; Thelwall, 2008; Zeng & Chini, 2017). Bibliometric analysis in this study was conducted using RStudio and VOSviewer software. Metadata was collected based on the Dimension database in the last 67 years (1956-2023) related to data literacy in various fields.

In this study, VOSviewer was used to analyze, visualize, and evaluate all the information about the publications that had been collected, such as bibliographic pairs of authors, countries, institutions, journals, and co-occurrence of author keywords (Orduña-Malea & Costas, 2021; Oyewola & Dada, 2022; Sovacool et al., 2020; van Eck & Waltman, 2014). The stages in this research can be seen in Figure 1.

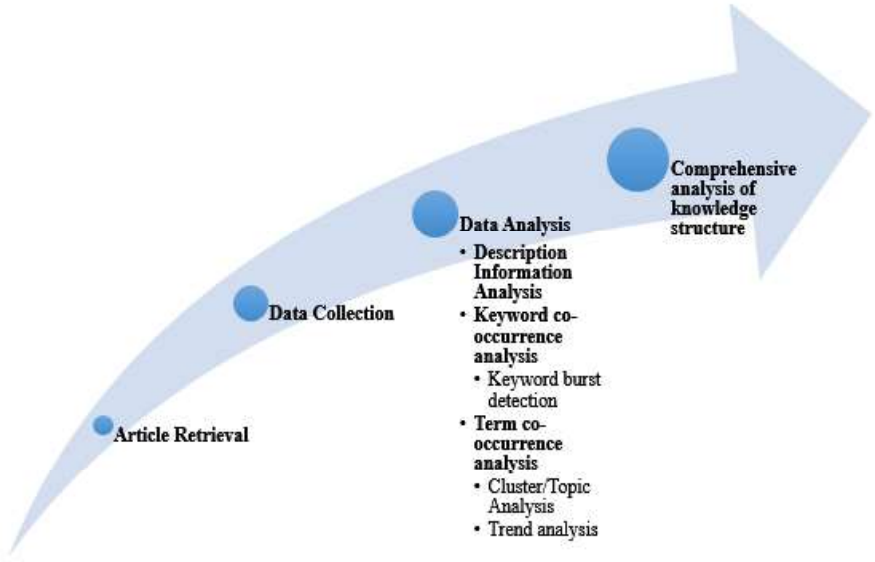

Figure 1. Research Design Framework

Once the data was collected, it was filtered, and 2,896 publications were selected. The entire dataset is available on Scopus.com. Three types of analysis were conducted to analyze and synthesize the data in the following order: (1) keyword co-occurrence analysis, (2) keyword explosion detection, and (3) term co-occurrence analysis. In addition, basic descriptive information analysis was used to categorize publications by year, source of scientific information by journal, discipline area of publication, prolific authors, and highly cited articles.

Specifically, the researcher completed the following series of steps: (1) retrieved relevant research articles from 1956 to 2023 with data literacy search terms; (2) Collected publication data of research titles, authors, keywords, and abstracts on Scopus; (3) Identified descriptive information, such as the distribution of publications by year, disciplinary focus, source, and author, and illustrated the most cited articles; (4) Applying keyword and term occurrence analysis with the help of visualization software such as RStudio and VOSviewer; (5) Detecting keyword bursts that have a high frequency of occurrence within a certain period; and (6) determining research topics and research trends using term cluster analysis from selected article titles and abstracts.

Research Result / Findings and Discussion

Publication Time. Figure 2 describes the number of research articles published by year from 1956 to 2023. Based on the Scopus dataset related to this research, the topic of data literacy first appeared in 1956. Until 2004, there were no publications at all related to the topic of data literacy. The topic then started to be discussed again in 2005-2008 with a very small number of publications, around 1-3 publications on the topic of data literacy. However, based on Figure 2, 2011 was the year when the trend of data literacy began to be discussed frequently in scientific research. Publications about data literacy continued to increase from year to year until the peak in 2022. Six hundred eighty-three publications discussed data literacy.

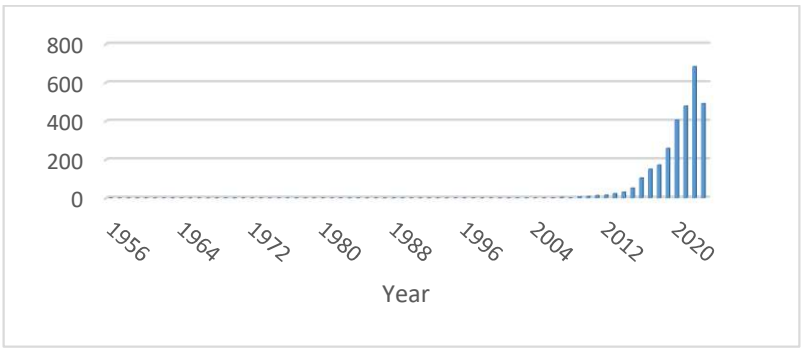

Figure 2. Distribution of Data Literacy Publications on the Scopus Database per Year

Diciplinary Focus. There is much research related to data literacy produced in various disciplines, especially disciplinary fields that include social sciences (43%) and computer science (24%), followed by engineering (7%), business management and accounting (5%), mathematics (4%), arts and humanities (4%), management (4%), pharmacy (4%), psychology (3%) and economics (2%). Figure 3 explains the distribution of literacy data publications in 1956-2023 based on the focus of the discipline as metadata on articles published in the Scopus database.

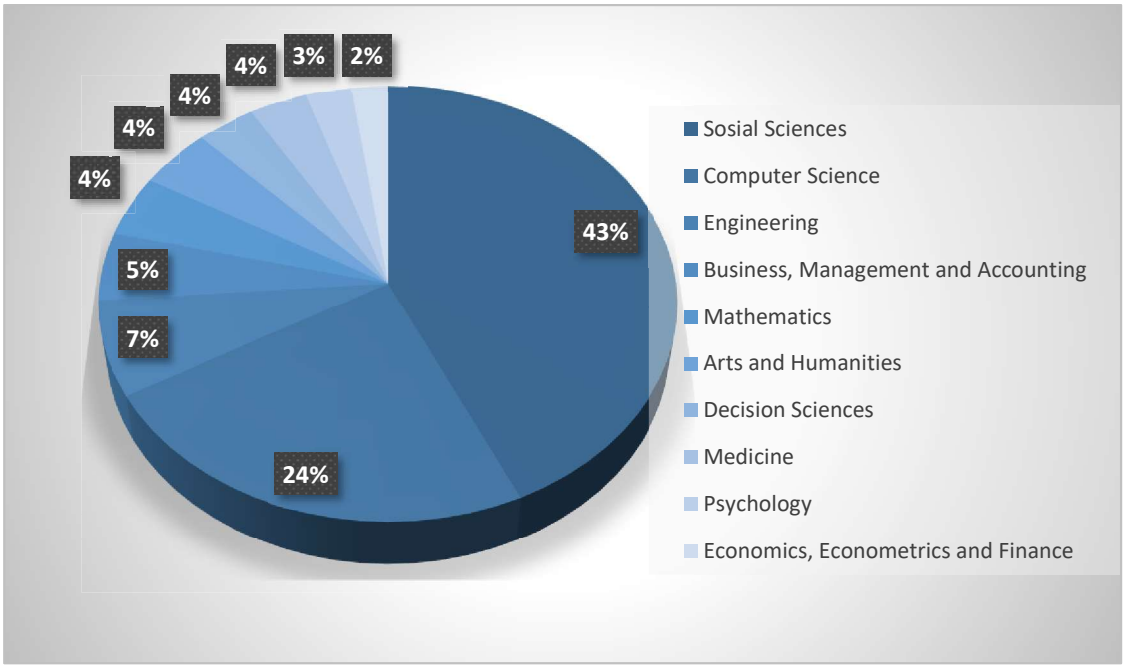

Figure 3. Distribution of Data Literacy Publications 1956-2023 by Disciplinary Fields

Scientific Publications on Data Literacy. Figure 4 shows the distribution of articles published by the top 10 journals from 1956 to 2023 based on the Scopus database. ACM International Conference Proceeding Series and Conference on Human Factors in Computing Systems-Proceedings accounted for 4.73% of the retrieved articles. The journals Communications in Computer and Information Science, Lecture Notes in Computer Science, and Frontiers in Education accounted for 3.18% of all data literacy articles reviewed in this study.

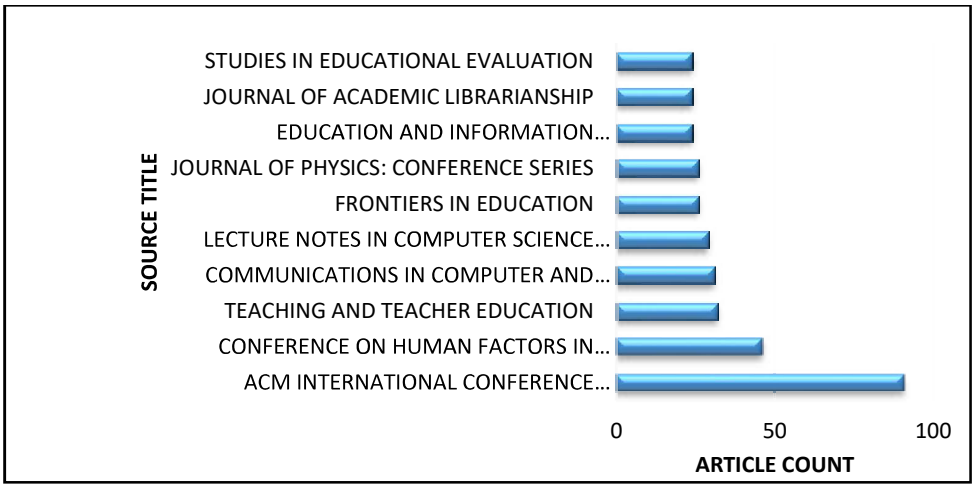

Figure 4. Distribution of Articles by Journal from 1956 to 2023 Based on Scopus Database

Prolific Author. The top five productive authors about data literacy on number of publications and nationality are Schildkamp (29/Dutch), Koltay (19/Hungary), Raffaghelli (15/Spain), Mandinach (14/San Francisco), and Poortman (14/Dutch). The data in this study is based on the Scopus database of 2896 articles specifically used in this study.

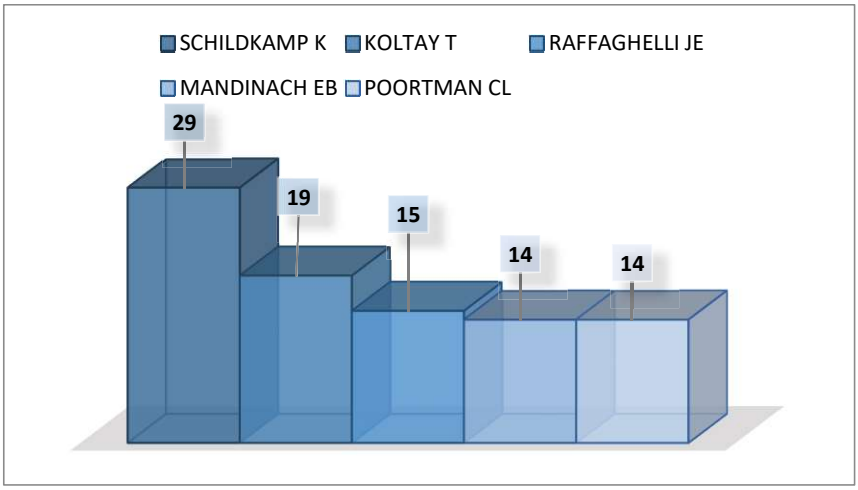

Figure 5. Most Productive Writer

Most Cited Publications. Table 1 shows the top ten cited references, total citations, and average citations per year in the Scopus database collection. The results of the most cited references are consistent with the findings of this study regarding the main disciplinary areas, i.e., for research topics related to data literacy (i.e., computer science and education), journals (i.e., Conference on Human Factors in Computing Systems) and authors (i.e., Mandinach, E. B.).

Table 1. References Cited, Total Citations, and Average Citations per Year in the Scopus Database Collection

References cited	Number of Citations	Average citations/year
Swan, M., (2012). *Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0. Journal of Sensor and Actuator Networks, 1(3), 217–253.*	721	60,08
Clements, D.H., & Sarama, J. (2009). Learning and Teaching Early Math: The Learning Trajectories Approach (1st ed.). Routledge.	298	19,87
Lepri, B., Oliver, N., Letouzé, E. *et al.* Fair, Transparent, and Accountable Algorithmic Decision-making Processes. *Philos. Technol.* **31**, 611–627 (2018).	275	45,83
Long, D., & Magerko, B. (2020). What is AI Literacy? Competencies and Design Considerations. *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*.	252	63,00
Mandinach, E. B., (2012). A Perfect Time for Data Use: Using Data-Driven Decision Making to Inform Practice, Educational Psychologist, 47:2, 71-85	248	20,67
Mandinach, E. B., & Gummer, E. S. (2013). A Systemic View of Implementing Data Literacy in Educator Preparation. *Educational Researcher*, *42*(1), 30–37.	236	21,45
Mihailidis, P., & Viotty, S. (2017). Spreadable Spectacle in Digital Culture: Civic Expression, Fake News, and the Role of Media Literacies in "Post-Fact" Society. *American Behavioral Scientist*, *61*(4), 441–454.	220	31,43
Widén, J., Carpman, N., Castellucci, V., Lingfors, D., Olauson, J., Remouit, F., Bergkvist, M., Grabbe, M., Waters, R., (2015). *Variability assessment and forecasting of renewables: A review for solar, wind, wave and tidal resources. Renewable and Sustainable Energy Reviews, 44(), 356–375.*	217	24,11
Aoun, J. E., (2017). Robot-Proof Higher Education in the Age of Artificial Intelligence	207	29,57
Abbas, J., Aman, J., Nurunnabi, M., & Bano, S. (2019). The Impact of Social Media on Learning Behavior for Sustainable Education: Evidence of Students from Selected Universities in Pakistan. *Sustainability*, *11*(6), 1683. MDPI AG.	206	41,20

State Scientific Productiveness. The results of the analysis of the data literacy dataset from the Scopus database regarding the most productive countries are shown in Figure 6. Countries with the highest number of publications are visualized in dark blue. The fainter the color means that, the fewer the scientific publications in that country. From Figure 6, it can be seen that the United States is the country that has the most scientific publications on data literacy, with a total of 2,120 documents recorded, followed by Germany with 467 documents.

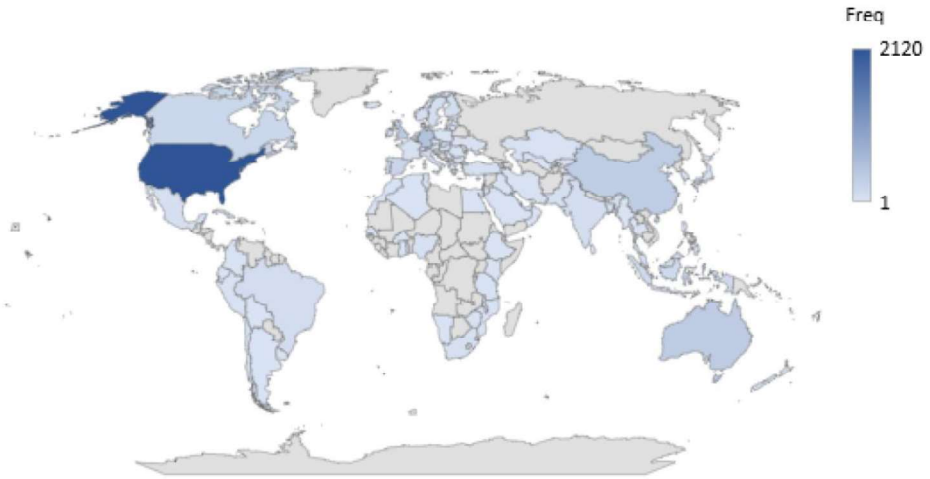

Figure 6. Most Productive Countries Writing Articles on Data Literacy

Keyword Co-occurrence Analysis. After the filtering process described in the data processing and analysis, a keyword co-occurrence network was generated by identifying groups of keywords in the 2896 selected publications with a high frequency of occurrence and a high degree of association. Figure 7 shows the network visualization of the co-occurrence of keywords (at least 2). It can be seen that "data literacy" is the most common keyword with 412 co-occurrences. The circle size can be this on the keyword "data literacy." The larger the circle, the more keywords have been widely used by researchers related to data literacy.

The results of the network visualization in Figure 7 shows that there are 8 clusters with 221 items regarding data literacy, namely, (1) Cluster 1 (in red) consists of 61 items; (2) cluster 2 (in green) consists of 33 items; (3) cluster 3 (in dark blue) consists of 30 items; (4) cluster 4 (yellow coloured) consists of 24 items; (5) cluster 5 (purple colored) consists of 23 items; (6) cluster 6 (black colored) consists of 22 items; (7) cluster 7 (orange colored) consists of 18 items; and (8) cluster 8 (brown coloured) consists of 12 items.

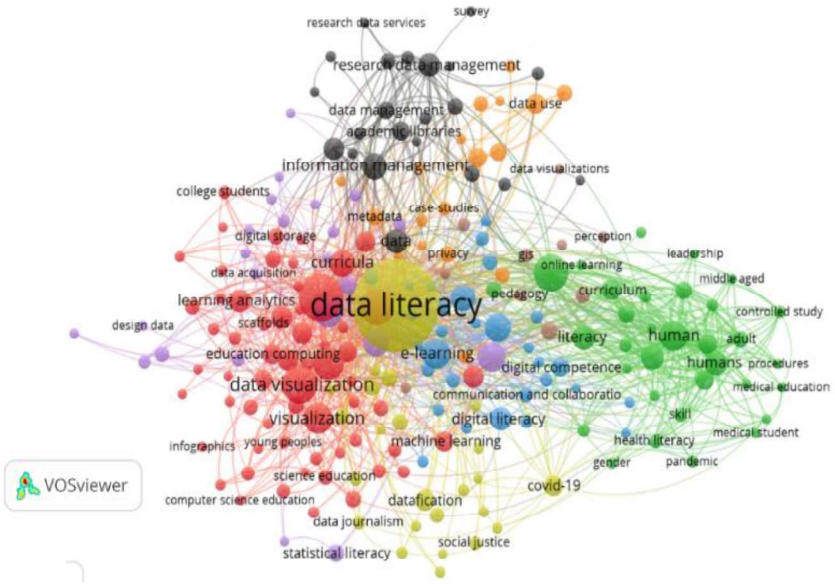

Figure 7. Network Visualisation of Keyword Co-occurrence

The clusters show that the research focuses on data literacy, meaning there are eight research focuses. The first research focus is the keyword with the largest circle in cluster 1, namely, students. The second research focus is the keyword with the largest circle in cluster 2, namely, information literacy and human. The third research focus is the keyword with the largest circle in cluster 3, namely, e-learning. The fourth research focus is the keyword with the largest circle in cluster 4, namely data literacy. The fifth research focus is the keyword with the largest circle in cluster 5, namely education. The sixth research focus is the keyword with the largest circle in cluster 6, namely information management. The seventh research focus is the largest circle in cluster 7, namely professional development and data use. The eighth research focus is the largest circle in cluster 8, namely learning. The eight research focuses above can be a reference for future researchers to determine research themes.

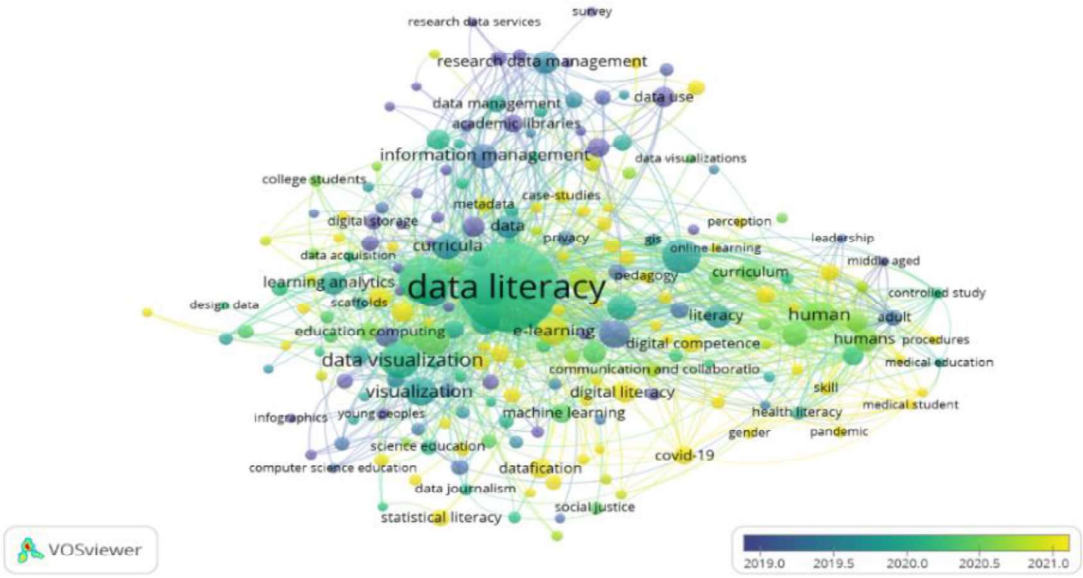

Figure 8. Overlay Visualisation of Shared Keyword Occurrence by Publication Year

Based on Figure 8, there are three different colors: the yellow color shows that the keywords were used together around 2021 to 2023, the blue color shows the use of keywords together around 2019, and the green color shows around 2020. This indicates a change in terms within a certain period. Keywords that become new themes are e-learning, datafication, statistical literacy, data analysis, data-driven, and high education. Based on the results of the discussion above, research or the number of publications related to data literacy in the Scopus database began to appear in 1956 and phased out for 47 years, and then, in 2004, began to increase steadily every year. The most significant number of documents is in the United States. The highest number of publications in the journal "ACM International Conference Proceeding Series" is 91 documents then the article with the highest number of citations, namely (2012) with the title "Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0". Journal of Sensor and Actuator Networks, 1(3), 217-253".

Conclusions

Based on the analysis of the results and discussion, the number of publications related to data literacy has been increasing every year since 2012, and this increasing trend continues until 2023. In particular, social science disciplines are the main research focus, contributing 43% of all existing research. ACM International Conference Proceeding Series is the most active journal in publishing articles related to data literacy. Kim Schildkamp, a Dutch researcher, made a significant contribution by publishing 29 papers related to data literacy. However, the most cited work in the literature is Swan et al. (2013) "Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0". The United States has the highest number of publications on this topic. Furthermore, several keywords emerged as new themes in data literacy research, including e-learning, datafication, statistical literacy, data analysis, data-driven, and higher education. This indicates that these keywords could be an interesting research focus for further exploration.

However, this research has some limitations, especially regarding database usage. The research only relied on the Scopus database, while many other databases can be used. Therefore, it is recommended that future research consider using data sources from various databases other than Scopus.

Acknowledgement

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I.S. Duysembaev
Kazakh-British Technical University, School of Materials Science and Green Technologies, Republic of Kazakhstan.
E-mail: i_duisembayev@kbtu.kz
ORCID 0009-0004-3817-3422

D.K. Zhambakin
Branch "Research and Development Center" of KazTransOil JSC, Republic of Kazakhstan.
E-mail: D.Zhambakin@kaztransoil.kz
ORCID 0000-0001-8758-3875

N.A. Ivashov
Branch "Research and Development Center" of KazTransOil JSC, Republic of Kazakhstan.
E-mail: NIvashov@kaztransoil.kz
ORCID 0009-0007-0652-0874

R.Kh. Sharipov
Kazakh-British Technical University, School of Materials Science and Green Technologies, Kazakhstan.
E-mail: r.sharipov@kbtu.kz

A.G. Didukh
Branch "Research and Development Center" of KazTransOil JSC, Republic of Kazakhstan.
E-mail: A.Didukh@kaztransoil.kz
ORCID 0000-0002-7626-6580

D.B. Abdukhalykov
Branch "Research and Development Center" of KazTransOil JSC, Republic of Kazakhstan. E-mail: D.Abdukhalykov@kaztransoil.kz
ORCID 0000-0001-7023-947X

El-Sayed Negim
Kazakh-British Technical University, School of Materials Science and Green Technologies, Republic of Kazakhstan. E-mail: a.negim@kbtu.kz
ORCID 0000-0002-4370-8995

Academic Research of the Protective Ability of Zinc-Filled and Epoxy Polyamide Paint Coatings against Atmospheric and Soil Corrosion

Abstract: Currently, zinc-filled coatings capable of providing protection against corrosion through a barrier and tread mechanism are becoming increasingly widespread. When exposed to an aggressive environment, the coating prevents steel corrosion by "healing" the damage. In this way, the corrosion process slows down, and the by-products formed during the activation of zinc are able to fill the space left by the defect. The article presents a description of the principle of "healing" with such coatings, as well as the results of laboratory and field tests carried out in order to study data on the effectiveness of protective characteristics in comparison with the traditionally used epoxy polyamide coating with parallel operation of electrochemical protection. It was noted that laboratory tests confirmed the "restorative ability" of the zinc-filled coating to prevent the formation of corrosion in places of applied defects.

Keywords: corrosion, paint and varnish coatings, corrosion protection, steel, zinc-filled coating.

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Introduction

In the process of pipeline transportation of oil and operation of oil trunk pipeline facilities, the issue of protecting metal structures from environmental influences and the occurrence of corrosion damage becomes vital. This factor can cause not only economic losses due to metal destruction, equipment downtime, and product loss, but also environmental damage due to oil release. Such critical production facilities as oil storage tanks, process pipelines and pipelines of the linear part of aboveground and underground construction operating under pressure are subject to corrosion destruction. To increase the maximum service life of these objects, both the active protection method is used - changing the electrochemical potential of the pipeline using cathodic protection means, and the passive protection method - applying anti-corrosion coatings to the metal surface.

Coatings insulate the metal and act as a protective barrier that prevents interaction with an aggressive environment. Such coatings must have resistance to chemical attack, abrasive wear, a high degree of adhesion and resistance to moisture. In addition, an important indicator is the durability of the coating, especially when operating equipment under conditions of electrochemical protection. Today, there are various types of protective coatings with different properties and composition. An important place is occupied by materials containing a metal component with a lower electrochemical potential compared to the protected metal, which are able to "work" simultaneously and according to the sacrificial protection mechanism (Pravin Deshpande, et al., 2021; Amrollahi et al., 2022; Chunping Qi et al., 2022; Kenzhaliyev, 2019).

Increasing the effectiveness of protection can be achieved by choosing the appropriate type of coating, taking into account the specific operating conditions of the equipment: type of metal being protected, weather and climatic conditions, corrosive components of an aggressive environment, probable mechanical impacts, etc. Considering the large length of oil trunk pipelines located in different climatic or soil conditions, safe oil pumping requires constant monitoring of the condition and increasing the degree of protection of equipment, pipelines and tank farms (Jinbao Huang et al., 2022; Kazakov & Grishina, 2022). In this regard, this article reflects work on comparing the protective properties of a two-component epoxy polyamide paint and varnish coating (hereinafter referred to as EPLP) and a zinc-rich paint and varnish coating (hereinafter referred to as TsLP) under operating conditions of electrochemical protection equipment for the purpose of possible use at production facilities.

Literature review (general information)

Nowadays, the protection of metal structures of main oil pipelines in open atmosphere conditions is provided by paint and varnish coatings. One example of an application is a two-component EPLP based on epoxy resins (Alibakhshi et al., 2022; Xiang Wang et al., 2021). Along with this, CLPs are becoming increasingly popular in the world, they provide protection against corrosion through the following mechanisms: tread, like traditional metal coatings, and barrier, like standard paint and varnish coatings. Sacrificial/cathodic protection is ensured due to the presence of zinc powder (particle diameter from 4 to 10 microns) with a low content of impurities and zinc oxides in the composition of the CLP. Thus, many iron-zinc micro galvanic couples are formed, capable of reacting upon contact with an aggressive environment, as a result of which zinc undergoes "sacrificial" dissolution with the formation of oxidation products (Figure 1). An important condition for tread protection is to ensure electrical contact of the zinc cluster with the steel surface, since when a defect is formed on the coating surface, zinc particles (cluster 2) begin to interact with the aggressive environment in the defect area, acting according to the cathodic mechanism (Wenting Xia et al., 2021). Anodic dissolution of zinc occurs, which proceeds until the defect and pores A are filled with the resulting poorly soluble zinc corrosion products, compacting them and stopping the access of the aggressive environment to the metal surface until the zinc particles dissolve. Thus, when a defect occurs, the steel is protected from corrosion by "healing" the damage.

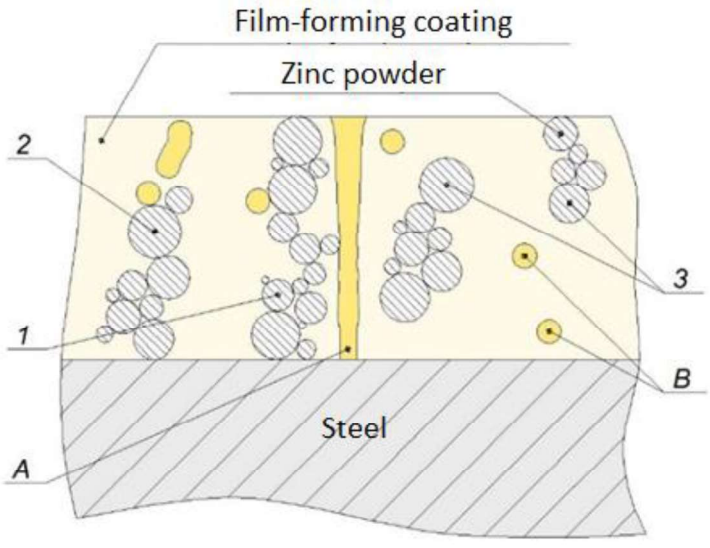

Figure 1. Main structural elements of the CLP: Pores: A – open (through); B – micropores;

At the same time, zinc is not an easy material to use and apply, which is characterized by clumping and settling in a short time. Poor coating preparation and surface contamination prevent the formation of contacting clusters of types 1 and 2 necessary for protection and their contact with the metal surface (Figure 1). Therefore, the main condition for the use of such coatings is abrasive blasting of the surface (up to Sa 2.5) and application of prepared and thoroughly mixed material. Protective protection is provided when the mass fraction of zinc particles is more than 65%.

Clusters are collections (chains) of zinc particles in contact with each other:

1 – infinite clusters, determined through conductivity, participate in the implementation of the tread protection mechanism immediately upon contact with an aggressive environment;

2 – clusters in contact with the base metal, but not coming to the surface, begin to actively influence the protective properties as the aggressive environment penetrates deep into the film;

3 – "hanging" clusters that are not in contact with the metal, and therefore do not participate in the operation of galvanic couples (Moradi et al., 2023; Lu Shen et al., 2022).

Experimental part

The protective ability of the coatings was determined using field and laboratory corrosion tests, which made it possible to identify the likely occurrence of defects and evaluate their behavior in specific corrosive environments.

The laboratory corrosion tests carried out are accelerated. During such tests, samples were exposed to artificial highly aggressive corrosive environments at high humidity and temperature. This causes accelerated destruction of the tested samples, which makes it possible to judge the presence of defects in the coating and predict, with varying degrees of reliability, its corrosion resistance under various operating conditions. However, due to the complexity of the ongoing corrosion processes, which depend on many factors and are not always amenable to accurate assessment, direct transfer of the results of laboratory or bench corrosion tests to the actual operating conditions of coatings in specific aggressive environments may not always be justified. Therefore, the results of accelerated corrosion tests of coated samples were compared with operating conditions in full-scale tests.

After receiving samples. Anti-corrosion coatings were applied to metal samples made of 17G1S steel. Before application, the samples were cleaned by abrasive blasting to Sa 2½ with an average roughness of 50-70 μm. Next, we coated the EPLP and TsLP.

Before application, the CLP was mixed to a homogeneous mass (with a drill with an attachment) and applied in three layers: the first - 20-30 μm dry film thickness (DFT), the second - 125 μm wet film thickness (WFT) or 60 μm DFT; the third – 125-150 μm TMP or 60 μm TSP, resulting in an average thickness of 140 μm TSP without taking into account roughness.

EPLP, having previously mixed the first component in the form of epoxy resin to a homogeneous consistency (with a drill with an attachment) and diluted the material with the hardener (second component) to no more than 10% of the volume, was applied in one layer of 180 μm TMS or 150 μm TSP.

Testing. In order to study the effectiveness of anti-corrosion protection of coatings, a visual assessment of the surface was carried out, adhesion was determined using the lattice notch method and changes in the thickness of coatings were determined based on the results of the following tests:

1) Resistance to static effects of liquids to determine the decorative and protective properties of coatings after exposure to liquids for a specified time. The test consisted of keeping the samples in the following liquids (Figure 2, a): 1) 12.5% sulfuric acid solution; 2) 12.5% potassium hydroxide. The desiccator with these liquids was placed in a drying cabinet heated to a temperature of (60±2) °C, and after 8 hours the desiccator was removed from the oven and kept at a temperature of (20±2) °C for 16 hours; 3) a 3% solution of "sea salt" (consisting of sodium chloride 75%, potassium chloride 4%, magnesium chloride 10%, calcium sulfate 5%, magnesium sulfate 6%) was kept at a temperature of (20±2) °C in within 24 hours.

2) Testing on the "Laboratory installation for modeling pipeline transport technologies" to determine the protective properties of coatings in a corrosive soil environment with the following parameters of the cathodic protection station (CPS): mode U = 0.1 V, I = 0.001 A; with a protective potential of -1.18 V; with natural potential without coating = -0.52 V. The electrical conductivity of the soil was 4998 μS/cm; Physico-chemical soil parameters: humidity in the range of 7-19%; chloride ions 15.5 mmol/100 g; sulfate ions 1260 mmol/100 g; pH = 6.098; Test time = 2515 hours.

The corrosion rate in a model soil environment for 17G1S steel without any coatings, determined practically, was: 0.08 mm/year without electrochemical protection (ECP) and 0.01 mm/year with ECP.

Steel samples (coated, uncoated, as well as with defects applied to the coatings in the form of a notch) were installed in a container with model soil at the ground-air interface, with some samples connected to the ECP system (Figure 2, c). The acid-base balance of soils was regulated by irrigating the soil with salt solutions and controlled by determining moisture content and chemical analysis of the soil. After testing for 2515 hours, the samples were removed from the ground to determine the decorative and protective properties of the coatings.

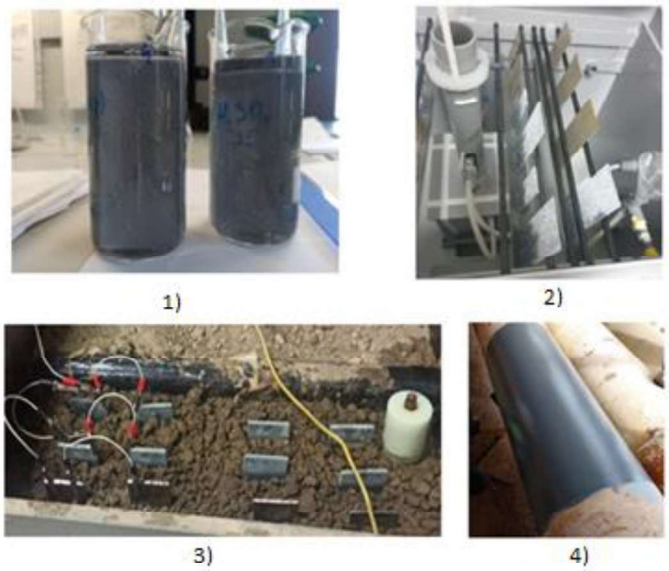

Figure 2. View of samples when tested for: 1) resistance to static effects of liquids; 2) for corrosion in an artificial atmosphere (salt fog); 3) laboratory installation for modeling pipeline transport technologies; 4) full-scale (real) conditions at production facilities

3) Testing under full-scale (real) conditions at production facilities. EPLP and TsLP were applied to above-ground process pipelines of the oil loading berth in Aktau (in marine atmosphere conditions) and under opposite conditions in the pump room at the oil pumping station in Ekibastuz at the initial section of the process pipeline with increased vibration (Figure 2, d). After 3689 hours (≈ 5 months), a visual assessment of the condition of the coating was carried out, and the thickness and adhesion of the coating were determined.

4) Corrosion test in artificial atmosphere (salt fog). The test samples were installed in a Biuged BGD 880 salt fog chamber with a spray of 5% sodium chloride solution in the pH range from 6.5 to 7.2 at a temperature of (35 ± 2) °C for 24 hours (Figure 2, b). After the tests, the resistance of the coatings to salt fog is determined by the spread of corrosion from the cut.

Results and analysis

Analysis of the surface condition of the samples after testing for resistance to static effects of liquids showed the following results (Figure 3):

CLP after exposure:

– in a solution of sulfuric acid has undergone a significant change, with almost complete peeling of the coating and the presence of general corrosion of the metal under the coating;

– in an alkaline solution there was a significant appearance of bubbles (swelling) on the surface, with the appearance of a large number of minor cracks (weak cracking) with no signs of corrosion;

– in a solution of "sea salt" showed a slight change in color and chalking of the coating.

EPLP after exposure:

– in a solution of sulfuric acid slightly changed color with the formation of general corrosion of the metal under the coating at the site of the defect;

– in an alkaline solution changed color without signs of corrosion;

– in a "sea salt" solution showed a slight change in color, but with the appearance of general corrosion of the metal under the coating at the defect site.

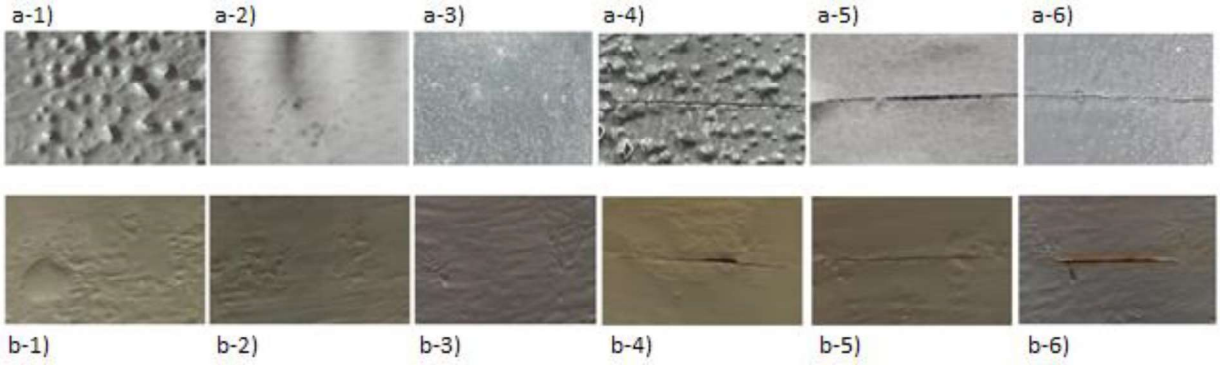

Figure 3. View of samples after testing for resistance to static effects of liquids

Samples with CLP without an applied defect: a-1) in an alkaline solution; a-2) in a solution of sulfuric acid; a-3) in a solution of "Sea salt"; with a defect applied: a-4) in an alkaline solution; a-5) in a solution of sulfuric acid; a-6) in a solution of "Sea salt".

Samples with two-component EPLP without an applied defect:

b-1) in an alkaline solution; b-2) in a solution of sulfuric acid; b-3) in a solution of "Sea salt"; with a defect applied: b-4) in an alkaline solution; b-5) in a solution of sulfuric acid; b-6) in a solution of "Sea salt".

The condition of the surfaces of the samples according to the results of testing in soil at the "Laboratory installation for modeling pipeline transport technologies" changed as follows (Figure 4):

– in samples with CLP with connected ECP, a change in color, absence of corrosion, slight cracking, and salt deposits were observed; without a connected ECP, a change in color was also noticed, but with the appearance of general corrosion and a moderate number of cracks.

– for samples with a two-component EPLP with a connected ECP, a slight change in color and no corrosion were observed; on samples with an applied defect without connecting an ECP, in addition to a slight change in color, the appearance of corrosion can be observed.

Figure 4. View of samples after testing on the "Laboratory installation for modeling pipeline transport technologies": Samples with CLP: a) without ECP; b) with ECP. Samples with two-component EPLP: c) without ECP; d) with ECP

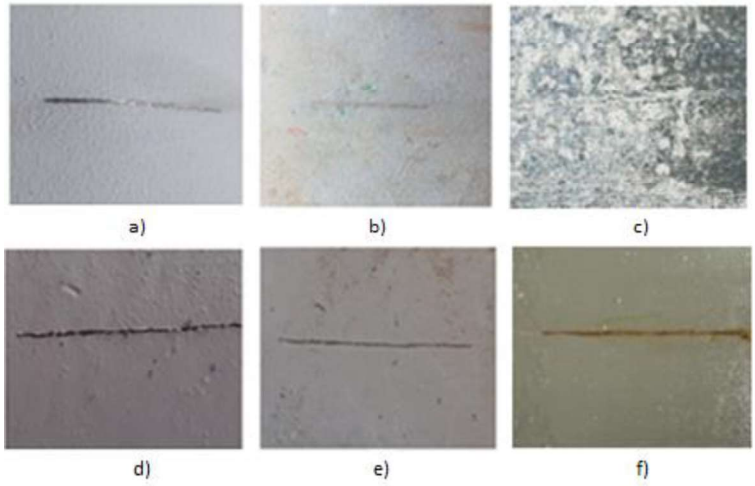

Figure 5. Type of samples: Samples with CLP: a) before testing under full-scale conditions; b) after testing under natural conditions; c) after testing in a salt fog chamber.
Samples with two-component EPLP: d) before testing under full-scale conditions; e) after testing under natural conditions; f) after testing in a salt fog chamber.

After testing the coatings in question under natural conditions at production facilities, the following result was obtained. The surface has a clearly visible color change, there are no signs of corrosion, including in places of applied defects (Figure 5, a, b, d, e). There is no change in coating thickness.

Based on the results of the corrosion test in an artificial atmosphere, it was noticed that corrosion products were present on the EPLP at the site of the applied defect (Figure 5, e). On the CLP at the site of the defect, a "self-healing" effect (overgrowing of the defect cavity) is observed without the occurrence of a corrosion process with a change in the color of the sample due to the formation of salt deposits (Figure 5, c).

Determination of the adhesion of coatings by the method of lattice cuts on samples after the tests showed the following results. EPLP after exposure to solutions of sulfuric acid and alkali has a slight partial peeling of the coating in the form of small flakes at the intersection of grating lines, exceeding 35% of the surface, and in the area of the applied defect there is complete peeling. CLP in solutions of sulfuric acid and alkali showed complete peeling of the coating. Based on the result obtained - a violation of the apparent continuity of the coatings - adhesion determination was not carried out on these samples (Figure 6, a-1, a-2). After exposure to the "sea salt" solution on both coatings, no signs of peeling were observed in any square of the gratings (Figure 6, a-3, b-3).

After testing the coatings in soil at the "Laboratory installation for modeling pipeline transport technologies", the CLP showed only slight peeling of the coating in the form of small flakes at the intersections of the grid lines (Figure 6, a-4, a-5). Samples with EPLP that were under ECP showed both partial, exceeding 35%, and complete peeling at the site of the applied defect (Figure 6, b-4). EPLP samples placed without ECP show in some places complete peeling, in others partial peeling along the grid cut lines and at their intersections (Figure 6, b-5).

The adhesion of the two coatings after full-scale testing under production conditions showed satisfactory results, since the edges of the cuts remained completely smooth, without signs of peeling in any square of the lattice (Figure 6, a-6, b-6).

The adhesion of the two tested coatings after testing in an artificial atmosphere (salt fog) showed a good result without signs of peeling in any square of the lattice (Figure 6, a-7, b-7).

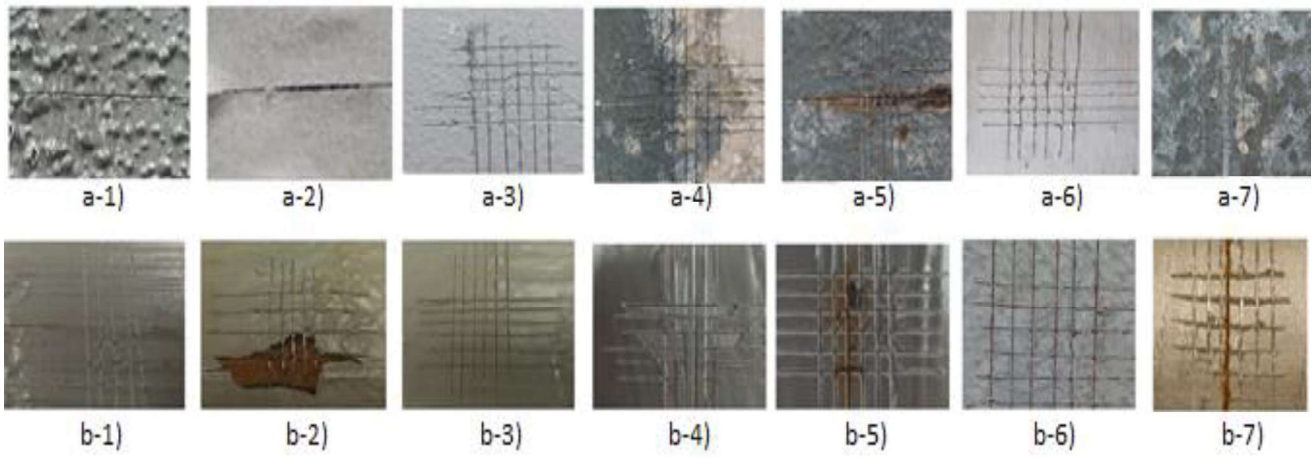

Figure 6. Determination of adhesion of paint and varnish coatings using the lattice cuts method. On samples with CLP: a-1) after a solution of sulfuric acid; a-2) after an alkaline solution; a-3) after the "Sea salt" solution; a-4) after tests in soil on a "Laboratory installation" with ECP; a-5) after tests in soil on a "Laboratory installation" without ECP; a-6) after testing under natural conditions at the production facility in Aktau; a-7) after testing in corrosion tests in an artificial atmosphere.

On samples with two-component EPLP: b-1) after a solution of sulfuric acid; b-2) after an alkaline solution; b-3) after the "Sea salt" solution; b-4) after tests in soil on a "Laboratory installation" with ECP; b-5) after tests in soil on a "Laboratory installation" without ECP; b-6) after testing under natural conditions at the production facility in Ekibastuz; b-7) corrosion tests in an artificial atmosphere.

After all tests, the thickness of the coatings did not show any significant changes in the direction of thinning. At some measurement points, thickening of the coating was observed due to salt deposition on the surface of the samples.

Results and conclusions

1. In the presence of a defect in an acidic solution and soil environment, samples with coated EPLP turned out to be the most susceptible to corrosion processes. Electrochemical protection significantly slows down the formation of corrosion products under these conditions. CLP in acidic and alkaline solutions is subject to complete or significant destruction with swelling, the appearance of cracks, ruptures, etc. From here, as a result of destruction, corrosion processes begin to occur. On the CLP placed under the ECP in the soil environment, a "self-healing" effect is observed without the appearance of signs of corrosion.

2. The coatings under consideration showed a good protection result after testing in air under natural conditions at production facilities.

3. When tested for corrosion in an artificial atmosphere, the protective properties of CLP prevail over the protective properties of EPLP due to the possibility of "self-healing" of defects (overgrowing of the defect cavity) without the corrosion process occurring.

4. Determination of coating adhesion after testing in corrosive environments confirmed the conclusions in points 1, 2, 3 and also showed corresponding results for all tests.

5. After testing the samples under field and laboratory conditions, no change in the thickness of the CLP and EPLP is observed.

6. It should be noted that the "restorative ability" of the CLP, confirmed during tests (tested on a "Laboratory installation for modeling pipeline transport technologies" and for corrosion in an artificial atmosphere or salt fog), is able to prevent the formation of corrosion in places of applied defects (provided that the aggressive environment influences gradually, or indirectly, as in the full-scale tests).

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Alina Nitsenko
Institute of Metallurgy and Ore Beneficiation,
Satbayev University, Almaty, Kazakhstan
E-mail: a.nitsenko@satbayev.university
ORCID ID 0000-0001-6753-0936

Xeniya Linnik
Institute of Metallurgy and Ore Beneficiation,
Satbayev University, Almaty, Kazakhstan
E-mail: x.linnik@satbayev.university
ORCID ID 0000-0002-0683-1409

Thermodynamic studies of the binary system of magnesium with the alloying metal – beryllium

Abstract: The results of studies to obtain thermodynamic constants of condensed and vapor phases of binary systems of magnesium with beryllium are presented in this paper, and liquid-vapor phase transitions at atmospheric pressure and in vacuum are also constructed. Mg - Be alloys of a given composition were prepared as a result of this work. The partial pressures of magnesium over binary alloys with beryllium were determined with the use of the boiling point method (isothermal variant). The partial vapor pressure of beryllium was found by numerical integration of the Gibbs-Duhem equation. The partial pressures of magnesium and beryllium are represented by temperature-concentration dependences. The boundaries of melt and vapor coexistence fields of magnesium-beryllium system at atmospheric pressure and in vacuum of 1.33 kPa are calculated and plotted on the state diagram. It is established that the separation of magnesium-beryllium system alloys does not involve technological difficulties.

Keywords: magnesium, beryllium, metal, alloy, diagram of state.

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Introduction

Magnesium is one of the common light structural metals, and it has low elasticity, strength and corrosion resistance. The specified parameters are significantly improved by alloying with the help of aluminum, zinc, beryllium, zirconium, titanium, etc. Magnesium and its alloys have found wide application in such areas as aerospace, automotive, computer, biomedical, energy due to high specific strength and stiffness, good biocompatibility, large hydrogen storage capacity (Chen, 2022; Song, 2022; Thangarasu, 2022; Wu, 2022; Yang, 2021; Zhou, 2022; Mohammadi Zerankeshi, 2022; Bobe, 2022; Dai, 2022; Sun, 2022; Zhu, 2022).

To date, the recycling method of light alloys, with a low content of refractory alloying elements based on magnesium, is poorly studied and is relevant due to the increase number of magnesium-containing products used. The number of used and failed devices, mechanisms and their components that need special recycling increases with the growth of their consumption (Mansurov, 2020). These materials are secondary raw materials for the extraction of valuable components, including magnesium, and are relevant worldwide (Barannik, 2010; Non-ferrous metals, 2023).

Well-known process flows intended to process magnesium scrap (Engh, 2021) include preliminary smelting in a crucible furnace to produce ingots with an average composition. The obtained ingots containing impurity elements of various metals are used in the process to prepare standard alloys as additives to raw liquid magnesium (Barannik, 2010).

To date, the processing method for light magnesium alloys containing refractory alloying elements has been poorly studied. Physical and chemical studies conducted for distillation processing of secondary magnesium raw materials containing rare refractory metals with the development of the recycling process for light alloys after remelting and obtaining new special alloys will provide new knowledge in this field.

Obtaining magnesium-beryllium alloy is difficult due to the fact that the vaporization temperature of magnesium is lower than the melting point of beryllium. Solid beryllium does not dissolve in magnesium at atmospheric pressure. It is known that beryllium immersed in boiling magnesium does not react with it. The magnesium boiling point can be raised to a temperature above the beryllium melting point, if magnesium is put in a hydrogen atmosphere, and a pressure of 100-120 atm is created. The matter of beryllium melting even under these conditions is placed in question. Deoxidation of beryllium compounds by molten magnesium is more promising. Accordingly, various methods were proposed to facilitate the release of oxide-free beryllium in a finely dispersed state under such conditions where melting can be accompanied by an exothermic reaction.

Thus, it is currently believed that beryllium cannot be widely used in magnesium alloys, with the exception of very small additives introduced to protect the alloy from burning out during the casting process and to reduce oxidation in the solid state.

Research Materials

Magnesium - beryllium field of existence of liquid alloys in the binary system is present presumably up to 90 at. % Be (Nayeb-Hashemi, 1987).

The alloys were obtained in sealed quartz ampoules preloaded with metals in the form of sawdust in a certain ratio, at a temperature of 800-850 °C for 12 hours, followed by quenching in water. Air was evacuated from the ampoules before sealing, so that the residual pressure was 1 Pa. Metals with the content of the main element, wt. %: Mg 99,99; Be 99,9 % were used. The compositions of the prepared alloys are specified in Table 1.

Table 1. Composition of magnesium - beryllium system alloys

Alloy number	**Wt. %**		**atm. %**	
	Mg	Be	Mg	Be
1	45.57	54.43	23.69	76.31
2	64.73	35.27	40.49	59.51
3	83.47	16.52	65.19	34.81
4	91.43	8.57	79.83	20.17

Research Methods

The composition of the obtained alloys of magnesium with beryllium was determined by chemical analysis method with the use of atomic emission spectrometer - Optima 8300 DV "Perkin Elmer".

The condensate obtained from the magnesium distillation from its alloys with beryllium was preliminarily studied to select the method to determine the vapor pressure of the alloy components.

The results showed that the vapor phase above the magnesium and beryllium melts is almost completely represented by magnesium. In this regard, the most acceptable way to determine the saturated vapor pressure of magnesium is the boiling point method (isothermal option). This method is based on a sharp increase in the evaporation rate of the volatile component near the equalization of the saturated vapor pressure of the metal and a given inert gas pressure.

The experimental part was conducted with the help of a vertical thermogravimetric unit with a quartz reactor where the alloy suspension is located, with an electric furnace, a vacuum pump intended to create a vacuum in the reactor, a cathetometer to fix the mass loss. A chromel-alumel thermocouple (thermoelectric converter DTPK021-1,2/0,7) with a single-channel microprocessor meter-regulator TRM1 with an accuracy of ±5 °C is used to control the temperature in the reaction area. Pressure is measured with an M110 aneroid barometer with an accuracy of ±67 Pa (±0.5 mm Hg) and a McLeod manometer with an accuracy of ±10 Pa. The sample was weighed before and after the experiment with a PA214C analytical balance (Ohaus-Pioneer) with an accuracy of ±0.1 mg.

The partial vapor pressure of beryllium was found by numerical integration of the Gibbs-Duhem equation.

Preliminary experiments showed that experiments must be performed at 800 °C and above to fix the boiling point reliably.

The method intended to calculate based on the partial pressures of the saturated vapor of the system components was taken as a basis to determine the liquid-vapor phase transition boundaries. The existing state diagram of the Mg - Be system was corrected by adding the melt - vapor phase transitions obtained by recalculation of the alloy compositions and the vapor phase composition.

Research Results

The magnesium vapor pressure values experimentally determined by the boiling point method, as well as the calculated values of magnesium and beryllium partial vapor pressures are specified in Table 2.

Table 2. Magnesium and beryllium partial vapor pressures over Mg-Be melts

Alloy composition, at. fraction.		Tempera ture	$\overline{p}_{Mg}$,	$\overline{p}_{Mg}$,	$\overline{p}_{Be}$,
Mg	Be	K/°C	experimental, kPa	estimated, kPa	kPa
0.2369	0.7631	1123 850	1.07 1.07 0.93	1.042	$2.61\cdot10^{-7}$
		1223 950	3.60 3.33 3.87	3.624	$3.82\cdot10^{-6}$
0.4049	0.5951	1123 850	1.87 2.00 1.73	1.871	$1.98\cdot10^{-7}$
		1223 950	6.93 7.20 6.67	6.934	$2.83\cdot10^{-6}$
0.6519	0.3481	1073 800	1.73 1.60 1.73	1.688	$2.08\cdot10^{-8}$
		1173 900	6.93 6.93 6.67	6.845	$3.94\cdot10^{-7}$
0.7983	0.2017	1073 800	2.40 2.13 2.53	2.379	$8.18\cdot10^{-9}$
		1173 900	9.33 9.20 8.93	9.146	$1.80\cdot10^{-7}$

The partial values of the vapor pressure of magnesium and beryllium are represented by the following temperature-concentration dependencies:

$$\ln \overline{p}_{Mg}[Pa] = (-14{,}746x_{Mg}^3 + 35{,}273x_{Mg}^2 - 23{,}214x_{Mg} - 13{,}395)\cdot T^{-1} + \\ + 12.452x_{Mg}^3 - 29.745x_{Mg}^2 + 20.106x_{Mg} + 20.367 + \ln x_{Mg}, \quad (1)$$

$$\ln \overline{p}_{Be}[Pa] = (14{,}746x_{Be}^3 - 31{,}084x_{Be}^2 + 14{,}836x_{Be} - 35{,}780 + 3{,}094\ln x_{Be})\cdot T^{-1} - \\ - 12.452x_{Be}^3 + 26.289x_{Be}^2 - 13.194x_{Be} + 24.574 - 1.028\ln x_{Be}. \quad (2)$$

The boundaries of the vapor-liquid equilibrium fields were calculated based on the partial values of vapor pressure. They were used to supplement the existing diagram. Figure 2.6.1 shows the state diagram of beryllium - magnesium with the boundaries of the vapor-liquid equilibrium fields at atmospheric pressure and in a vacuum of 1.33 kPa.

The boiling point was determined to be equal to the temperature at which the sum of the partial vapor pressures of the system components is equal to atmospheric (101.3 kPa) or other pressure corresponding to the conditions of vacuum technologies under Dalton's law due to the absence of the boiling process for liquid chalcogenide solutions due to the high density of their constituent components.

The vapor phase composition is defined as the partial pressure fraction of the component in the total pressure above the alloy.

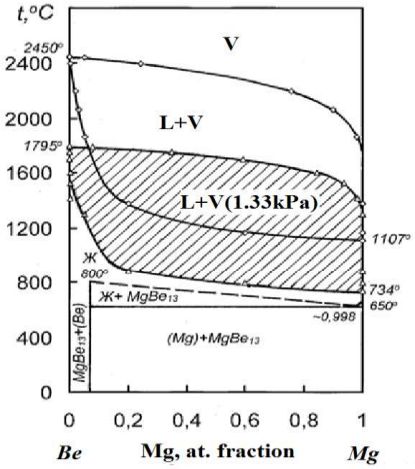

Figure 1. Phase diagram of magnesium - beryllium system

Conclusion

Insufficient information (or its absence) on the vapor-liquid equilibrium in the magnesium-beryllium system has been established based on the analysis of the study results in published works enabling us to judge about the possibility to separate melts into components. The magnesium partial pressure values over beryllium binary alloys were determined by the boiling point method (isothermal variant), and the partial pressure of beryllium was found by the method of numerical integration of the Gibbs-Duhem equation. The obtained values of partial pressures of the Mg-Be system components were presented in the form of temperature-concentration dependences. Then the boundaries of the liquid and vapor coexistence fields were calculated based on these dependences, and the existing state diagram was supplemented.

It can be seen during analyzes of the supplemented phase diagram that the coexistence fields of melt and vapor phases at atmospheric and low pressure (133 kPa) overlap each other. Considering the position of the boundaries of the coexistence fields of liquid and vapor at atmospheric pressure and in vacuum it can be seen that the separation of magnesium-beryllium system alloys does not involve technological difficulties. The vapor phase will be represented by magnesium.

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Abdulla Khursanov
PhD, Senior Researcher, Chairman of the Board of Almalyk MMC JSC
E-mail: info@agmk.uz
Republic of Uzbekistan

Abdurashid Hasanov
DSc, Professor, Deputy Chief Engineer for science of Almalyk MMC JSC
E-mail: abdurashidsoli@mail.ru
Republic of Uzbekistan

Behzod Tolibov
Doctor of Technical Sciences, Professor,
Innovative Development Agency
E-mail: b.tolibov@mininnovation.uz
Republic of Uzbekistan

Physical Properties of Liquid Slag, their Influence on the Basic Parameters of Technological Processes

Abstract: In this article given physical properties of liquid slag, their influence on the basic parameters of technological processes in Almalyk mining and metallurgical plant. The physical properties of melts directly affect the main parameters of pyrometallurgical processes, as well as the design and operation features of equipment. The physical properties of melts (F) are functions of the composition of the phase under study (Xij) and external parameters that determine the state of the system. These properties reflect the structure of the melt, i.e., they are structure-sensitive properties. The physical properties of the liquid phase should also be understood as its properties that are not associated with changes in its material composition or chemical properties, or are associated to an insignificant extent.

Keywords: slag, matte, copper, temperature, density, viscosity, surface layer, electrical conductivity, interfacial properties, double electrical parameters, crystallization, thermal conductivity, separation, smelting, furnace.

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Introduction

The physical properties of melts directly affect the main parameters of pyrometallurgical processes, as well as the design and operation features of equipment. The physical properties of melts (F) are functions of the composition of the phase under study (Xij) and external parameters that determine the state of the system. These properties reflect the structure of the melt, i.e., they are structure-sensitive properties. The physical properties of the liquid phase should also be understood as its properties that are not associated with changes in its material composition or chemical properties, or are associated to an insignificant extent (Yessengaliyev et al., 2022).

The distinction between physical and chemical properties is quite arbitrary, since physical properties, as mentioned earlier, are functions of the chemical composition.

The relationship between physical properties and chemical composition is quite complex and in most cases cannot be calculated theoretically, so experimental methods are usually used to determine it. Physical properties (F_1) can be related to one phase (j)

$$F_1 = F_1(X_{ij}) \quad (1)$$

Where, *1* is the index of properties, so to interphase interaction in the absence of material exchange between phases

$$F = F(X_{ij\#1} \cdot X_{ij\#2 \ldots\ldots} X_{ij\#n}) \quad (2)$$

Physical properties and the interaction of two phases: interfacial electrical layer, etc. are of practical importance.

If the j-th phase consists of m components, i.e. (I = 1.2…….m), then if the condition is met

$$F(X_{ij}) = \sum_{i=1}^{i=m} X_{ij}F_1 \quad (3)$$

$$\sum X_{ij} = 1 \quad (4)$$

where F_{1i} is a similar property of the i-th component of property F, which is additive with respect to the component composition.

To establish additivity, it is necessary to correctly select the method of expressing the value of the property and its dimension. For example, in a number of cases, the density of liquid slags is additive with respect to the density of the components included in them, if these densities are presented in the form of molar volumes with the appropriate dimension.

Additivity conditions can also be written as

$$\frac{\partial F(X_{ij})}{\partial X_{ij}} = F_{1ij} = C, \;\; C = const \quad (5)$$

In most cases, additivity is not observed. Methods for analytical and graphical representation of "composition-property" relationships are given earlier and will be used further to illustrate the most important properties of slags depending on their composition.

The most important properties are: dependence of the state of aggregation on temperature, density, viscosity, surface layer, electrical conductivity, interfacial properties, double electrical parameters. These properties are the most important; then the hedgehogs significantly influence the technological process and the design of the equipment used. They determine the speed of phase separation, the durability of refractories, the dimensions of the melting unit, the process temperature and much more. The most important physical properties of melts will be discussed in detail later in this section.

However, there are other physical properties that can be divided into two groups:

– physical properties, the influence of which on technology and equipment is known and the values of these properties are used in technological and structural calculations.

– physical properties, the influence of which on the technological process has not been established or is absent.

The first group includes such properties as thermophysical (thermal conductivity, degree of surface emissivity, etc.), parameters of diffusion, heat content, heat capacity, etc.

The second group includes: radioactivity, radiation permeability and parameters of interaction with ionizing radiation, magnetic properties, acoustic properties.

However, the lack of information about the practical use of the properties of the second group does not mean that their use is impossible. Thus, in the literature there is information about attempts to use acoustic or magnetic treatment to disrupt the stability of separation dispersoids and intensify the processes of coarsening of fine suspended matter (Shmonin, 1981; Vanyukov & Zaitsev, 1967; Kenzhaliyev, 2019).

In ferrous metallurgy, MHD separation systems are being developed to separate metal from blast furnace and open-hearth slags.

The electrical conductivity of slags was not of interest for practical metallurgy for a long time, but became a very important parameter from the moment when the use of electrothermal furnaces began for melting raw materials and depleting slags.

The parameters of the interaction of liquid metals with a magnetic field were of purely academic interest until the use of induction furnaces began.

Therefore, if a physical property is not used in black copper production processes, this does not mean that it will not be used in the future.

State diagrams of slag systems. Phase diagrams of slag systems characterize their phase state at each given point of the general composition. The phase diagrams include composition-dependent temperatures of the beginning and end of crystallization F_1 and F_2.

$F_1=F^l$ (temperature at the liquidus line),

$F_2=F^s$ (temperature at the solidus line),

$F=F(X_i^0)$,

Where, $\{X_i^0\}$ - set of concentrations of components reflecting the initial state of the system. In the literature there are diagrams of the state of slag systems of various compositions. If they are given in weight fractions (percentages), then they require conversion to mole fractions for ease of use. In the case of using a unified notation system, Musical conversion formulas are used. For a given initial state, it is possible to

determine the equilibrium compositions and the ratio of liquid and solid phases in the temperature range, the temperature of the beginning and end of crystallization.

This means that the state diagram can be used to establish a dependency

$$M_j = F_j(X_j^0 TP) \quad (6)$$

$$X_{ij} = F_{ij}(X_i^0 TP) \quad (7)$$

Analytically, any function, even a discontinuous one, can be represented using the methods of modern mathematics in the form of a set of known functions, with any predetermined degree of accuracy.

The set of known functions is an approximating function. However, the use of classical mathematical apparatus is difficult due to the great complexity of approximating functions for real systems. Until recently, the use of such functions was almost impossible due to purely mathematical difficulties and computational complexity. Therefore, only the analytical expression for the dependence $F^l\{X_{ij}\}$ for limited regions of the phase diagram has received some development. The delimitation of regions, as a rule, is carried out along closed contours, including at the boundary, but not containing inside, figurative points corresponding to the compositions of the eutectics and the crystallization line. In this case, the approximation formulas are much simpler.

Another difficulty that often prevents the use of the full approximation principle is the lack of data on individual areas of the system.

Therefore, in most cases, graphical methods for determining the state of systems are still used: state diagrams. One significant assumption must be made here. Currently, there is a huge database in the form of state diagrams of binary, triple and more complex systems. The development of modern mathematics and computer technology makes it possible to turn any graphic information into digital information and back. Even formal scanning from a drawing or drawing without user intervention.

The state diagrams in the computer memory are already recorded in digital form. The development of digital technologies allows us to hope that they are able to replace analytical approximation methods and be used to perform technological calculations. In this case, the user can have at his disposal both illustrative and graphic material and the ability to analyze it by computer construction of partial dependencies and their graphs for given variables and intervals.

In accordance with the previous section, their molar concentrations will be designated as $X_{2.3}$ and $X_{5.3}$, respectively. The molar contents of the elements Cu, Fe, S, O are designated as $X_{1.3}$, $X_{4.3}$, $X_{19.3}$, $X_{24.3}$ and FeO and Fe_3O_4 as $X_{6.3}$ and $X_{7.3}$, respectively.

If the phase diagram uses the weight fractions of components in percent (%), then they are designated as $X^в_{ij}$ and are converted into X_{ij} according to a known ratio.

Analysis of binary phase diagrams shows that the FeS-FeO system is homogeneous with a FeS content of more than 50% over the entire operating temperature range. The Cu_2S-FeS system is homogeneous at any composition at temperatures above 1423˚K.

Let us give a description of the liquidus surface of this system as interpreted by the author. A significant area of the liquidus surface is occupied by the field of primary crystallization of FeO by monotectic reactions

$L_{FeO} – FeO_s + L_S$.

The critical point of this zero is shifted from the center towards Cu_2S-FeS and has a composition of 50% Cu_2S, 27% FeO, 23% FeS and a temperature of 1165˚C.

The conodes, constricting the compositions of equilibrium coexisting sulfide and oxide melts formed as a result of the stratification of the oxysulfide melt, have a fan-shaped course from compositions concentrated in Cu_2S towards FeS-FeO. As the temperature increases, the delamination area shrinks. The temperature of the triple point E is 850˚C and is consistent with the work data [3].

The main conclusion from the above data is that the factor determining the nature of separation in the homogeneous FeS-FeO system is the presence of the third component Cu2S.

The data from both of the above phase diagrams can be used to determine the melting points and crystallization points in oxygen-containing and metallized mattes.

Naturally, these parameters will differ somewhat from the crystallization parameters characteristic of industrial mattes due to the presence of other components and contain iron both in the form of FeO and Fe_3O_4.

The state diagrams of slag systems are much more complex than matte systems. A common complication is the presence of iron in di- and trivalent forms. We accept the following notations for the main components of slag and their contents:

$(FeO)_i = \{_{6.4}$; $(Fe_3O_4)_i = X_{7.4}$; $(Fe_2O_3)i = X_{8.4}$; (8)

$(SiO_2)_i = \{_{11.4}$; $(CaO)_i = X_{12.4}$; $(Al_2O_3)i = X_{13.4}$; (9)

In equilibrium with the slags characteristic of copper production processes, there may be separate solid phases based on magnetite or silicon dioxide with their content of $X_{7.5}$ and $X_{11.6}$, respectively.

In non-ferrous metallurgy, iron-silicate slags are mainly used, the main components of which are iron and silicon oxides, and in some new processes, ferrite-calcium slags, the main components of which are iron and calcium oxides. Ferrous metallurgy slags (blast furnace, open hearth) occupy an intermediate position. Melting the slag does not always immediately lead to its fluidity. Due to the need for disaggregated silicon-oxygen complexes, the number and complexity of which increases with increasing SiO2, in the slag (X11.4), overheating of the slag is necessary. For slags with a high SiO2 content, the overheating temperature can reach hundreds of degrees. For highly basic ferrite-calcium slags, the overheating temperature is minimal; for other slags it has an intermediate value. The viscosity of slags also increases from ferrite-calcium slags to iron-silicate slags with a high content of silicon dioxide. These issues will be discussed in detail below. As for the questions of mathematical description of the properties of the corresponding slag, they are similar to those that were outlined for mattes.

The difference is that the phase diagram of slag systems is much more complex than the phase diagram of matte systems.

Thus, the basic binary state diagrams of slags are the state diagrams (FeO –SiO_2) ($X^B_{6.4} - X^B_{11.4}$); (FeO - CaO) ($X^B_{6.4} - X^B_{12.4}$); (SiO_2 – CaO) ($X^B_{11.4} - X^B_{12.4}$).

The first phase diagrams were obtained in equilibrium with gamma iron in relation to ferrous metallurgy. Highly reduced slags practically do not contain Fe^{3+}, therefore the content of Fe_3O_4 and Fe_2O_3 was not taken into account. On the other hand, slags with a high Fe^{3+} content were studied, obtained by smelting in the gas phase, which is air.

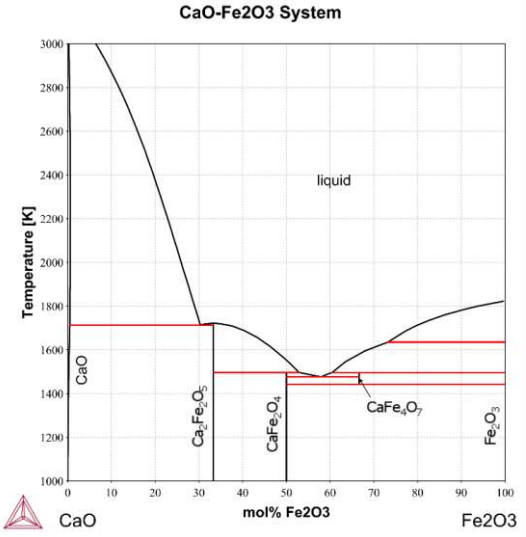

Fig.1. State diagram CaO – Fe_2O_3

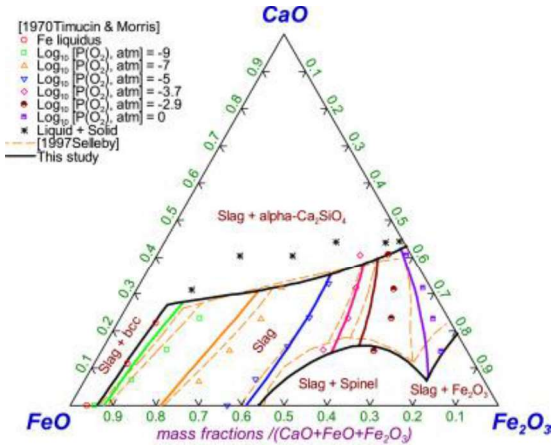

Fig. 2 State diagram CaO – FeO – Fe_2O_3 $(X^B_{12.4} - X^B_{6.4} - X^B_{8.4})$

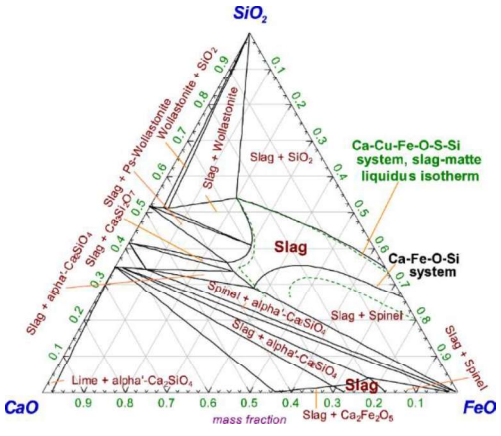

Fig.3. (1) State diagram (CaO – FeO – SiO_2) $(X^B_{12.4} - X^B_{6.4} - X^B_{11.4})$

In this case, the state diagram is of particular interest (Fe_2O_3 - CaO) ($X^B_{8.4} - X^B_{12.4}$), shown in Fig 1.

Non-ferrous metallurgy slags are closest to the FeO - SiO_2 system. There are two chemical compounds in this system: fayalite Fe_2SiO_4 and iron metasilicate $FeSiO_3$ (Vanyukov & Zaitsev, 1967). In the phase diagram obtained by other researchers (Shmonin, 1981) (according to scientists from Germany), the presence of iron

metasilicate is not confirmed, although in other respects it is similar to Selivanov's diagram (Vanyukov & Zaitsev, 1967; Hasanov, 2003).

For a better understanding of the melting and crystallization processes, it is necessary to consider ternary phase diagrams.

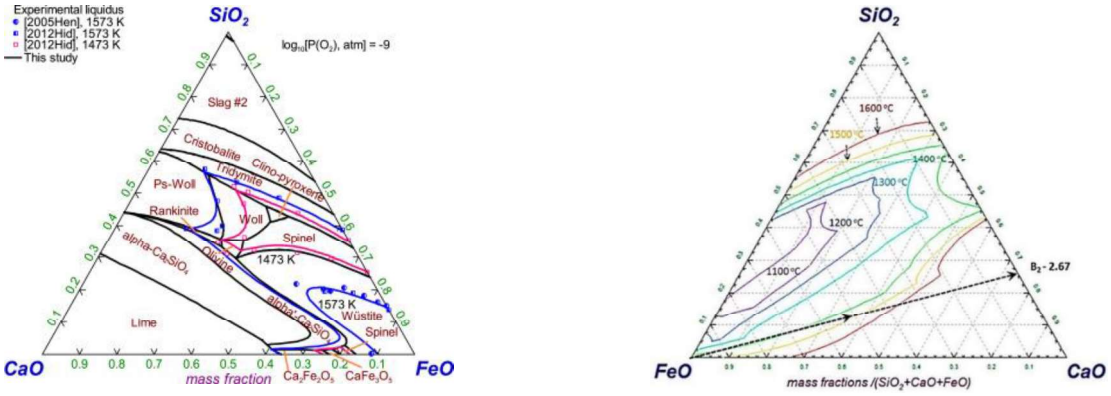

Fig. 3 (2). State diagram (CaO – FeO – SiO_2) $(X^{B}_{12.4} - X^{B}_{\mathbf{6.4}} - X^{B}_{\mathbf{11.4}})$

The state diagram is of some interest, (CaO-FeO-Fe_2O_3) $X_{12.4}$ - $X_{6.4}$ -$X_{8.4}$ shown in Fig.2.

This phase diagram also shows the partial pressure of oxygen (Po_2). From this diagram it can be seen that although the melting temperature increases with the replacement of FeO by Fe_2O_3, it does not increase very much. The dependence of Po_2 on composition is such that it allows the reduction of some oxides to metals. As a result of this, it is possible to obtain copper-poor slags over high-calcium ferritic slags, but this issue is beyond the scope of this section.

Next, consider two ternary state diagrams (CaO-FeO- SiO_2) **(**$X_{12.4}$ - $X_{6.4}$ -$X_{11.4}$) и (CaO - Fe_2O_3- SiO_2) ($X_{12.4}$ – $X_{8.4}$ -$X_{11.4}$) according to (Tsukihashi & Kimura, 2000).

These state diagrams are shown in Fig.3 and 4. Fig.5 shows the state diagram (FeO - Fe_2O_3 - SiO_2) ($X_{6.4}$ – $X_{2.4}$ -$X_{11.4}$).

From these diagrams it is possible to obtain approximate data for a system with different Fe^{3+}/Fe^{2+} ratios. Copper production slags are characterized by a low content of Fe^{3+} and CaO and can be considered within the framework of these phase diagrams (Hidayat et al., 2017).

The introduction of additional oxides (Al_2O_3) $X_{13.4}$, as well as (MgO, Na_2O, K_2O, MnO, etc.) into the system leads to the consideration of quaternary, quintuple and sixfold state diagrams. Even their graphic representation is associated with a number of difficulties, and working with graphic data is much more difficult than with state diagrams of two-component and three-component systems. The simplest method is the following: X_{ij} is fixed for the 1st additional component. Then a state diagram is drawn up from the condition

$$\sum_{j}^{i=3} X_{ij} = 1 - X_{ij} \qquad (10)$$

For example, you can imagine a state diagram ($X^{в}_{11.4} – X^{в}_{12.4}$ -$X^{в}_{6.4}$) (CaO – FeO – SiO_2) при $X^{в}_{13.4}$ (Al_2O_3) = 10%.

Then $X^{в}_{11.4}$ - $X^{в}_{12.4}$ -$X^{в}_{6.4}$ = 90%.

Such triple state diagrams are sections of the general quadruple state diagram along a flat plane $X^{в}_{13.4}$ = 10%. There are quite a lot of fragments of such state diagrams in the literature.

Within the framework of this approach, we can consider the quaternary phase diagram (CaO - FeO - Fe_2O_3 - SiO_2) ($X_{11.4}$ - $X_{6.4}$ - $X_{8.4}$ - $X_{12.4}$), obtained in equilibrium with g-iron under isothermal conditions of 1450°C and 1550°C and changing the weight fraction of SiO_2 from 0 to 30%. This diagram shows only phase boundaries under isothermal conditions and oxygen partial pressures. However, such state diagrams are of significant interest for further use.

State diagrams ($X_{11.4}$- $X_{6.4}$ - $X_{8.4}$- $X_{12.4}$) (CaO - FeO - Fe_2O_3- SiO_2) are shown in Fig. 6 for the indicated supplied temperatures (Tsukihashi & Kimura, 2000).

Analysis of the phase diagram of slag systems makes it possible to determine the composition and phase ratio in a single association during slag crystallization, as well as to estimate the melting temperature (liquidus) and the end of crystallization (solidus). From the phase diagram, the composition of isolated compounds and eutectics can be determined.

In accordance with the work of the school of N.S. Kurnakov, the smoothness diagram can be used to judge the presence and, to some extent, dissociation of a chemical compound. If on a binary smoothness diagram the liquidus line has a common tangent at the top for common branches, then this indicates almost complete dissociation of the compound in the molten state. If the top of the maximum was formed by two branches of the liquidus line and there is a discontinuity in the derivative $\partial T/\partial X$, then this indicates a slight dissociation. A measure of the strength of chemical compounds is the angle between the tangents at the maximum point. This thermodynamic situation is depicted in Figure 1.

In the first case $\partial T/\partial X_+ = \partial T/\partial X_- = 0$.

In the second case $\partial T/\partial X_+ \neq \partial T/\partial X$ and have different signs. A measure of the strength of connected lines is either the value of the angle α between the tangents, or

$$K_\Sigma = K_1 + K_2 = |\partial T/\partial X_+| + |\partial T/\partial X_-| \qquad (11)$$

There are other possibilities for obtaining information using a state diagram, but they are beyond the scope of this section.

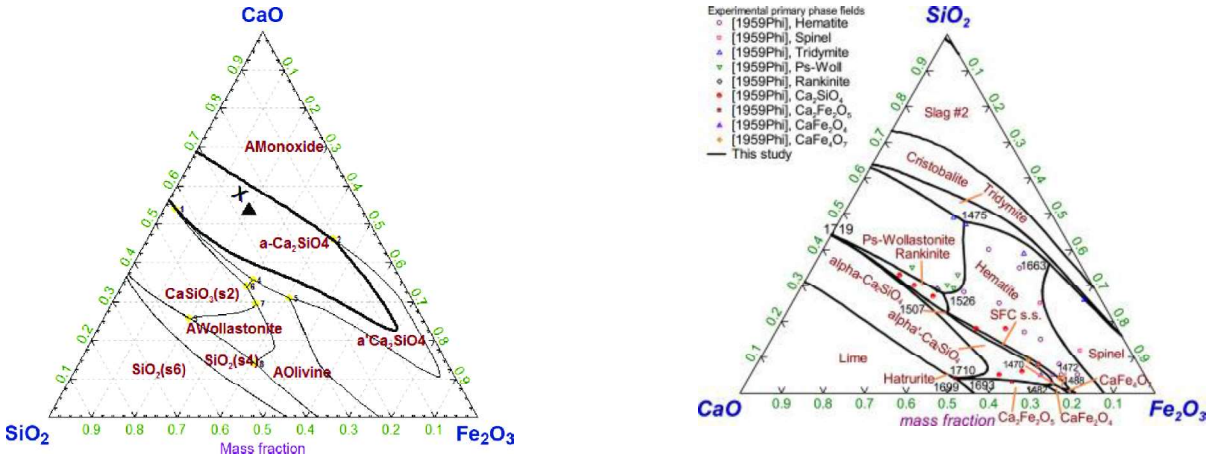

Fig. 4. State diagram ($CaO - Fe_2O_3 - SiO_2$) $(X^B_{12.4} - X^B_{8.4} - X^B_{11.4})$

The most interesting results can be obtained by comparing various properties of the system using methods of modern physicochemical analysis. The fields of the primary phase were experimentally determined and univariant lines in the CaO–FeO–Fe_2O_3–SiO_2 system in air, projected onto the CaO–Fe_2O_3–SiO_2 plane, were calculated. The numbers correspond to the calculated invariant temperatures in K.

The calculated univariant lines and liquidus isotherms at intermediate oxygen partial pressures of 10^{-9} atm, 10^{-8} atm, 10^{-7} atm, 10^{-6} atm and 10^{-5} atm are presented in Fig. 6. Only experimental points with exact or round Lg[$P(O_2)$, atm] are plotted in these figures; further experimental data [5] for other Lg[$P(O_2)$, atm] are not given. Earlier experimental data from Henao et al. [6] were selected for comparison; experimental data from a later paper by Henao et al. [4] were excluded due to inconsistencies found in the data.

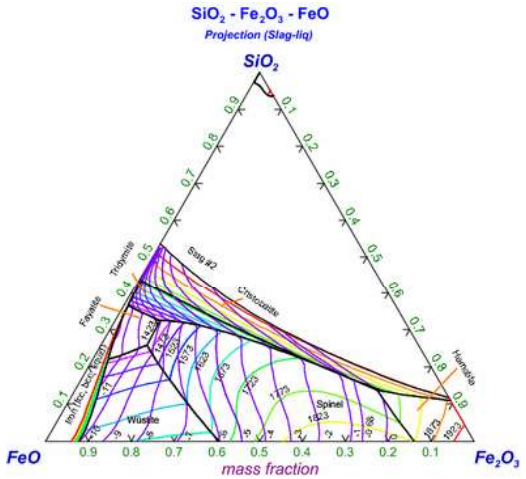

Fig.5. State diagram FeO – Fe_2O_3 – SiO_2

Figure 6 shows the pseudo-ternary phase CaO-FeO-SiO_2 at a partial oxygen pressure of 10^{-9} atm; the field of the primary spinel phase is observed at temperatures below 1481K (1208°C). An increase in the partial pressure of oxygen to 10^{-8} atm and 10^{-7} atm (Fig. 6) leads to an expansion of the field of the primary spinel phase due to the field of the primary wustite phase. At oxygen partial pressures of 10^{-6} atm (Fig. 6) and 10^{-5} atm (Fig. 6), spinel is the only primary phase field observed in the iron oxide corner. An increase in the partial pressure of oxygen also leads to stabilization of the field of the primary pseudowollastonite phase relative to the field of the primary wollastonite phase.

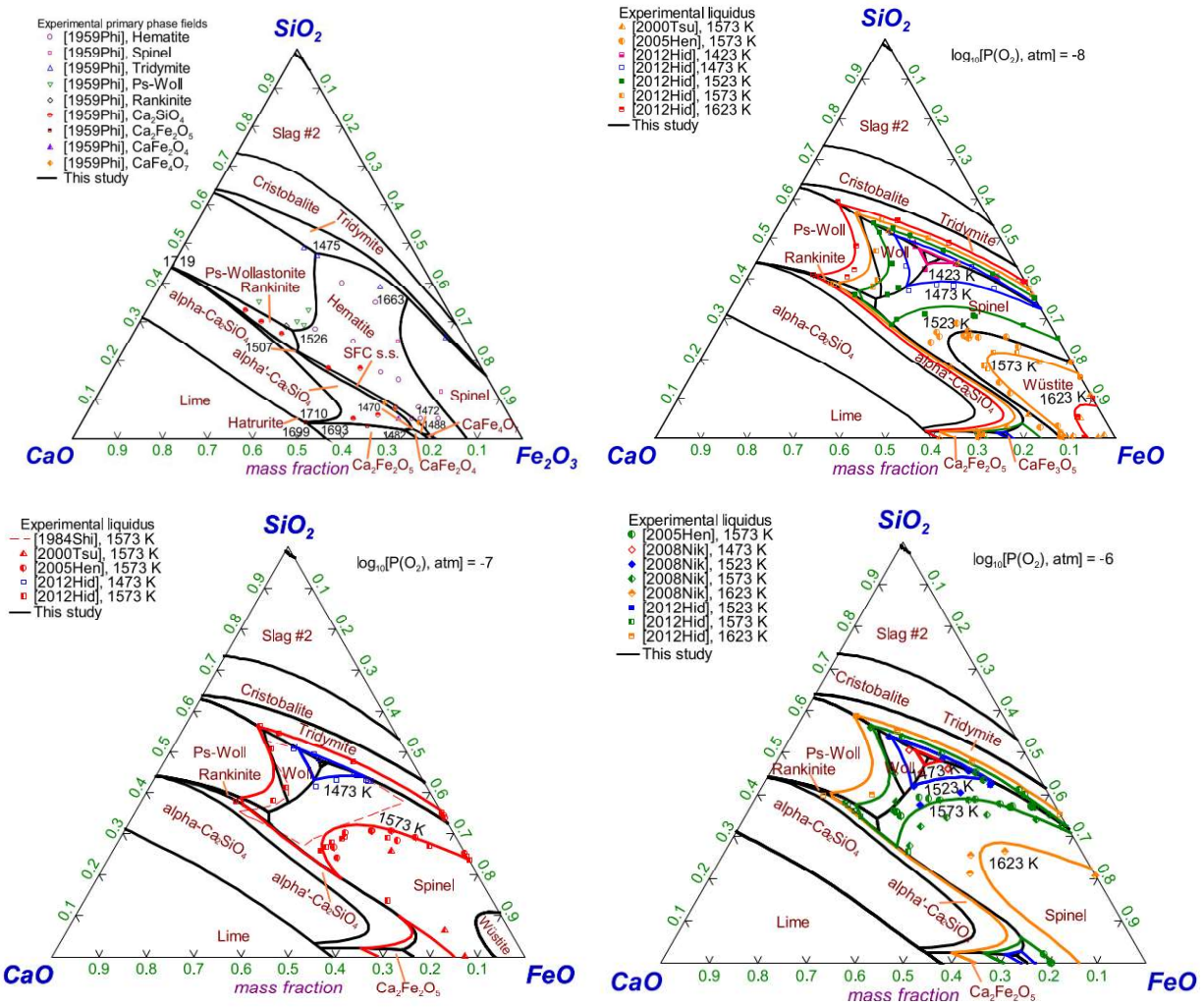

Fig 6. State diagram CaO – FeO – Fe_2O_3 – SiO_2 different SiO_2 content and temperature

Figure 6 shows the presence of fields of the primary phase of olivine and clinopyroxene in a narrow range of compositions. At 1473 K (1200°C) and $P(O_2)=10^{-9}$ atm at the edge of the primary spinel phase field, the phase ensemble Liquid + Spinel + Olivine is predicted by the model parameters, while the phase ensemble Liquid + Spinel + Ca_2SiO_4 is predicted reported by Hidayat et al. [6]. The parameters of the present model appear to overestimate the field stability of the primary olivine phase. There are no experimental works at temperatures below 1473 K (1200 °C) at $P(O_2) = 10^{-9}$ atm and, therefore, there is no experimental data confirming the presence of the field of the primary phase of clinopyroxene, presented in Fig. 6.

Liquidus isotherms at these intermediate oxygen partial pressures are optimized primarily based on experimental data presented by Tsukihashi & Kimura (2000) and Hidayat et al. (2017), which use the equilibration-quench-EPMA method, a reliable and accurate method for determining compositions liquidus and solidus. In general, experimental data on liquidus (Shishin et al., 2019) are well described. Since the liquidus composition of spinel is sensitive to temperature, some of the calculated liquidus compositions in the field of the primary phase of spinel do not fully correspond to experimental data. The slope of the spinel liquidus is almost gentle; therefore, a relatively small change in temperature will lead to a significant change in the composition of the liquidus.

Conclusion

A complete critical re-evaluation of all available phase diagrams and thermodynamic data for the CaO–FeO–Fe2O3–SiO2 system was carried out and a database containing optimized model parameters was obtained. A wide range of experimental data is reproduced within experimental error using a small number of model parameters. In particular, the liquidus is reproduced in a wide range of oxygen partial pressures from

saturation with metallic iron to pure oxygen, including intermediate lg[P(O_2), atm] = $^{-9, -8, -7, -6}$ and $^{-5}$. On the calculated liquidus projection in air, the SFC phase appears for the first time, which is of paramount importance for the agglomeration of iron ores. The present thermodynamic optimization was carried out as part of a broader research program aimed at fully characterizing phase equilibria and thermodynamic properties, followed by the development of a thermodynamic database for the Al-Ca-Cu-Fe-Mg-Si-O-S multi-component system.

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Maulet Meruyert
Sarsen Amanzholov East Kazakhstan University,
Ust-Kamenogorsk, Kazakhstan
E-mail: maulet_meruert@mail.ru
ORCID ID 0000-0003-1570-0301

Wojciech Wieleba
Wroclaw University of Science and Technology,
Wroclaw, Poland
E-mail: wojciech.wieleba@pwr.edu.pl.
ORCID ID 0000-0002-5461-9568

Impact of aluminum content upon the microstructure of Ni-Cr-Al gradient coatings

Abstract: Studied the aluminium concentration in the composite powder NiCr-Al influences the structure of NiCr-Al gradient coatings. Gradient coatings based on NiCr-Al were obtained by detonation spraying, with a phased reduction in the barrel filling volume with acetylene-oxygen gas mixture from 50% to 25%. The coatings' microstructure was analyzed across different aluminum concentrations: 15%, 20%, and 30%. By adjusting the aluminum concentration in the powder mix, we achieved coatings with a gradient formation. The findings indicated that the phase composition of the gradient coating is significantly influenced by the Al mass percentage. The findings suggest a powder composition of 80%NiCr and 20%Al to produce NiCr-Al coatings with a good gradient structure.

Keywords: Ni-Cr-Al coating, gradient coating, detonation spraying, microstructure, XRD.

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Introduction

Power plant components are currently exposed to high temperatures, leading to corrosion, oxidation, hot corrosion, and other detrimental effects. As a solution, protective coatings that offer heat resistance are applied to the superalloy surfaces. Among these, coatings in the MCrAlX system (where M represents Ni, Co, or NiCo; X signifies Y, Ce, Si, Ta) are most prevalent (Darolia, 2013). This popularity stems from the coating's attributes: M and Cr offer wear and heat resistance, while Al combats oxidation by forming Al_2O_3 on the surface. Elements like Y enhance the coating's adhesion. Nevertheless, coatings from this system have room for enhancement. An excessive presence of Al and Cr elements can lead to coating cracks. Conversely, a minimal Al presence can result in an inadequate Al_2O_3 film, compromising oxidation resistance. Hence, ongoing research aims to augment the performance attributes and prolong the lifespan of the MCrAlX coatings.

In recent times, efforts to enhance the corrosion resistance of MCrAlY coatings have centered on refining MCrAlX coatings with reactive elements through laser processing and by creating multilayered and gradient coatings. The introduction of reactive elements or their oxides can bolster the high-temperature corrosion and oxidation resistance of MCrAlX coatings. Yet, there are divergent views regarding the impact of integrating reactive element oxides on the oxidation properties of MCrAlY coatings (Shuting et al., 2017). As a result, the spotlight has shifted towards multilayer and gradient coatings using MCrAlY as a foundation. The structure and chemical composition of such multilayer/functional gradient materials undergo progressive changes to enhance various attributes like mechanical, thermal, and physical properties (Bolelli et al., 2012; Naebe et al., 2016; Song et al., 2011). Recent innovations in functionally graded coatings have proven effective for operations under high temperatures and challenging thermal scenarios (Naebe et al., 2016; Lee et al., 1996; Movchan & Yakovchuk, 2012).

In an earlier research (Rakhadilov et al., 2021), we introduced a technique to produce a gradient coating of NiCr-Al using detonation spraying. A unique aspect of this method involves achieving the desired gradient structure by adjusting the barrel's gas fill volume during the coating procedure, thereby controlling the NiCr-Al composite powder distribution from the base material to the coating's outer surface. Essentially, this means establishing a majority of heat-resistant and wear-resistant particles, primarily Ni and Cr, on the substrate surface, with Al concentrations gradually increasing from the substrate towards the outer coating, culminating in a high Al presence on the exterior. This facilitates the formation of a substantial Al_2O_3 layer on the surface of the coating.

The primary objective of the present study is to examine how the mass ratio of Al composite powder NiCr-Al influences the structure and characteristics of NiCr-Al gradient coatings.

Research methods and Materials

Heat-resistant steel, 12Kh1MF, was selected as the base material. The steel's chemical makeup includes 0.15% C; 0.37% Si; 0.7% Mn; 0.3% P; 1.2% Cr; 0.35% Mo; 0.3% V; and 0.2% Cu. For coating application, the steel was shaped into discs with a 50mm diameter and 3 mm thickness and then polished using SiC grinding paper from P100 to P1000. Before the coating process, the sample surface underwent sandblasting. NiCr and Al powders (with 99.99% purity) were combined in varying proportions (Table 1). This mixture was then processed in a PULVERISETTE 23 planetary ball mill at a frequency of 30 Hz for 2 hours to produce composite powders.

The coating was produced using the CCDS 2000 detonation system [9]. An oxygen-acetylene blend with a ratio of O_2/C_2H_2 = 1.856 served as the explosive gas, while nitrogen functioned as the carrier gas. To achieve gradient coatings, the barrel's gas fill volume was progressively reduced from 50% to 25%. A detailed methodology for creating a gradient coating is elaborated upon in the earlier study (Rakhadilov et al., 2021; Buitkenov et al., 2020). The specific parameters used for the coating process can be found in Table 1.

Table 1. Technological parameters for obtaining NiCr–Al gradient coatings

Powder, wt %	O_2/C_2H_2	Barrel Filling Volume,%	Spray Distance, mm	Number of Shots
NiCr70Al30	1,856	50-25	250	40
NiCr80Al20	1,856	50-25	250	40
NiCr85Al15	1,856	50-25	250	40

We determined the phase composition of the sprayed coatings via the X-ray diffraction technique (XRD) using an X'PertPRO diffractometer with Cu-Kα radiation (λ = 2.2897 Å) at a voltage of 40 kV and a current of 30 mA. The diffractograms were decoded using the HighScore program with measurements were performed in the range of 2Θ equal to 200–900 with 0.02 step size and 0.5 s/step counting time. We photographed the surface of the coatings at 5× optical magnification using a metallographic microscope (Altami MET 5S model).

Results and discussion

Using the CCDS2000 detonation unit, gradient NiCr-Al coatings with different aluminium mass ratios were successfully produced. The coatings produced ranged in thickness from 70-116μm (figure 1). The thickest coating, measuring 116μm, was achieved with an Al mass ratio of 15%. In contrast, the thinnest coating, at 70μm, resulted from an Al mass ratio of 30%. It's likely that during detonation spraying, a significant portion of a softer element in the powder mix, Al in this instance, melts and adheres to the material's surface. Particles of comparatively harder elements embed themselves into the malleable matrix.

X-ray diffraction phase analysis of the gradient NiCr-Al coatings, with varying aluminium mass percentages (15%, 20%, 30%), is depicted in Figure 2. The data suggests that alterations in the Al mass percentage result in phase transitions within the gradient NiCr-Al coatings. With Al mass percentages of 15% and 20%, the coatings primarily consisted of $CrNi_3$ and Al phases. However, when Al mass percentage reached 30%, a new γ-Al_2O_3 phase emerged.

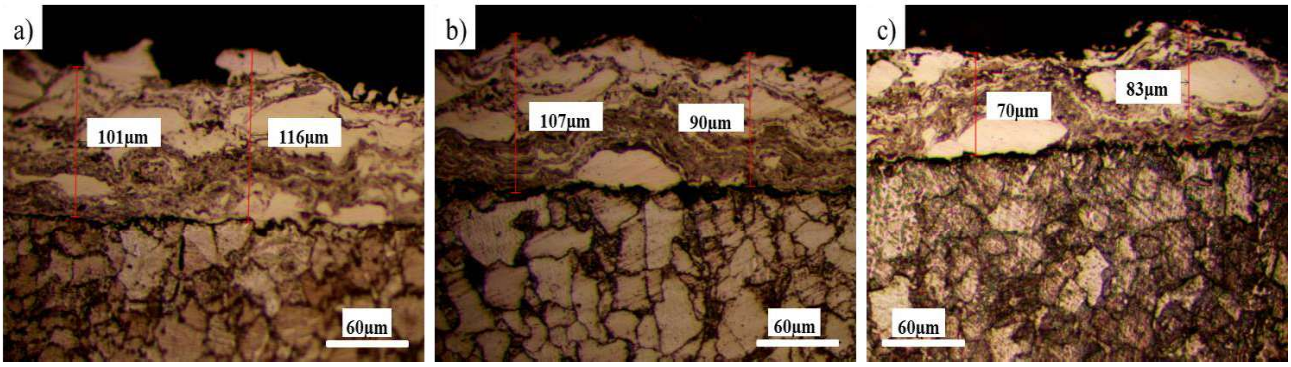

Figure 1. Microstructure and thickness of NiCr-Al gradient coatings at different Al mass ratios:
a) NiCr85Al15, b) NiCr80Al20, c) NiCr70Al30

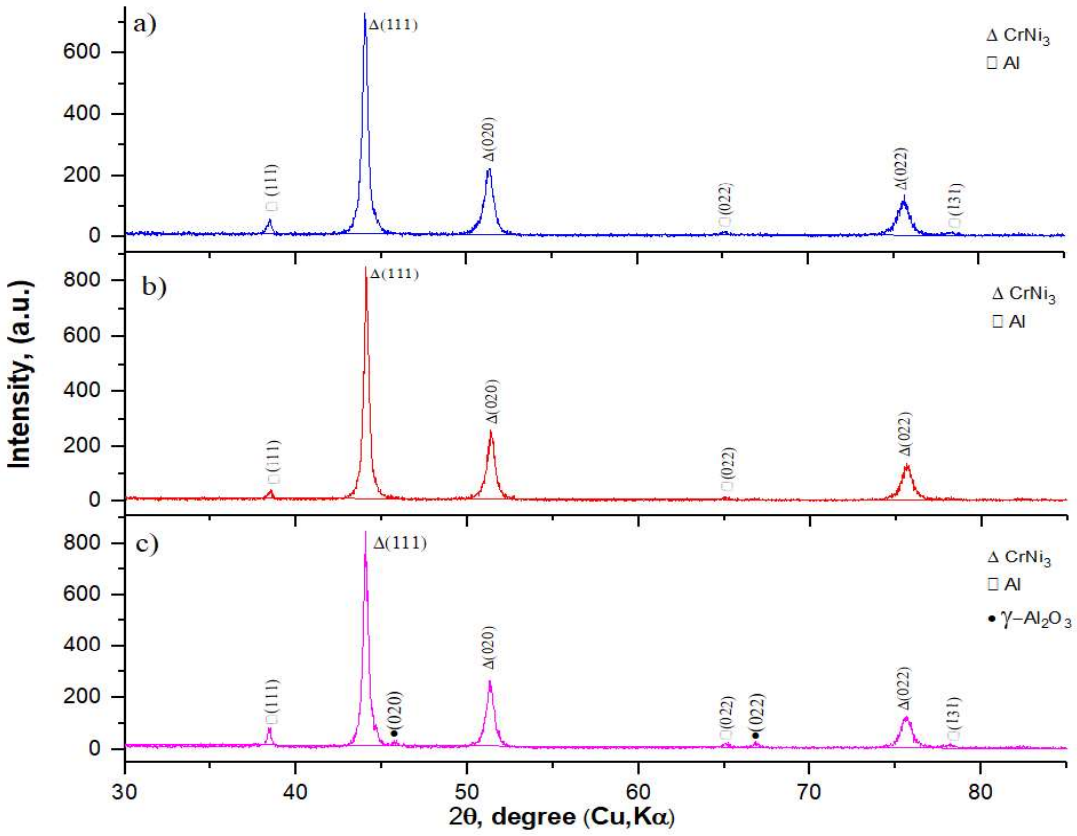

Figure 2. X-ray phase structure analysis of NiCr-Al gradient coatings at different Al mass ratios:
a) NiCr85Al15, b) NiCr80Al20, c) NiCr70Al30

Conclusions

NiCr-Al coatings with varying aluminum concentrations of 15%, 20%, and 30% were produced using detonation spraying. We explored how the coating's structure formation was influenced by the powder's composition. The detonation spraying technique was adjusted to achieve a gradient structure by altering the barrel's filling volume with an acetylene-oxygen gas mix, decreasing it from 50% to 25% throughout the NiCr-Al coating procedure. Our findings indicated that a composite mix of NiCr – 80% and Al- 20% is ideal for creating gradient-structured coatings with a higher Al concentration in their surface layers. We observed the formation of aluminum oxides γ-Al_2O_3 in coatings with a 30% Al content. The coating's characteristics revealed a correlation between the coating's thickness and the composite powder's composition. Specifically, NiCr70Al30 coatings are thinner compared to NiCr85Al15 and NiCr80Al20 coatings. It's likely that during the detonation

spraying, a significant portion of a softer element, in this case, Al, melts and adheres to the material's surface. Particles of the harder elements are embedded into the softer matrix. The microstructural analysis of the NiCr70Al30 coatings' cross-section supports this theory.

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Bagila Baitimbetova
Satbayev University, Kazakhstan
E-mail: baitim@physics.kz
ORCID ID https://orcid.org/0000-0002-3728-2430

Gulsana Kydirbai
Satbayev University, Kazakhstan
E-mail: gulsana.2000@gmail.com
https://orcid.org/0009-0009-6706-1637

Investigation of vibrational properties of carbon films obtained by magnetron sputtering method

Abstract: In the present work, thin carbon films and nanofibers of different morphologies were obtained by magnetron sputtering on a modernized VUP-2 unit. Information of vibrational properties of carbon films and nanofilaments was obtained by Raman spectroscopy. Carbon nanofilaments were obtained in the G band region 1580-1595 cm-1, which is in good agreement with the known literature data. Apparently, the most fascinating results were achieved when steel-3 was used as a substrate. This is probably due to the presence of carbon in steel-3, which serves as a condensation center for the formation of carbon structures, including carbon tubes. The study of amorphous films and their applications in diverse industries constitutes a significant area of scientific research, and this article offers an overview of synthesis methods and potential material applications.

Keywords: Carbon thin films, magnetron sputtering, vibrational properties, material applications, synthesis methods.

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Introduction

Nowadays, the production of thin films from metals and semiconductors is becoming increasingly important. Modern microelectronics is largely based on the use of thin film technologies (Chen, 2001; Karboz & Dossayeva, 2019). The main methods of deposition of such films and layers with thicknesses measured in hundreds and thousands of nanometers are vacuum deposition methods. These methods allow to obtain films with a given composition and desired geometric profile, while possessing a high degree of repeatability. One of the most promising and dynamically developing classes of materials are carbon nanostructures. The creation and study of thin carbon materials with various structures intended for use as sensors in micro-, nano-, and optoelectronics (Nafradi et al., 2006; Garcia, 2002; Johnson, 2000) remain urgent tasks in the field of molecular electronics (Kenzhaliyev, 2019; Smith, 1998; Wan, 1999).

It is important to note that film formation processes play a key role in many methods of creating nanostructures. In a general sense, technology embodies a set of methods and means used to achieve specific goals and transform an initial state into a desired state. Thus, thin film technology in this context is a set of methods used to create and modify thin films, as well as the corresponding equipment. It is important to note that the properties of films are closely related to the conditions under which they are produced, so thin film technology also addresses sample characterization and methods for studying them. Magnetron sputtering is based on the formation of a ring-shaped plasma above the surface of the cathode. This plasma results from the collision of electrons with gas molecules, most often argon. During the discharge process, the positive ions formed are accelerated towards the cathode and bombard its surface, resulting in the knocking out of material particles from this surface. The purpose of this work is to create thin carbon films and nanofilaments of various shapes using the method of magnetron sputtering on the modernized unit VUP-2.

Experimental Setup and Methods

A technique for synthesizing carbon nanofilaments using magnetron nanotechnology has been developed and successfully applied. This process is carried out by magnetron sputtering of graphite target at constant current and different pressures of working gas at room temperature. The coating rate under fixed conditions is: voltage U=500 V, discharge current I=30 mA, temperature T=250°C, pressure P=3.2 * 10^{-2} Pa, and application time t=10 minutes. Raman spectra were measured using MT-MDT Ntegra Spectra at room The spectra were excited by a semiconductor laser (λ=473 nm).

Results and Discussion

Information on the nanostructure of hydrocarbon clusters in the structure of carbon films can be obtained by Raman spectroscopy. The results of Raman spectroscopy of the samples obtained by us are summarized in Table 1 and fig 1. Raman spectroscopy, which investigates the vibrational modes of a carbon matrix, is a valuable source of information.

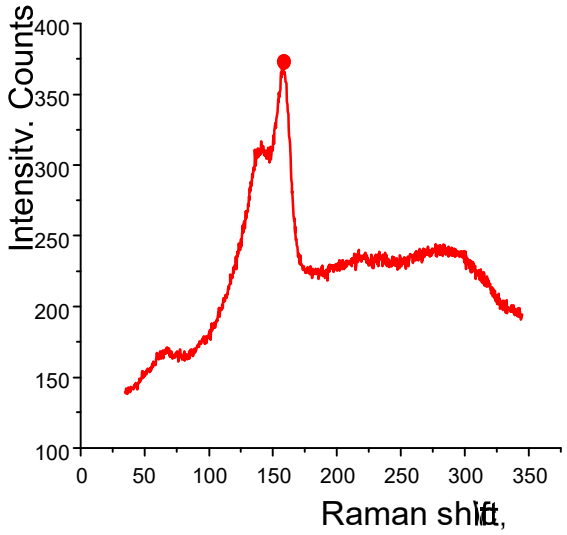

Figure 1. Raman spectrum obtained by synthesis on a substrate (steel-3) using the magnetron sputtering technique.

Table 1. Parameters of Raman spectra of carbon films obtained by magnetron sputtering method

Substrate	**D-line**		**G-line**
ω, cm^{-1}	**Width of lines at half height, cm^{-1}**	**ω, cm^{-1}**	**, Width of lines at half height, cm^{-1}**
~1348	62	~1584	72
~1359	38	~1588	52
~1348	61	~1584	21

From the presented graphical data, it can be seen that two characteristic bands are observed in all the spectra: the D-line in the region of 1350 $cm^{-1}$and the G-line in the region of 1593 cm^{-1}.

In the spectra of glass, organic glass and steel-3 films, a relatively intense graphite G-band spectrum in the region of 1580-1590 cm^{-1} /From the presented graphical data, it can be seen that two characteristic bands are observed in all the spectra: the D-line in the region of 1350 $cm^{-1}$and the G-line in the region of 1593 cm^{-1}.

In the spectra of glass, organic glass and steel-3 films, a relatively intense graphite G-band spectrum in the region of 1580-1590 cm^{-1} is observed, indicating the presence of well-ordered carbon nanotubes.

The crystalline X-ray spectra of carbon films, as well as the spectra of various modifications of amorphous carbon in glass, organic glass, and steel-3 substrates, are characterized by the presence of a broad

band, which can be conditionally divided into two components of Gaussian type, with a small compound component in this region. A distinctive feature of these films is the presence of a substantial amount of nanostructured graphite. These results are confirmed by X-ray diffraction studies, which also reveal peaks of crystalline graphite at 1360 cm^{-1} and 1590 cm^{-1}.

Of the three substrates considered, the sample formed on steel substrate (steel-3) appears to be the most efficient. This can be explained by the presence of carbon in the steel-3 material, which serves as a center for the crystallization of carbon nanotubes, which promotes more intense formation of graphite structure.is observed, indicating the presence of well-ordered carbon nanotubes.

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Of the three substrates considered, the sample formed on steel substrate (steel-3) appears to be the most efficient. This can be explained by the presence of carbon in the steel-3 material, which serves as a center for the crystallization of carbon nanotubes, which promotes more intense formation of graphite structure.

Conclusions

The study of thin carbon films on glass, organic glass, and steel-3 substrates using Raman light scattering revealed the presence of a rather intense graphite G-band spectrum in the region of 1580 cm^{-1}-1595 cm^{-1}. This characteristic indicates the presence of well-ordered carbon nanotubes in these films.

The most interesting results were obtained when steel-3 was used as a substrate. This is probably due to the presence of carbon in steel-3, which serves as a center for condensation of carbon structures including carbon tubes. This contributes to a more efficient formation of ordered carbon nanostructures and, consequently, a more intense G-band spectrum in the Raman spectrum.

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Fedor E. Popov
NAO "Karaganda Industrial University", Kazakhstan
E-mail: fedor_popoff@mail.ru
ORCID ID 0000-0002-1204-9982

Nikita A. Lutchenko
Nazarbayev University JSC, Kazakhstan
E-mail: nikita.lutchenko@nu.edu.kz
ORCID ID 0000-0003-0283-4642

Alexander V. Panichkin
JSC "Institute of Metallurgy and Enrichment" affiliated to Satbayev University, Kazakhstan
E-mail: a.panichkin@satbayev.university
ORCID ID 0000-0002-2403-8949

Alexander S. Arbuz
Nazarbayev University JSC, Kazakhstan
E-mail: alexandr.arbuz@nu.edu.kz
ORCID ID 0000-0002-2081-0612

Investigation of the possibility of introducing yttrium oxide by vacuum induction melting to produce nickel-free stainless steel

Abstract: The possibility of smelting an oxide-dispersed strengthening steel alloy using five different approaches involving the introduction of finely dispersed Y2O3 particles into liquid Fe-13Cr steel alloy under vacuum conditions has been investigated. To achieve the objective, five series of experiments were carried out, each differing in the conditions and process of the experiments. Two series of melting, were performed to evaluate the possibility of mechanical introduction of yttrium oxide into the melt under different conditions of introduction. The subsequent three series, were carried out to study the possibility of oxidation of metallic yttrium in the melt with the formation of yttrium oxide particles. In these experiments such parameters as duration of melt holding time and residual pressure in the furnace chamber were varied. When the obtained ingots were analysed by X-ray fluorescence (XRF), inductively coupled plasma atomic emission spectroscopy (ICP-AES) and energy dispersive X-ray spectroscopy (EDS), it was found that a significant amount of yttrium oxide was not successfully incorporated into the steel volume. A method using oxidation of metallic yttrium in the melt by reduction of added iron oxide was found to be the most promising.

Keywords: ODS steel, yttrium oxide, induction furnace, nickel-free steel.

Cite this article as: Popov F.E., Panichkin A.V., Lutchenko N.A., Arbuz A.S. (2023). Investigation of the possibility of introducing yttrium oxide by vacuum induction melting to produce nickel-free stainless steel. *Challenges of Science*. Issue VI, 2023, pp. 240-244. https://doi.org/10.31643/2023.30

Introduction

The study of new materials for application in various fields of science and technology is an important task for scientists. One of the most important materials contributing to the technological progress of mankind is steel, which is widely used in various spheres of human life (Kenzhaliyev, 2019; Chukmanova et al., 2022; Ozili & Ozen, 2023). Nuclear power represents one of the solutions to the energy crisis and is becoming widespread in developed countries such as USA, China, France, Japan, etc. (Valone, 2020). This method of energy production is not only environmentally friendly but also highly efficient.

The study of structural materials for use in nuclear power generation is an important task for scientists. Steels used in this field must fulfil various requirements such as high resistance to high pressures, reactor neutron irradiation, aggressive corrosion, etc. (Wang et al., 2021). Nickel steels, which are the basic materials for all generations of nuclear plants, cannot cope as well with new generation and future reactors. One of the main problems with nickel steels is due to the fact that nickel under the influence of neutron irradiation changes to the radioactive isotope nickel-63, which creates difficulties with subsequent utilization. The

solution to this problem can be oxide dispersion hardened steels (ODS), which are ceramic particles embedded in the metal matrix of steel.

The advantages of such steels over nickel steels are their resistance to the accumulation of induced radiation on the material. The most common method of production of steels with ODS is powder metallurgy, based on the large number of scientific studies devoted to this topic. The least common methods are additive lachser melting and hybrid processes (Ermakov et al., 2013). However, the use of liquid metallurgy to create ODS steels remains a less explored area, which can be judged from the limited number of scientific publications on this topic.

In most cases, the microstructure of ODS steels is characterised by submicron grains, low defect density, presence of nano-oxides with diameter <d> ≈ 1-5 nm, density N ≈ 10^23-24 m^{-3} and content of about 0.5-1%. These structures possess coherent and semi-coherent interfaces as well as dislocations between the nanooxides and the matrix (Hirata et al., 2011; Zinkle, 2013; Stan, 2020; Zhang, et al., 2015).

In this study, a series of experiments were carried out to investigate the possibility of introducing yttrium oxide into steel using liquid metallurgy. Five series of melts were carried out, of which two studied the possibility of mechanical introduction of yttrium oxide into the melt, and in three - the possibility of oxidation of metallic yttrium with subsequent formation of yttrium oxide in the melt.

Research Methods

For the experimental part the induction vacuum furnace UIPV-0,001 was used. This furnace is designed for melting in vacuum or inert gas atmosphere at temperature up to 2200 C and residual vacuum pressure not less than 10 Pa. The materials used were AISI 410 steel, yttrium (III) oxide nanopowder sintered <50 nm (Sigma-Aldrich), metallic yttrium, pure iron powder and iron oxide powder. In the experiment, 5 series of melts were carried out under 5 different conditions each (Figure 1).

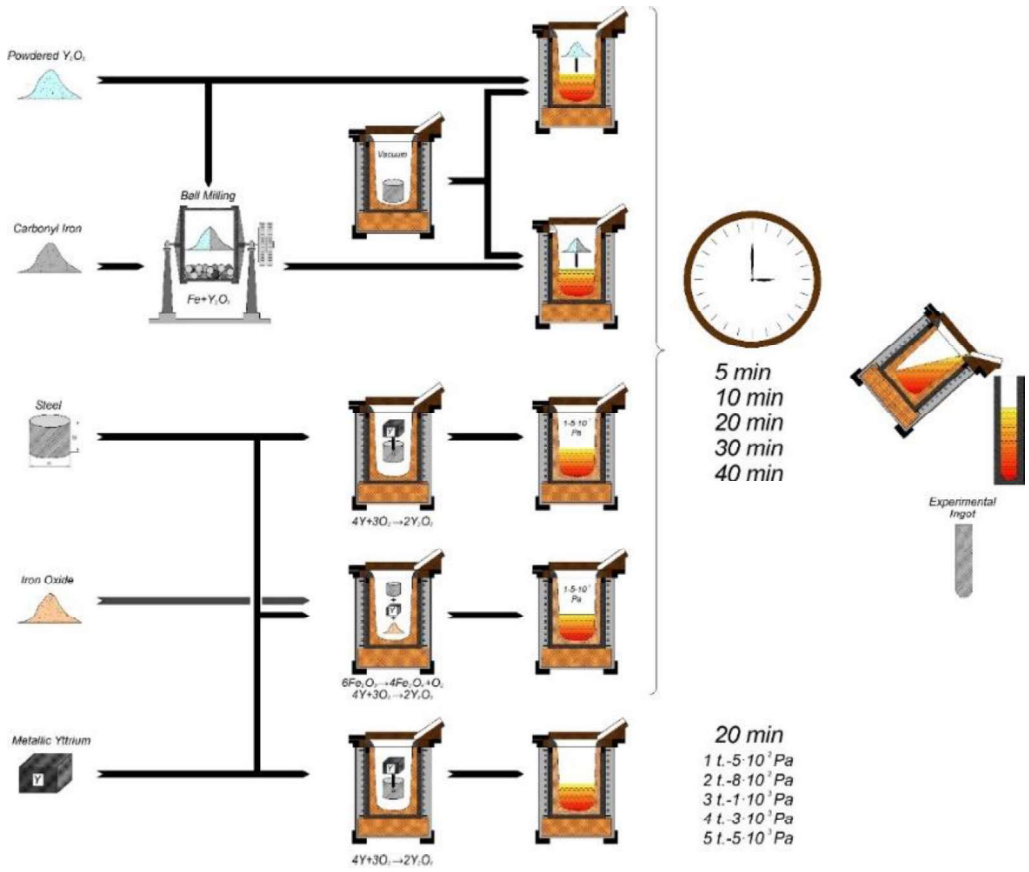

Fig. 1. Schematic diagram of the steelmaking experiment

Three techniques were used to investigate the molten steel: inductively coupled plasma mass spectrometry (ICP-MS) (Thermo scientific iCAP RQ ICP-MS), inductively coupled plasma atomic emission

spectroscopy (ICP-AES) (Thermo Fisher Scientific iCAP 6300 DUO) and scanning microscopy/energy dispersive X-ray spectroscopy (SEM/EDS) (Jeol JSM IT-200LA). For the first two analyses, chips from different locations of the ingot were used to average the results; for the EDS analysis, the steel was sawn into 5 mm thick discs and pressed into epoxy resin (Figure 2).

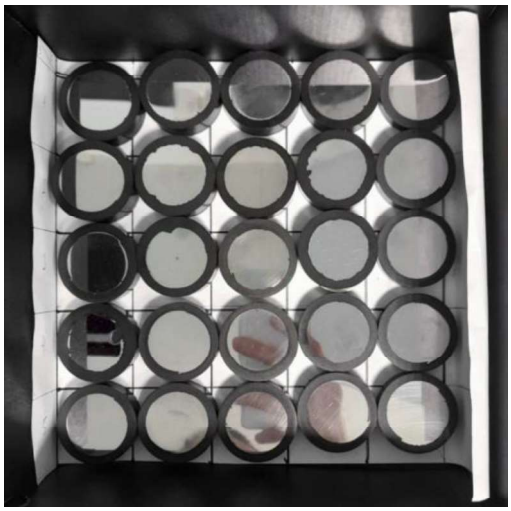

Fig. 2. Steel prepared for EDS analysis

Research experiment

During the experiment five series of experiments were carried out, and here is a brief description of each of them:

In the first series of experiments, the possibility of introducing yttrium oxide nanopowder into the melt of steel by mechanical method followed by solidification was investigated. The melting was carried out at a temperature of about 1600 °C in a vacuum atmosphere with a pressure of ≥ 100 Pa. During the experiment, the holding time of the melt in the crucible after complete melting was varied between 5, 10, 20, 30 and 40 minutes. After holding time, the steel was poured into an ingot with a diameter of 30±1 mm.

In the second series of experiments, the possibility of introducing yttrium oxide nanopowder on a carrier of pure iron powder into the steel melt was investigated. A planetary mill with tungsten carbide balls was used to mix the two powders. The powder mixture was poured into the steel melt at a temperature of about 1600 °C and under vacuum with a pressure of ≥ 100 Pa. In the experiment, the holding time of the melt in the crucible after melting the steel was varied as 5, 10, 20, 30 and 40 minutes. After holding time, the steel was poured into a crystalliser with a diameter of 30±1 mm.

In the third series of experiments the possibility of oxidation of metallic yttrium in the furnace from residual oxygen was investigated. Metallic yttrium was placed in a drilled hole in steel. Melting took place at a temperature of about 1600 °C and residual pressure in the furnace chamber in the range of 1-5·102 Pa. In the experiment, the holding time of the melt in the crucible after complete melting of the steel varied from 5 to 40 minutes. After holding time, the steel was poured into a crucible with a diameter of 30±1 mm.

In the fourth series of experiments the possibility of oxidation of metallic yttrium during reduction of iron oxide in the process of melting was investigated. Metallic yttrium was placed in a drilled hole in steel and closed with a stopper. Iron oxide powder was placed at the bottom of the crucible and steel with metallic yttrium was placed on top. Melting took place at a temperature of about 1600 °C and residual pressure in the furnace chamber in the range of 1-5·102 Pa. The experiment varied the holding time of the melt in the crucible after complete melting of the steel from 5 to 40 minutes. After holding time, the steel was poured into an ingot with a diameter of 30±1 mm.

In the fifth series of experiments the oxidation of metallic yttrium from oxygen supplied to the furnace chamber was investigated. Metallic yttrium was placed in a drilled hole in the steel and closed with a plug. The melting was carried out at a temperature of about 1600 °C and a melt residence time of 20 minutes in the furnace. During the melting process, the residual pressure in the furnace chamber varied in the range of $5 \cdot 10^2$ Pa, $8 \cdot 10^2$ Pa, $1 \cdot 10^3$ Pa, $3 \cdot 10^3$ Pa, $5 \cdot 10^3$ Pa. After tempering, the steel was poured into a mould with a diameter of 30±1 mm.

Results and discussions

The obtained steel samples were investigated by ICP-AES, ICP-MS, SEM/EDS methods. Steel melts of series I-II, in which the possibility of introducing yttrium oxide by mechanical means was investigated, did not show positive results for yttrium content in steel. But positive results were shown by melts of series III-V, where the possibility of oxidation of metallic yttrium was investigated. The results are given in Table 1. Data for melts of series I and II are not given due to lack of sufficient yttrium content. Since yttrium was detected in different fractions in different analyses, it was decided to use EDS analysis to detect yttrium oxide particles in the steel.

Table 1. ICP-AES and ICP-MS analyses of the obtained steel in III-V series of the experiment

	ICP-AES	**ICP-MS**
№ ingot	**Y, ppm**	**Y, %**
III,4	0,0127	0,28
IV,1	0,0552	0,97
IV,4	0,0044	0,17
V,1	0,0013	0,03

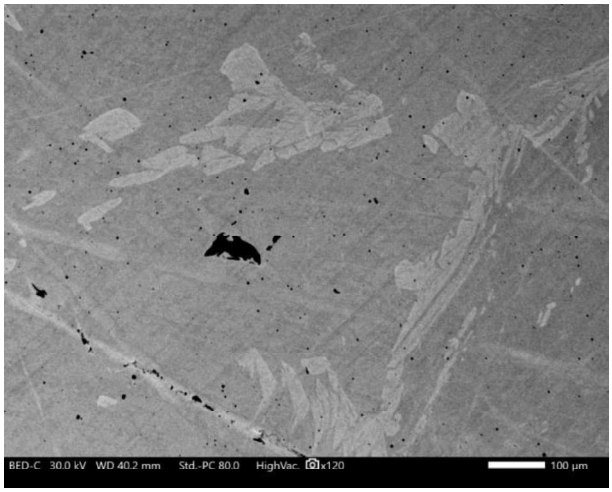

Fig. 3. SEM images of steel with non-metallic inclusions

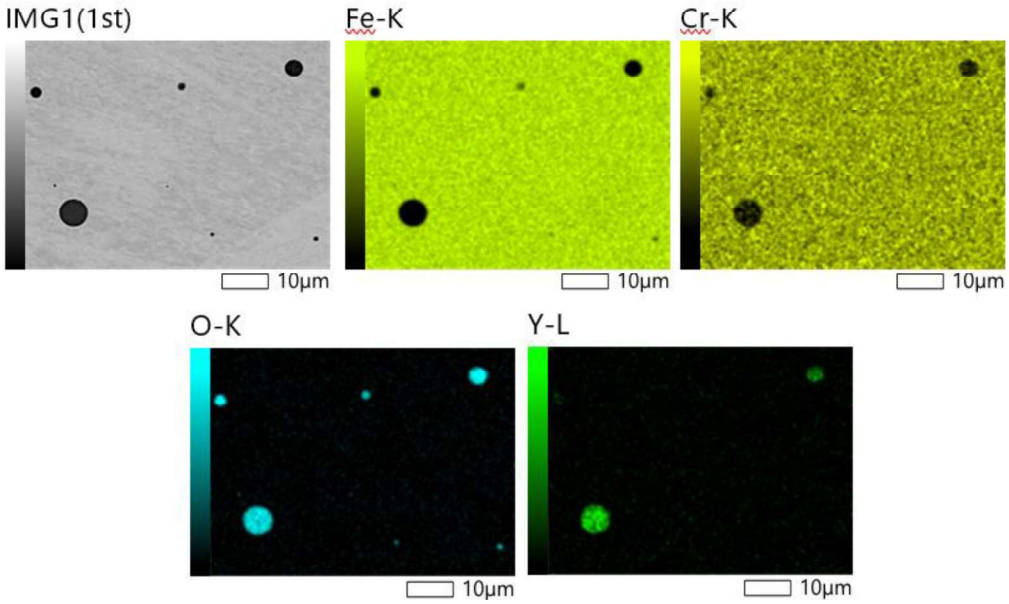

Fig. 4. EDS analysis of non-metallic inclusions

On SEM-images in the sample with a large amount of fixed yttrium(IV,1) non-metallic particles in the steel volume were visible (Fig. 3). In which yttrium concentration could be suspected, which was additionally confirmed by EDS-analysis (Fig. 4).

Conclusions

Analysis of the melted steel revealed non-metallic inclusions where yttrium and oxygen are concentrated. This observation may indicate the presence of yttrium oxide compounds in these inclusions. However, this method of introducing yttrium into the steel was not effective because yttrium oxide is not dispersed in the ferritic matrix of the steel and therefore does not fulfil the function of strengthening the material.

The study showed the following conclusions:

Obtaining ODS steel by mechanical introduction of yttrium or oxidation of metallic yttrium cannot be used as a structural material.

When the steel was melted to oxidise metallic yttrium, all the yttrium concentrated in non-metallic inclusions that do not interact with the steel matrix.

The results obtained from this work provide information for further research aimed at developing methods for producing steels with oxide-dispersed structures (ODS) using liquid metallurgy.

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Rugaya Tuanaya
Graduate School
Universitas Negeri Yogyakarta, Indonesia
E-mail: rugayatuanaya.2021@student.uny.ac.id
ORCID ID 0000-0002-1010-7026

Widihastuti
Graduate School
Universitas Negeri Yogyakarta, Indonesia
E-mail: widihastuti@uny.ac.id
ORCID ID 0000-0001-8242-658X

Edi Istiyono
Graduate School
Universitas Negeri Yogyakarta, Indonesia
E-mail: edi_istiyono@uny.ac.id
ORCID ID 0000-0001-6034-142X

Haryanto
Graduate School
Universitas Negeri Yogyakarta, Indonesia
E-mail: haryanto@uny.ac.id
ORCID ID 0000-0003-3322-904X

Validity and Reliability Analysis of Character Instruments for High School Students in Coastal Areas of Maluku

Abstract: The research is a development of character assessment instrument for high school students in coastal areas in Maluku. This study aims to test the quality of character assessment instrument of high school students in coastal areas of Maluku which consists of content validity, construct validity and reliability. The sample in this study amounted to 56 students with the sampling technique using random sampling technique. Content validity used is Aiken's V, while Confirmatory Factory Analysis is used to prove construct validity. Reliability analysis using Cronbach Alpha. The results of the analysis show that the content validity of the character assessment instrument of coastal high school students in Maluku all items have met the valid criteria, construct validity with CFA provides evidence that there are 18 items that do not fit, while the reliability coefficient is 0.9 with a very high category.

Keywords: Character education, Character of coastal students, Instrument quality.

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Introduction

Value education, moral education, character education, and character education are several interpretations of character education (Arifudin, 2022). A distinctive quality or attribute that is unique is called character. Following childhood, an individual develops a personality, which is correlated with the actions of those around them in a predictable manner (Kevin Ryan, 1999: 5). Character education is crucial for all people (Sudrajat, 2011; Manaf et al, 2020 & Irawati et al, 2022). Applied in school, home, and community environments, character education aims to form positive attitudes, foster the development of social competence, address student behavior (Gable et al., 2013), improve skills (Helterbran & Strahler, 2013), and improve good attitudes (Napitupulu, 2019).

This is consistent with Ferdiansyah's (2022) message, which is that character education essentially seeks to promote the conception of decent people with appealing, moral, modest, honest, clever, compassionate, and resilient personalities. Students that exhibit strong character will be inspired to improve in their ability and dedication to accomplish the best things, do everything properly, and have a purpose in life. In order to have a good and tough character, one must maximize one's potential while also being conscious, motivated, and feeling something for everyone and everything, including God Almighty, himself, others, the environment, nation, state, and the global community at large. Sofyan (2020) asserts that education serves a dual purpose of improving an individual's character and preparing them for the real world. Education also helps people become more skilled and ethically and aesthetically aware, and most importantly, it shapes how people

behave in daily life. As stated by Par (2017), the primary objective of character education is to instill the value of goodness. Children who live in coastal areas have a different level of character strength than children who live in agrarian, rural, or mountainous settings. The environmental factors in the occupied region are the reason for the discrepancy. The findings of Freeks (2015), Handayani & Brodjonegoro (2015), and Jennings, Mitchell, & Hannah (2014) indicated that character development is greatly influenced by the environment.

The world's largest archipelago is Indonesia. With the second-longest coastline in the world and almost two-thirds of its land covered by water, it is home to the fifth-largest population in the world, 60% of whom reside in coastal regions (Brotosusilo et al., 2016). Kinship, reciprocal collaboration, and well-established family trust are traits of Indonesian coastal communities, according to research by (Cahaya, 2015; Wekke & Cahaya, 2015). Fatalism (respect for God, people, nature, and life) is a belief held by some (Hakim, 2019). People who live near the coast follow the advice of local knowledge while making decisions. Noble values are applicable according to local wisdom, and as a result, youngsters living near the coast should abide by these principles.

Character education ought to be tailored to the needs of students' everyday situations (local knowledge) in order to help them overcome obstacles in life. In coastal regions, "local wisdom" describes actions that develop into a way of life. All people who live along the coast have an obligation to cultivate character values. Teachers will find it easier to provide assessments in the classroom that are focused on learning success because of the values that students have been assigned. Students that possess high standards of morality and integrity will help them succeed academically. Furthermore, one of the goals of the Pancasila Student Profile is that this can be a strength in overcoming the problems of 21st-century living.

Research Methods

***Participants*.** This research is development research with the aim to produce products in the form of non-cognitive instruments, namely character assessment instruments for high school students in the coastal areas of Maluku. The development stages follow the steps of instrument development from Istiyono (2020), namely: (1) Determination of objectives, (2) Determination of competencies and materials to be tested, (3) Preparation of item distribution matrix, (4) Preparation of grids, (5) Writing and assembling test items, (6) Preparation of scoring rubrics, (7) Validity of test items, (8) Revision to improve test items, (9) Instrument assembly and (10) Test trials. The sample in this study were high school students who lived in the coastal areas of Maluku, totaling 56 people. Sampling in this study using random sampling technique.

Measurement. The instrument used in this study is a character assessment instrument for high school students in Maluku coastal areas. Based on the number of answer options, this instrument consists of 56 items and uses a Likert model scale with five answer options, namely: "very appropriate", "Always/Strongly", "Agree Often/Agree", "Sometimes/Doubt", "Rarely/Disagree", "Never/Strongly Disagree". The use of the middle option is intended to facilitate participants who have a moderate attitude towards the statements given (Klopfer & Madden, 1980). It is feared that not providing a middle option will cause participants to feel "forced" to choose bipolar answer choices.

In this study, the content validity was analyzed using Siken's V index. The construct validity of the character assessment instrument of high school students in Maluku coastal area was analyzed by Confirmatory Factor Analysis (CFA) with the help of LISREL software (Jöreskog & Sörbom, 2006). CFA is part of factor analysis used to test the extent to which each indicator reflects the dimensions of a construct (Pedhazur, 1997). In this case, the extent to which the items of a research instrument are valid in measuring what is to be measured. Reliability analysis uses crocbach alpha which is analyzed using the help of R Studio software.

Instrument Characteristics. The product developed in this research is a non-cognitive instrument, namely a character assessment instrument for high school students in the Maluku coastal area which is a questionnaire instrument for students. The initial design of the questionnaire instrument is shown in Table 1.

Table 1. Draft character assessment instrument for high school students in Maluku coastal area

No.	Character	Number of Item
1	Religious	10
2	Be friendly	13
3	Work-hard	6
4	Caring for Parents	9

5	Independent	7
6	Discipline	11
	Total	56

The developed instrument contains 6 character values, each of which is represented by items that have been tested valid. The instrument consists of a grid and a questionnaire instrument.

Results and Discussion

The research results display and discuss the content validity, construct validity, and reliability of the character assessment instrument for high school students in the coastal areas of Maluku.

***Content Validity*.** The design of the character assessment instrument for high school students in Maluku coastal areas was analyzed by experts to determine content validity. There were seven experts who became validators so that the minimum value of the v index that must be achieved based on Siken's V index is 0.75 (Aiken, 1985). The results of expert validation showed that all items on the character assessment instrument of high school students in the coastal area of Maluku had met the criteria of "valid". Overall, the content validity of all items on the character assessment instrument of high school students in the coastal areas of Maluku is in the very valid category or has high validity, because the lowest index is 0.75 and the highest is 0.93 which is a high validity category (Istiyono, 2020: 350). The results of the Aiken index calculation are presented in table 2.

Table 2. Aiken index calculation results

No	Expert							S1	S2	S3	S4	S5	S6	S7	Sigma S	V	Criteria
	1	2	3	4	5	6	8										
Bt1	4	5	4	5	5	4	5	3	4	3	4	4	3	4	25	0,89	Valid
Bt2	3	5	4	4	5	3	5	2	4	3	3	4	2	4	22	0,79	Valid
Bt3	5	5	5	4	5	5	5	4	4	4	3	4	4	4	27	0,96	Valid
Bt4	5	5	3	4	3	5	3	4	4	2	3	2	4	2	21	0,75	Valid
Bt5	3	4	4	4	4	5	4	2	3	3	3	3	4	3	21	0,75	Valid
Bt6	5	5	5	5	4	4	5	4	4	4	4	3	3	4	26	0,93	Valid
Bt7	5	5	5	5	5	4	5	4	4	4	4	4	3	4	27	0,96	Valid
Bt8	5	4	5	5	4	4	5	4	3	4	4	3	3	4	25	0,89	Valid
Bt9	4	3	4	5	5	4	3	3	2	3	4	4	3	2	21	0,75	Valid
Bt10	5	5	5	5	4	4	5	4	4	4	4	3	3	4	26	0,93	Valid
Bt11	5	5	5	4	5	4	4	4	4	4	3	4	3	3	25	0,89	Valid
Bt12	3	4	3	5	5	4	4	2	3	2	4	4	3	3	21	0,75	Valid
Bt13	3	4	4	5	5	4	4	2	3	3	4	4	3	3	22	0,79	Valid
Bt14	5	3	4	4	5	4	4	4	2	3	3	4	3	3	22	0,79	Valid
Bt15	5	4	5	5	4	4	5	4	3	4	4	3	3	4	25	0,89	Valid
Bt16	5	4	4	5	5	4	5	4	3	3	4	4	3	4	25	0,89	Valid
Bt17	3	4	4	4	4	4	5	2	3	3	3	3	3	4	21	0,75	Valid
Bt18	4	5	5	5	5	4	3	3	4	4	4	4	3	2	24	0,86	Valid
Bt19	4	5	4	5	4	2	5	3	4	3	4	3	1	4	22	0,79	Valid
Bt20	4	4	4	5	4	4	5	3	3	3	4	3	3	4	23	0,82	Valid
Bt21	5	5	4	5	3	4	5	4	4	3	4	2	3	4	24	0,86	Valid
Bt22	4	4	4	5	5	4	5	3	3	3	4	4	3	4	24	0,86	Valid
Bt23	4	4	3	5	5	4	5	3	3	2	4	4	3	4	23	0,82	Valid
Bt24	5	5	5	5	5	4	5	4	4	4	4	4	3	4	27	0,96	Valid
Bt25	5	4	5	5	5	3	4	4	3	4	4	4	2	3	24	0,86	Valid
Bt26	4	4	5	5	4	3	5	3	3	4	4	3	2	4	23	0,82	Valid
Bt27	4	4	5	5	4	3	5	3	3	4	4	3	2	4	23	0,82	Valid
Bt28	5	5	5	5	4	2	4	4	4	4	4	3	1	3	23	0,82	Valid

No	Expert							S1	S2	S3	S4	S5	S6	S7	Sigma S	V	Criteria
	1	2	3	4	5	6	8										
Bt29	5	5	4	5	5	3	4	4	4	3	4	4	2	3	24	0,86	Valid
Bt30	5	4	4	5	4	3	5	4	3	3	4	3	2	4	23	0,82	Valid
Bt31	5	4	4	5	5	3	5	4	3	3	4	4	2	4	24	0,86	Valid
Bt32	5	3	4	5	4	3	5	4	2	3	4	3	2	4	22	0,79	Valid
Bt33	5	4	4	5	4	4	5	4	3	3	4	3	3	4	24	0,86	Valid
Bt34	5	4	4	5	4	3	5	4	3	3	4	3	2	4	23	0,82	Valid
Bt35	5	5	4	5	5	3	4	4	4	3	4	4	2	3	24	0,86	Valid
Bt36	5	5	3	5	5	5	5	4	4	2	4	4	4	4	26	0,93	Valid
Bt37	4	3	4	5	4	5	3	3	2	3	4	3	4	2	21	0,75	Valid
Bt38	5	5	4	5	3	4	5	4	4	3	4	2	3	4	24	0,86	Valid
Bt39	4	5	5	5	5	4	5	3	4	4	4	4	3	4	26	0,93	Valid
Bt40	5	5	4	5	5	4	5	4	4	3	4	4	3	4	26	0,93	Valid
Bt41	5	2	4	5	4	4	5	4	1	3	4	3	3	4	22	0,79	Valid
Bt42	5	4	3	5	5	3	5	4	3	2	4	4	2	4	23	0,82	Valid
Bt43	3	3	4	5	4	5	4	2	2	3	4	3	4	3	21	0,75	Valid
Bt44	5	3	4	5	4	4	5	4	2	3	4	3	3	4	23	0,82	Valid
Bt45	5	5	3	5	3	4	5	4	4	2	4	2	3	4	23	0,82	Valid
Bt46	3	4	5	5	3	4	4	2	3	4	4	2	3	3	21	0,75	Valid
Bt47	5	4	4	5	4	4	5	4	3	3	4	3	3	4	24	0,86	Valid
Bt48	5	5	4	4	5	4	5	4	4	3	3	4	3	4	25	0,89	Valid
Bt49	5	4	4	5	5	4	5	4	3	3	4	4	3	4	25	0,89	Valid
Bt50	5	4	5	5	5	4	5	4	3	4	4	4	3	4	26	0,93	Valid
Bt51	5	5	4	5	4	4	5	4	4	3	4	3	3	4	25	0,89	Valid
Bt52	5	4	4	5	5	5	5	4	3	3	4	4	4	4	26	0,93	Valid
Bt53	5	5	3	5	3	5	4	4	4	2	4	2	4	3	23	0,82	Valid
Bt54	5	5	4	5	5	4	5	4	4	3	4	4	3	4	26	0,93	Valid
Bt55	5	4	4	5	5	3	5	4	3	3	4	4	2	4	24	0,86	Valid
Bt56	5	4	4	5	5	4	5	4	3	3	4	4	3	4	25	0,89	Valid

Construct Validity. Then the instrument was tested on 56 students. The results of the trial were subjected to classical item analysis and proof of construct validity and reliability analysis. instrument to determine item validity and instrument reliability. Proof of construct validity using Confirmatory Factor Analysis with Goodness of Fit criteria that must be met to declare a fit construct refers to the opinion of Schermelleh-Engel, Moosbrugger & Mueler (2003: 52) and Hair, Black, Babin et al. (2014: 578-581) which states, there are three types of Goodness of Fit measures, namely Absolute Fit Indices, Incremental Fit Indicies and Persimonius. The three types are explained by Latan (2013: 53) as presented in table 3.

Table 3. Goodness of Fit Summary

Types of goodness of fit measure	Types	Cut-off value
Absolute fit indices	1. Chi-Square (X^2)	≤ 0
	2. Goodness-of-Fit Index (GFI)	>0,9
	3. Root Mean Square Error of Approximation (RMSEA)	0,05-0,08
Incremental Fit	1. Goodness of Fit Index (AGFI)	≥ 0,9
	2. Normed Fit Index (NFI)	> 0,90; > 0,95
	3. Comparative Fit Index (CFI)	> 0,90; > 0,95
	4. Incremental Fit Index (IFI)	> 0,90; > 0,95
	5. Relative Fit Index (RFI)	> 0,90; > 0,95

Persimonius	1. Parsimonius Normed Fit Index (PNFI)	0,06-0,09
	2.Parsimonius Goodness of Fit Index (PGFI)	>0,60

The results of the analysis in order to prove construct validity using Lisler software show that the model does not fit because it only meets three values, namely Chi-Square ($X2$) 0.000, RMSEA 0.14 and PNFI 0.29. The analysis results are presented in table 4.

Table 4. Confirmatory Factor Analysis Results Second Order Analysis

Size type goodness of fit	Types	Value	Information
Absolute fit indices	1. Chi-Square (X^2)	0,000	Meet
	Goodness-of-Fit Index (GFI)	0,35	Does not meet
	Root Mean Square Error of Approximation (RMSEA)	0,14	Meet
Incremental Fit	Adjusted Goodness of Fit Index (AGFI)	0,29	Does not meet
	Normed Fit Index (NFI)	0,30	Does not meet
	Comparative Fit Index (CFI)	0,39	Does not meet
	Incremental Fit Index (IFI)	0,40	Does not meet
	Relative Fit Index (RFI)	0,27	Does not meet
Persimonius	Parsimonius Normed Fit Index (PNFI)	0,29	Meets Not meets
	Parsimonius Goodness of Fit Index (PGFI)	0,32	

The results of the model fit analysis using second order conducted on R Studio software are presented in Figure 1 in the form of a path diagram. Figure 1 shows that the results of the trial data analysis for each item that has a factor weight value of more than 0.5 are 38 items and items that have a weight value of <0.5 are 18 items. The factor weight value of each item shows adequate validity. The criteria used to declare the factor weight acceptable or valid refers to the opinion (Ghozali & Fuat, 2014: 158). Because there are 18 items that have a factor weight of less than 0.5, they can be accepted or valid. It was concluded that in the development of character instruments for high school students in Maluku coastal areas, there were 18 items that were not valid according to the construct. This then requires follow-up whether the item will be removed or corrected and retested.

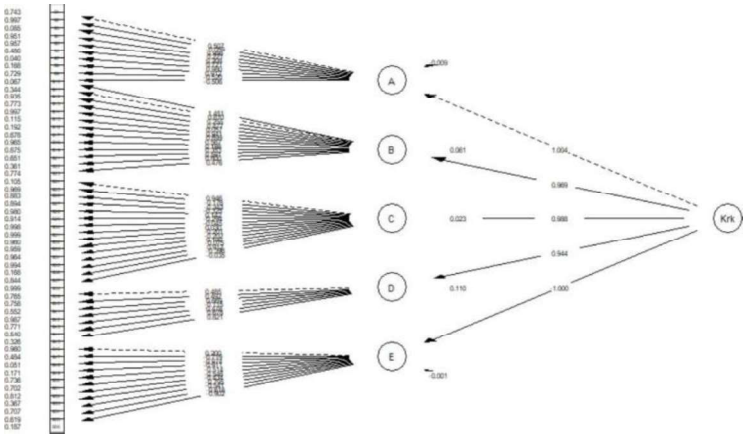

Figure 1. Standardized Solution of Second Order Approach

Reliability. Reliability analysis was carried out on 56 items of character instruments for high school students in Maluku coastal areas. The analysis was carried out using the Cronbach Alpha method performed on the R Studio software, which provided information on the Cronbach alpha value of 0.9 with a very high level of reliability (Istiyono: 2020). This value also shows that the reliability of the instrument has been met, which is more than 0.7 so that the instrument for assessing the character of high school students in the Maluku coastal area can be used by teachers and students (Wells, C.S., & Wollack, 2003). The results of the analysis are presented in Figure 2.

```
> print(rangkum_0, digits = 1)
           [,1]
nItem      55.0
nPerson    56.0
alpha       0.9
scaleMean 178.0
scaleSD    35.6
```

Figure 2. Cronbach alpha analysis results

Conclusion

The content validity test on the character assessment instrument for high school students in the Maluku coastal area shows that all items are categorized as valid, while the construct validity shows that the results of the trial data analysis for each item that has a factor weight value of more than 0.5 are 38 items and items that have a weight value <0.5 are 18 items, and the reliability value is 0.9 with a very high reliability level category. Future research is expected to perfect the process of proving construct validity, namely by fixing 18 items that have not met the criteria for goodness of fit.

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Ibnu Rafi
Yogyakarta State University, Special Region of Yogyakarta, Indonesia
E-mail: ibnurafi789@gmail.com
ORCID ID 0000-0002-6809-4678

Heri Retnawati
Yogyakarta State University, Special Region of Yogyakarta, Indonesia
E-mail: heri_retnawati@uny.ac.id
ORCID ID 0000-0002-1792-5873

How do Indonesia and New Zealand facilitate their students in learning statistics? A comparative study on the intended mathematics curriculum

Abstract: Students' learning outcomes can be influenced by the intended curriculum as the main guidelines for teachers in facilitating their students to learn. Comparative study can be conducted to evaluate to what extent the intended curriculum of a country is designed to give an opportunity for students to learn compared to the other countries. The present comparative study was aimed at describing the similarities and differences between Indonesia and New Zealand in facilitating their students in learning statistics. To gain this objective, the official documents of curriculum of those Countries were analyzed qualitatively. The analysis was focused on the expected competence. The results show that New Zealand provides more facilities for their students in learning statistics through statistical investigation and literacy than Indonesia. At the particular level, both Indonesia and New Zealand give the same content but the depth of the discussions given to their students is different. These results could be beneficial for both countries as well as the others as the consideration to improve the quality of their curriculum.

Keywords: comparative study, Indonesia and New Zealand, intended curriculum, statistics.

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Introduction

An education held by a country has the aims and purposes which might be different from the other countries because of the existing difference in terms of the national philosophy of education which they are referring to. Education plays a crucial role in a country as well as for the citizen of that country as it can be used as a means for promoting good quality of the economy, society, and human being. According to Idris, Hassan, Ya'acob, Gill, and Awal (2012), the essential purpose of education is to facilitate individuals to become knowledgeable and internalize the attitudes and moral values of their society so that they can actively and efficiently participate in developing their society as well as contribute to the development of their country. Furthermore, Bhardwaj (2016) states that the education conducted by a country, basically, is intended to educate people so that they become better citizens who have a good character and time management, more confidence in doing something useful and communicating with others, and also successful in pursuing their desired goal.

In general, the practice of the implementation of education can be divided into three forms of education. These three forms of education consist of formal education, non-formal education, and informal education. The formal education, which it becomes the focus of this study, is a well-organized and structured form of education in which it has to involve the educator, the student, and the educational institution and also it cannot be separated from a curriculum (Dib, 1988; Grajcevci & Shala, 2016). Glatthorn, Boschee, and Whitehead (2009) define curriculum as the widely accessible plans which are intentionally developed to be used as a

guideline for conducting educational activities in the schools and the realization of those plans in the classroom with all of the unplanned things in the learning environment which might affect the process of educational activities. Such unplanned things are well-known with the term 'hidden curriculum'. Referring to this definition, it can be said that the curriculum does really matter in conducting educational activities. The importance of the curriculum is also supported by Wijaya (2017) who revealed that the performance of students could be affected by the curriculum.

Actually, the curriculum should not be defined in only one fixed definition because it has various definitions that rely on the point of view and agenda of each educational authorities or stakeholders (Su, 2012). For instance, Su (2012), through her study on the various perspectives of curriculum, summarized the concepts of curriculum into five perspectives from the narrowest one to the broadest based on its components; namely curriculum as a set of educational objectives, as content of subject matters, as plans, as documents, and as programs for experiences. In the narrowest perspective, curriculum is seen as set of desired educational objectives that should be achieved by students through educational activities. In contrast, in the broadest perspective, curriculum is perceived as holistic and interactive programs for experiences in which it not only covers the planned components such as documents in the form of syllabus (content of subject matter, educational goals, instructional methods, and assessment), but it also covers the learning environment and extracurricular activities, hidden curriculum, and cultures.

The perspectives on the curriculum proposed by Su (2012) are similar to the model of curriculum in which it divides into three levels; namely the intended curriculum, implemented curriculum, and attained curriculum (Eggen, Pelgrum, & Plomp, 1987; Hirsch & Reys, 2009; Leung, 1992; Valverde, Bianchi, Wolfe, Schmidt, & Houang, 2002; van den Akker, 2003). Of these literatures, the intended curriculum could be specified as the official, standard, and national documents issued by the government in which it usually includes the rationale or philosophical foundation of conducting education, the learning objectives or the expected learning outcomes, the content standard of learning that is expected to be learned by the students, and the methods that can be used by the teachers to facilitate students to learn in the learning process. Arguably, the intended curriculum is the curriculum that lies on the level of educational system of a country. The intended curriculum which is implemented in educational institution (i.e. school) and classroom, then, is perceived as the implemented curriculum. Similarly, the implemented curriculum reflects contents, methods, strategies, and activities of learning which are actualized by the teacher throughout the process of learning in the classroom. The last, what the students have experienced and gained through that learning process facilitated by the teacher is known as the attained curriculum. Such three levels model of curriculum, later, could be expanded by adding the potentially implemented curriculum as a level between the intended and implemented curriculum (Hirsch & Reys, 2009; Schmidt, Raizen, Britton, Bianchi, & Wolfe, 2002; Valverde et al., 2002). The potentially implemented curriculum, also well-known as the textbook curriculum, refers to the instructional material that are used to support in understanding and implementing the intended curriculum and it can be in the form of the textbook, workbook or educational software (Hirsch & Reys, 2009; Schmidt et al., 2002; Valverde et al., 2002).

Considering the aforementioned model of curriculum, it can be argued that the intended curriculum is the crucial thing for conducting education in a country due to its significant influence towards the implemented and attained curriculum. Other than that, Hirsch and Reys (2009) states that the implemented curriculum provides a guidance in developing textbook and assessment as a tool to monitor the program of school and students learning. In addition, what students attained (i.e., achievements and attitudes) from the learning process facilitated by their teachers, eventually, determined by the intended curriculum. The empirical study conducted by Zuzovsky (2003) showed that the implemented curriculum is the determining factor, although it is not the one and only, of students' learning outcomes.

To know the students' learning outcomes, what students know and can do, the assessment should be conducted. The assessment could be conducted locally, nationally, or internationally. International assessment has attracted the attention of many countries and even some of those countries decided to reform their educational system, which it may include the intended curriculum, after taking into consideration on the results of that international assessment. The two international assessments which commonly have gained more attention than others from many countries are the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS). PISA is a triennial assessment which is aimed to assess the students of 15 year olds in reading literacy, mathematics literacy, and science literacy (OECD, 2019). PISA is considered as the assessment which not relies on the curriculum standard (Volante, 2018;

Wijaya, 2017) because such assessment is focused on examining students' competence in generalizing and applying what they have learned in school in unfamiliar setting (OECD, 2019). In contrast, TIMSS, which is a quadrennial assessment conducted to examine the fourth and eighth grades students in science and mathematics, is the assessment which uses curriculum of three levels as previously mentioned (Mullis & Martin, 2017). Consequently, when we are discussing about the intended curriculum of a country, then referring the results of TIMSS becomes much more relevant. Furthermore, Mullis and Martin (2017) also states that the data of TIMSS results combined by the context questionnaire scales can be utilized to monitor the possibly impact caused by the certain educational policies and detect exactly in which areas students are less success than expected.

The TIMSS assessment is constructed based on the two dimensions, namely content dimension that reflects the subject matter (i.e., mathematics and science) and cognitive dimension that reflects the students' process of thinking (Mullis & Martin, 2013, 2017). In case of mathematics subject at the fourth grade, the content dimension comprises of three content domains, namely number, measurement and geometry, and data. While at the eighth grade, it comprises of four content domains, namely number, algebra, geometry, and data and probability. Data, as one of content domains that appears at fourth and eighth grades, is considered as the important content that should be learned by every student at school by means of understanding, handling, and using data to solve problems. Because statistics is concerned with working on the data, the aforementioned statement becomes relevant along with the necessity of students to be facilitated in learning statistics at school. In addition, Christozov, Chukova, and Mateev (2007) argued that learning statistics is so important as it applies in many field. Discussing about handling data and statistics, one of the countries that should be considered in this case is New Zealand. Forbes (2014) states that "New Zealand has been leading the world in terms of the data handling, and in more recent years, data visualisation approach in its school statistics curriculum" (p. 1). Moreover, the latest TIMSS results in Mathematics (Mullis, Martin, Foy, & Hooper, 2015b, 2015a) showed that New Zealand at the position between intermediate international benchmark and high international benchmark in which the New Zealand students perform best in the data and data and probability domain. Accordingly, it would be interesting to study about the curriculum of New Zealand specifically in the data and probability domain.

The results data of international assessment, especially TIMSS, provides such a wide opportunity for us to perform a cross-national or international comparative study. This type of study is conducted to compare the two or more countries at the national context in which the objects of study can be in the form of the educational system and policy, national regulation, and political issue (Cai, Mok, Reddy, & Stacey, 2016; Wahlström, Alvunger, & Wermke, 2018). In the context of educational system and policy, some of the objectives of comparative study as mentioned by Postlethwaite (Cai et al., 2016) are to identify the possible contributing factors to the educational system and outcomes as well as to describe the similarities and differences between educational systems and interpret the possible reasons behind the existence of them. This study, therefore, was intended to analyze the similarities and differences between intended curriculum of Indonesia and New Zealand in the domain of statistics because Indonesia has a low performance in TIMSS, especially in the data domain (Mullis et al., 2015b, 2015a).

Research Methods

This is a comparative curriculum study (Cai et al., 2016) in which the cross-national qualitative study with documentary methods (Mangen, 1999) were carried out in this study. The main object of this study was the intended mathematics curriculum of Indonesia and New Zealand. As a consequence, to achieve the objective of this study, the official documents of intended mathematics curriculum of both countries were analyzed qualitatively. The documents that were analyzed in the present study were the Regulation of Minister of Education and Culture of the Republic of Indonesia Number 37 of 2018 on Amendment to Regulation of Minister of Education and Culture Number 24 of 2016 on Core Competencies and Basic Competencies of Subject Matter in Curriculum 2013 for Units of Primary and Secondary Education (MoEC, 2018) and the New Zealand curriculum for English-medium teaching and learning in years 1–13 (MoE, 2015). The analysis of these documents was begun with the preliminary investigation into educational structures of those two countries (see Table 1) and after that the analysis was continued on the national mathematics curriculum. Lastly, we analyzed on the learning objectives in statistics domain and the extent to which the statistics contents are designed to facilitate students to learn statistics.

Table 1. An overview of Education System in Indonesia and New Zealand

Age Range	New Zealand			Indonesia	
	Year	Typical Curriculum Level	School Level	School Level	Grade
5-6	1	Early Level 1	Primary school		
6-7	2	Level 1		Elementary school	1
7-8	3	Early Level 2			2
8-9	4	Level 2			3
9-10	5	Early Level 3			4
10-11	6	Level 3			5
11-12	7	Early Level 4	Primary school or intermediate school		6
12-13	8	Level 4		Junior high school	7
13-14	9	Early Level 5	Secondary school; Junior secondary school		8
14-15	10	Level 5			9
15-16	11	Level 6	Secondary school; Senior secondary school	Senior high school	10
16-17	12	Level 7			11
17-18	13	Level 8			12

(Christozov et al., 2007; KICE & NZQA, 2015; MoE, n.d., 2015; Torar & Wahono, 2016)

Results and Discussion

In Indonesia, the existing curriculum was designed in order to facilitate their students to develop their competences in which these competences comprise of spiritual attitude competences, social attitude competences, knowledge competences, and skills competences (MoEC, 2018). The last two competences, then, were divided into core competences and basic competences. The core competences among the subject matters are not different, while the basic competences among the subject matters were set to be different. In the case of mathematics subject matter, there are five focus or scope of mathematics materials that are expected to be learned by students in elementary and high school. These are the concepts and operations of number, relation and algebra, measurement and geometry, statistics and probability, and calculus. What students expected to learn those five mathematics scopes when they are learning at school from 1st grade of elementary school until 12th grade of senior high school is set by basic competencies in knowledge and skills domain as well.

As for in New Zealand, the 'Mathematics and Statistics' is considered as one of eight learning areas specified in the New Zealand curriculum. That learning area is not considered as "Mathematics" because of some differences between them in terms of ways of thinking and the ways of solving problems (MoE, 2015). This learning area, then, derived into three strands, namely number and algebra, geometry and measurement, and statistics. The statistics strand is divided into three focus of learning competences, i.e., statistical investigation, statistical literacy, and probability. In contrast to the mathematics curriculum of Indonesia, what students expected to learn or achieve is set by the levels, i.e., level 1 up to level 8 (see Table 1). These levels are created with the aim to provide an opportunity for their students to understand the concepts within mathematics and statistics "at their own pace and go as far as they feel comfortable with" (Christozov et al., 2007).

Considering the structure of education system in Indonesia and New Zealand as provided in Table 1, the comparisons between both countries in facilitating their students to learn statistics are be presented in Table 2 up to Table 9. Such interesting result in which the statistical literacy is explicitly mentioned in the intended curriculum of the New Zealand. The statistical literacy is one of competencies required to be developed by the students in the era of fourth industrial revolution. This literacy minimally includes the understanding towards the rationale of collecting data, the data collected by using random and non-random sampling techniques, data privacy issue, the way to create descriptive analysis, the reason behind the data adjustment, and predictive modeling (Gould, 2017). Even though in the intended mathematics curriculum of Indonesia does not mention explicitly the competence of statistical literacy, the provided descriptions in Table 4, for instance, has represented that the intended mathematics curriculum of Indonesia also facilitates their students to develop their statistical literacy by means of learning statistics.

The result of this study also showed that students in New Zealand are facilitated to learn statistics in every year of the study, from year 1 up to year 13. In contrast, at the several grades, the students in Indonesia

are not facilitated to learn statistics (see Table 2, Table 7, and Table 8). Moreover, students in New Zealand is facilitated to learn statistics earlier than students in Indonesia in which the students in New Zealand start to learn statistics at the Year 1, while the students of Indonesia start to learn statistics when they at the Grade 3. Therefore, when the students of Indonesia and New Zealand are sitting down at the same age or year, the content learned by students of New Zealand more advanced than Indonesia.

Table 2. The competence in statistics expected to be achieved by students by the end of year 2

Country	Aspect	Description
Indonesia	Basic Competence in the Knowledge Domain	-
	Basic Competence in the Skills Domain	-
New Zealand	Statistical Investigation	Employ the statistical enquiry cycle (posing and solving questions; collecting, classifying and counting, and presenting category data; and discussing the results) as a means of investigation activities
	Statistical Literacy	Construct an interpretation of the statements made by the other students based on the statistical enquiries and probability activities

Table 3. The competence in statistics expected to be achieved by students by the end of year 4

Country	Aspect	Description
Indonesia	Basic Competence in the Knowledge Domain	Give an explanation towards the data related to the student itself in which that data is displayed in the form of pictogram
	Basic Competence in the Skills Domain	Display the data about the student itself in the form of pictogram
New Zealand	Statistical Investigation	Carry out investigations through the cycle of statistical enquiry (i.e. pose and answer the problems; collect and handle the categorical and whole-number data)
	Statistical Literacy	Make a comparison towards the statements with the attributes of simple data displays from probability activities and statistical enquiries

Table 4. The competence in statistics expected to be achieved by students by the end of year 6

Country	Aspect	Description
Indonesia	Basic Competence in the Knowledge Domain	Give an explanation towards the data related to the student itself and his surroundings in which that data is displayed in the form of bar chart
		Give an explanation towards the data related to the student itself or his surroundings and the methods used to collect that data
		Explain the data display related to the student itself and compare it to the data from his surroundings in the form of data list, table, pictogram, bar chart, or line chart
	Basic Competence in the Skills Domain	Collect the data related to the student itself and his surroundings and display that data in the form of bar chart
		Analyze the data related to the student itself or his surroundings and the methods used to collect that data
		Organize and display the data related to the student itself and compare it to the data from his surroundings in the form of data list, table, bar chart, pictogram, or line chart
New Zealand	Statistical Investigation	Carry out investigations through the cycle of statistical enquiry (i.e. collect and handle multivariate categorical, whole number and time-series data to find Solutions to the question; recognize pattern and trend within and between the sets of data; and communicate the findings by using data displays)
	Statistical Literacy	Make a judgment towards the other students' work on presenting the findings of the statistical enquiries and probability activities

Table 5. The competence in statistics expected to be achieved by students by the end of year 8

Country	Aspect	Description
Indonesia	Basic Competence in the Knowledge Domain	Explain and compare the mode, median, and mean of the ungrouped data in order to determine which value best represents that data
		Analyze the relationship between the data and data display (table, line chart, bar chart, and pie chart)
	Basic Competence in the Skills Domain	Solve a problem related to mode, median, and mean of the ungrouped data
		Display and interpret the data in the form of table, line chart, bar chart, and pie chart
New Zealand	Statistical Investigation	Devise a plan and also carry out investigations through the cycle of statistical enquiry (i.e., decide the suitable variables and methods to collect data; recognize any patterns and trends by means of working on multivariate category and time-series data; visualize the comparison of distributions; and present the findings properly)
	Statistical Literacy	Conduct an evaluation towards the other students' statements on the findings of the statistical enquiries and probability activities

Table 6. The competence in statistics expected to be achieved by students by the end of year 10

Country	Aspect	Description
Indonesia	Basic Competence in the Knowledge Domain	Analyze the data according to the data distribution, mode, median, and mean to make a conclusion, decision, and prediction
	Basic Competence in the Skills Domain	Pose and solve the problem related to the data distribution, mode, median, and mean to make a conclusion, decision, and prediction
New Zealand	Statistical Investigation	Carry out the cycle of statistical enquiry such as make a comparison sample distribution by using centre, spread, and proportion measures
	Statistical Literacy	Make a judgment on the statistical enquiries or probability activities conducted by the other students which includes, for instance, the judgment about the validity of obtained results

Table 7. The competence in statistics expected to be achieved by students by the end of year 11

Country	Aspect	Description
Indonesia	Basic Competence in the Knowledge Domain	-
	Basic Competence in the Skills Domain	-
New Zealand	Statistical Investigation	Carry out the cycle of statistical enquiry such as manage the sources of variation through the use of random sampling and make an informal inference
	Statistical Literacy	Make a judgment towards the reports issued in the media based on the aspects of data display, statistics, and methods used to derive a claim

Table 8. The competence in statistics expected to be achieved by students by the end of year 12

Country	Aspect	Description
Indonesia	Basic Competence in the Knowledge Domain	-
	Basic Competence in the Skills Domain	-
New Zealand	Statistical Investigation	Carry out the cycle of statistical enquiry including work with random sampling techniques and exploratory data analysis as parts of the investigation towards phenomena
		Make an informal predictions and recognize the influence of sample size on the variability of an estimate

Country	Aspect	Description
	Statistical Literacy	Make a judgment based on the statistical concepts to the report by means of make an interpretation towards the risk and relative risk and identify the errors either caused by or not caused the random selection

Table 9. The competence in statistics expected to be achieved by students by the end of year 13

Country	Aspect	Description
Indonesia	Basic Competence in the Knowledge Domain	Determine and analyze the central tendency and distribution of the data which represents in the form of histogram and the table of frequency distribution
		Explain the characteristic of the data which normally distributed
	Basic Competence in the Skills Domain	Determine the solutions to the problem related to the data displays from the result of measurement and enumeration in the form of histogram and the table of frequency distribution
		Solve a problem related to normal distribution and its inference
New Zealand	Statistical Investigation	Carry out the cycle of statistical enquiry including conduct experiment using the principles of experimental design and survey and work with the additive model and linear regression as parts of conducting investigation towards the phenomena
		Determine the estimation and confidence interval for proportion and means, recognize the concept of the central limit theorem, and conduct randomization or resampling to determine the quality of evidence as a means of drawing a conclusion
	Statistical Literacy	Make an evaluation towards the large-scale of statistically based reports by means of posing critique on the emerged causative-relationships claims and interpreting the existed margin of error

Conclusion

This comparative study was reported the findings on the similarities and differences of the intended curriculum of Indonesia and New Zealand in facilitating their students to learn mathematics. From the results of this study, it is hoped that those results can be useful for Indonesia, especially, and New Zealand as one of the consideration in refining and improving the intended mathematics curriculum as a means to give a more facilitation for students to learn statistics deeply. The future works is encouraged to conduct comparative study on the textbook that are used in Indonesia and New Zealand to learn statistics.

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Nabilah Nabilah
"Educational Research and Evaluation" Yogyakarta State University, Indonesia
E-mail: nabilah0011pasca.2022@student.uny.ac.id
ORCID ID 0009-0004-1414-7502

Fina Riqiyah
"Educational Research and Evaluation" Yogyakarta State University, Indonesia
E-mail: finarifqiyah.2022@student.uny.ac.id

Sa'adatul Ulwiyah
"Educational Research and Evaluation" Yogyakarta State University, Indonesia
E-mail: saadatul.2022@student.uny.ac.id

Widowati Pusporini
"Educational Research and Evaluation" Yogyakarta State University, Indonesia
E-mail: widowatipusporini@uny.ac.id
ORCID ID 0000-0001-9069-4293

Trend Research Sustainable Developments Goals in Indonesia within ASEAN Nations from 2015 to 2023: A Bibliography Analysis

Abstract: This study aims to identify and analyze the development of research related to sustainable development goals (SDGs) in Indonesia from 2015 to 2023 using bibliometric analysis methods. The SDGs represent a global commitment in addressing various social, economic, and environmental challenges faced by the world today. This study focuses on the main trends developing in SDGs research in Indonesia, including research productivity, collaboration between researchers, and dominant research themes. Bibliometric methods were used to collect and analyze data from various sources, such as scientific journals and reviews available in the Scopus database. The data analysis process involved the use of keyword visualization tools such as VoS Viewer, as well as R-studio Biblioshiny bibliometric analysis software. The results of the analysis show that sustainable development is a trending topic and peaks in 2020-2023. In addition, the evolution of research over a certain half-life (2017-2023) revealed that water sanitation, biodiversity, and food security became the main focus in SDGs-related publications. For almost the past decade, Indonesia has been the country that produced the highest number of SDGs-related articles in the Scopus database. This bibliometric study provides a comprehensive understanding of the development of SDGs research in Indonesia and can be a reference for other researchers to understand the growing trends and fictions in efforts to achieve development goals in Indonesia.

Keywords: Sustainable Development, Bibliometrics, Indonesia, Analysis, Trend.

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Introduction

Sustainable Development Goals (SDGs) is a global agenda launched by the United Nations (UN) in 2015. The main goal of the SDGs is to create a more sustainable world with an emphasis on crucial issues such as eradicating poverty, reducing inequality, overcoming climate change, and environmental preservation (Aji & Kartono, 2022). The SDGs agenda consists of 17 goals covering various aspects of human life, including health, education, food security, justice and environmental conservation (Irhamsyah, 2019; Arlinwibowo et al., 2020).

Before the adoption of the SDGs, there were the Millennium Development Goals (MDGs). MDGs is a program launched by the United Nations in 2000 for the period from 2000 to 2015. (Oktavia et al., 2022). The MDGs are a series of eight goals that aim to address social and economic problems around the world, such as eradicating extreme poverty, improving maternal and child health, and gender-based rape (Oratmangun, 2003). The MDGs created the basis for global attention to sustainable development, and the SDGs then continued this role with a broader and deeper focus.

Indonesia, as a UN member country, has committed to achieving these SDGs targets. However, achieving these goals in Indonesia is faced with various challenges, such as the impact of climate change, global warming, rapid urbanization, health problems and economic inequality (Malihah, 2022; Putra & Suflani, 2022; Sitorus et al., 2024). These challenges show the complexity of efforts to achieve the SDGs in Indonesia. Therefore, to achieve sustainable development goals in Indonesia, a deep understanding of research trends that have been carried out in the context of the SDGs in this country is very important.

Bibliometric analysis, as a research method that uses bibliographic data to measure and analyze research trends, will be used in this research. This approach will provide a more comprehensive understanding of the development of research related to SDGs in Indonesia. Based on bibliometric analysis, this research can identify the growth in the number of publications, evaluate the most dominant research topics, analyze collaboration between researchers, and identify the literature sources that are most widely used in related research (Ulwiyah et al., 2023; Zafrullah et al., 2023). This bibliometric analysis will help identify the most significant research trends in the context of the SDGs in Indonesia, provide a strong data basis for decision making, and guide future research directions.

Bibliometric research has been carried out in various fields, including SDGs studies that use bibliometric analysis (Maryanti et al., 2022; Obaideen et al., 2023; Pizzi et al., 2020; Prieto-Jiménez et al., 2021; Setiyowati et al., 2022; Sweileh, 2020). However, the difference between this research and previous studies is the special focus on analyzing SDGs in Indonesia. This research makes an important contribution in completing the understanding of the latest research trends on SDGs in Indonesia, as well as providing comparisons with ASEAN countries.

The main aim of this research is to conduct a bibliometric analysis of SDGs research trends in Indonesia over the last decade. In this context, this research will attempt to answer the following research questions:

(Q1) Evolution of publication: How is the trend of publication growth and trends of Sustainable Developments goals?

(Q2) Country of literature source: How do global trends regarding SDGs publications compare with trends in Indonesia and other ASEAN countries?

(Q3) Collaboration network analysis: What are the trends in collaboration and significant contributions?

(Q4) Main keywords: What are the keywords that emerge and dominate themes in literature related to SDGs, especially in ASEAN?

It is hoped that this research will provide valuable insights for researchers, the government and other stakeholders in efforts to achieve sustainable development goals in Indonesia. It is also hoped that the results of this research can guide future researchers in choosing research topics that are relevant and have the potential for collaboration in the context of the SDGs.

Research Methods

Bibliometric mapping analysis is a tool for analysis which systematically evaluates the scholarly impact and influence of academic articles and researchers within a specific field of study. Bibliometric mapping is recently gaining more interest in different disciplines (Aria & Cuccurullo, 2017; Arici et al., 2019; Song et al., 2019). Perhaps, the suitability of bibliometric for science mapping may have caused this extending acceptance among scholars (Aria & Cuccurullo, 2017). Conducting bibliometric mapping analysis is a systematic process that involves several key steps, including data collection, screening, extraction, and synthesis.

Literature search and data collection

The paper bibliometric analysis is retrieved from Elsevier Scopus database, which is known as the world largest abstract and citation database of peer-reviewed literature (Chi, 2003). Scopus also provides the most documents for bibliometric analysis and also offers search analysis tools for representative figures (Alryalat et al. 2019). The search string for this study is made up of several compound phrases joined together with the OR operator. The first search field contained keywords "sustainable" AND "development" AND "goals". The initial query without any filtering gained 64732 documents as the results. The search and retrieval of the data were conducted on September 12 2023. These results were later filtered to exclude some irrelevant items based on our inclusion and exclusion criteria. The inclusion and exclusion criteria are presented in Table 1. In total, 1092 papers were collected after refining based on the inclusion and exclusion. Then, these data were exported for the next analysis. The summary information of the dataset presented in Table 2.

Table 1. Inclusion and exclusion criteria for retrieving the dataset

	Code	Criteria
Inclusion Criteria	IC1	Articles containing one of the keywords in either title, abstract, or keywords.
	IC2	Documents written in the English language
	IC4	Articles in journals and conferences papers
	IC5	Subject areas in "Environment, Social, energy, multidisciplinary, arts"
Exclusion Criteria	EC1	Published articles before 2015

Table 2. Data synthesis indicating primary information and summary of the dataset

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2048:43:00
Sources (Journals, Books, etc)	316
Documents	1088
Annual Growth Rate %	51,38
Document Average Age	2,17
Average citations per doc	9,329
References	1
DOCUMENT CONTENTS	
Keywords Plus (ID)	4029
Author's Keywords (DE)	2895
AUTHORS	
Authors	5102
Authors of single-authored docs	75
AUTHORS COLLABORATION	
Single-authored docs	81
Co-Authors per Doc	5,13
International co-authorships %	35,75
DOCUMENT TYPES	
Article	578
Research article	3
Article conference paper	2
Conference paper	404
Conference paper article	3
Conference paper review	1
Review	96
Review conference paper	1

Research Results and Discussion

Data Preprocessing with VOS Viewer. A crucial component of bibliometric analysis and visualization is data pretreatment, which makes sure the incoming dataset is clear, pertinent, and prepared for in-depth examination. This section's main goal is to ensure the data quality assurance measures taken to eliminate duplicates, ensure consistency in metadata, and maintain data integrity. This study is using VoS viewer for visualizing and interpreting the provided data. VoS viewer's text mining functionality allows users to analyze large amounts of text data, aiding in bibliometric mapping and bibliometric analysis (Eck and Waltman, 2011). The aims of the analysis are to explore the underlying structure and relationships within a research dataset.
The initial data collection phase involved setting a minimum threshold of 10 occurrences, resulting in the selection of 655 articles that met this requirement. Afterwards, 393 relevant articles were found for visualization after this dataset was analyzed using VoS viewer. The articles were subsequently clustered into four distinct topics, each represented by a different color: Red, Blue, Green, and Yellow (see Figure. 1).
The clusters reveal associative relationships among specific terms or keywords within the dataset. For instance, the associatively connected "Red" cluster has 152 terms, indicating an integrated research theme or topic. Similarly, the "Green," "Blue," and "Yellow" clusters also show associative connections among 83, 85, and 73 terms, indicating distinct yet interconnected areas of research.

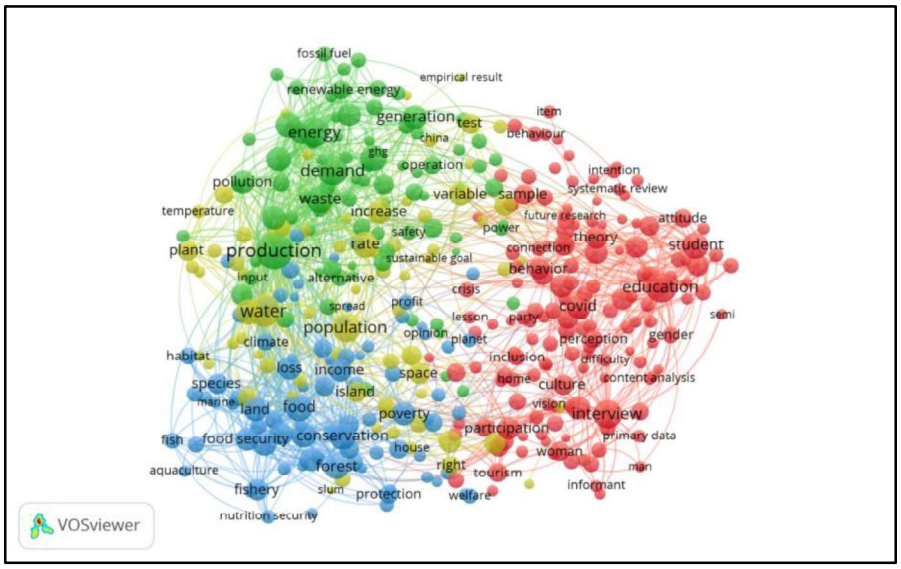

Figure 1. VoS Viewer visualization

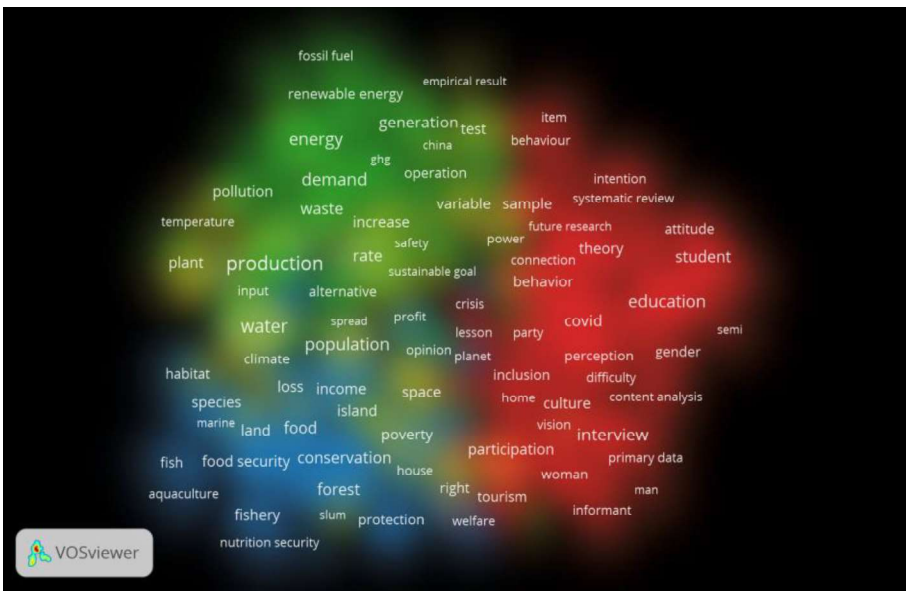

Figure 2. Visualization VoS Viewer for Theme Density

Data analysis using bibliometrix R-package software. This study used the open-source bibliometrix R-package software, which offers a range of tools for performing quantitative research in bibliometrics. Bibliometrix is R-package software which was developed by Aria and Cuccurullo in 2017. It has the main algorithms for conducting statistical and science mapping analysis. The recent versions of bibliometrix R-package (i.e., 2.0 upwards) contains a web interface app (Biblioshiny) introduced to aid users without having a coding skills expert to conduct bibliometric analysis. Data can be imported in BibTex, CSV, or Plain Text formats from Web of Science or Scopus databases using the Biblioshiny interface. The study analysis is presented in the result section.

(Q1) Evolusi publikasi: How is the trend of publication growth and trends of Sustainable Developments goals?

This section presented the annual scientific production of articles in the field of Sustainable Developments goals from 2020 to 2023. Analysis from the bibliometrix R package shows that the field of Sustainable Development goals has a 51,38% annual growth rate (see Figure. 13) of scientific production from 2020 to 2023. As shown in Figure. 3, generally, the number of articles produced has increased over time, showing a noticeable peak in 2020 and a steady increase in 2021 and 2022. This points to an increasing amount of research output in the area being studied, which may indicate a rise in interest and activity in the field in recent years.

On the other hand, there have been some variations in the average number of citations for articles in each year. For example, the comparatively high average citation count of 8.82 in 2016 suggests that articles published in that year received more citations on average. But in the years that followed, the average number of citations fell, with notable drops in 2018 and 2019. It is noteworthy that the average number of citations rose once more in 2020 and has stayed mostly steady in 2021 and 2022.

Table 3. Articles production and average citation per year

Year	Articles production	Average Citation
2015	7	4,59
2016	13	8,82
2017	17	7,37
2018	96	1,87
2019	88	2,95
2020	176	3,03
2021	259	3,02
2022	239	2,13
2023	193	1,05

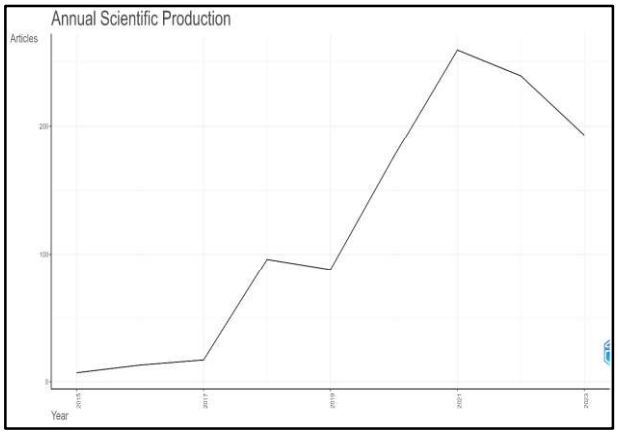

Figure 3. Annual scientific production

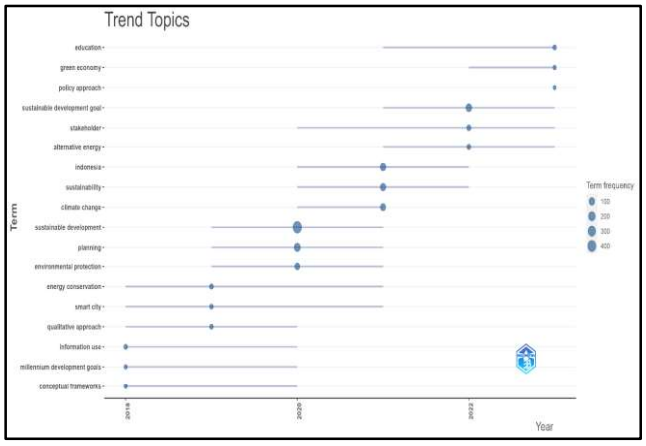

Figure 4. Trend topics

The results of trending topics show that in 2018-2022 the topics of "sustainable development", "planning", "sustainable development goals" are the most researched topics followed by the topics of "Indonesia", "sustainability", and "climate change".

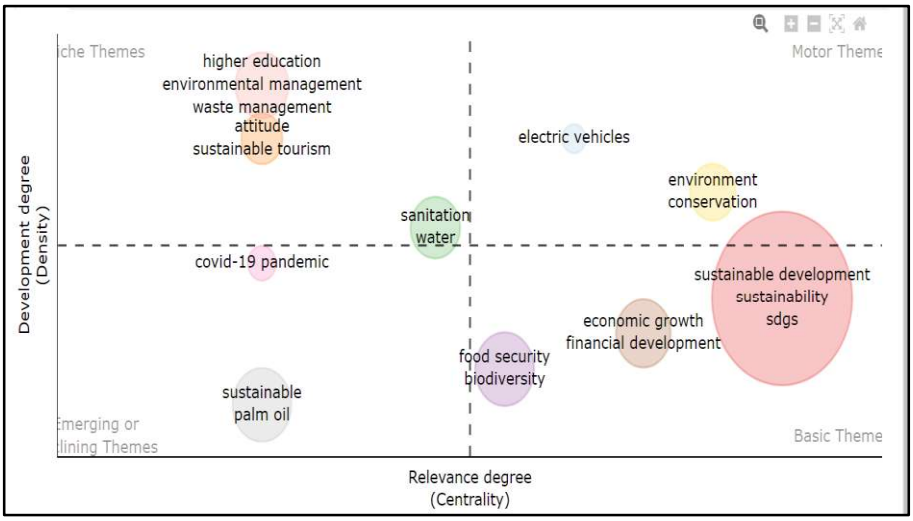

Figure 5. Trend topic based on 2017-2023 time slice

(Q2) Country of literature source: What is the global trend in SDGs publications when compared to the trend in Indonesia and other ASEAN countries?

Based on the country of origin of the corresponding author, the biblioshiny analysis results are divided into single country publications and multiple country publications with a focus on analyzing among ASEAN countries, which are dominated by Indonesia, Malaysia, Thailand as shown in Figures 6 and 7. Figure 8 displays the development of productivity and publication trends in the period 2015-2021. As a result, Indonesia shows a significant increase over time compared to other ASEAN nations such as Malaysia and Thailand.

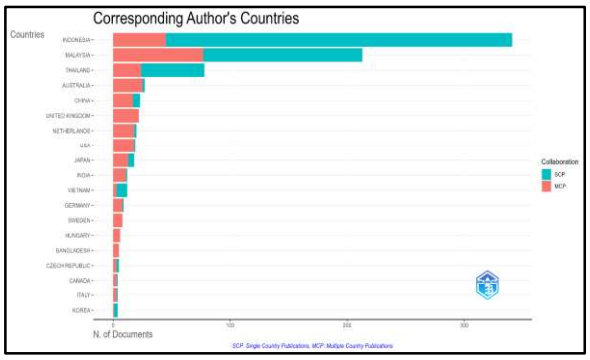

Figure 6. Corresponding author's country

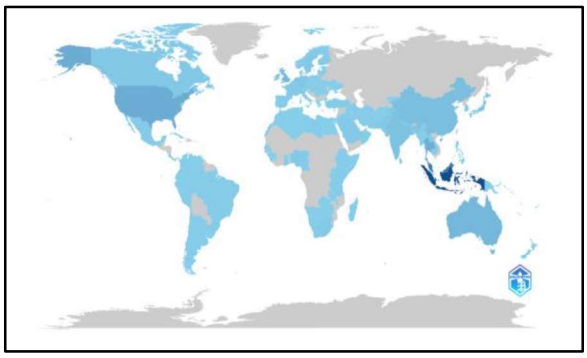

Figure 7. Maps distribution of corresponding author's country

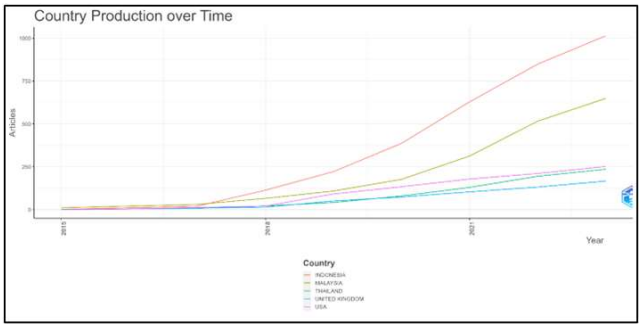

Figure 8. Country production overtime

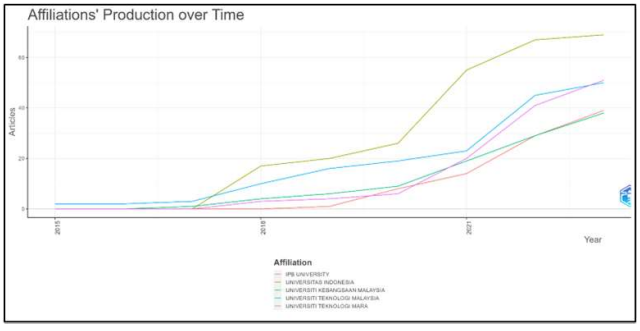

Figure 9. Affiliations' production over time

Focusing on Indonesia as a country in ASEAN with active publications related to the SDGs theme, the institutions with the highest production of articles related to this theme in Indonesia are produced by the University of Indonesia and IPB University. When compared to other institutions in ASEAN, Universiti Teknologi Malaysia and Universiti Teknologi Mara are the institutions with high productivity in producing articles related to SDGs. Figure 10 shows that the country with the highest number of citations is Malaysia.

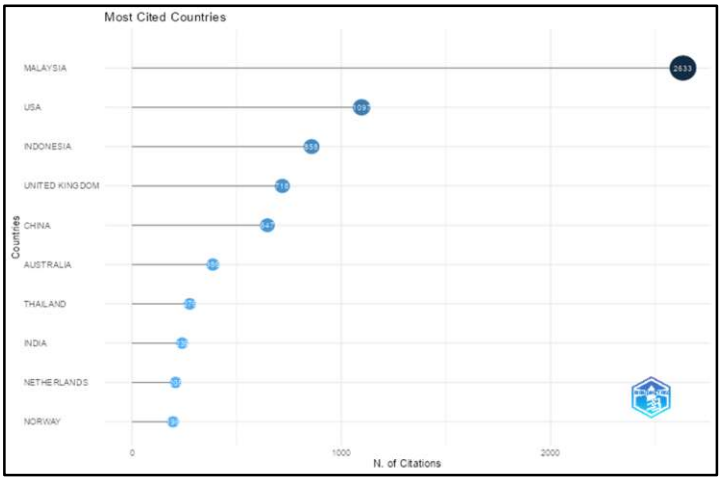

Figure 10. Most cited countries

(Q3) Collaboration network analysis: What are the collaboration trends and significant contributions?

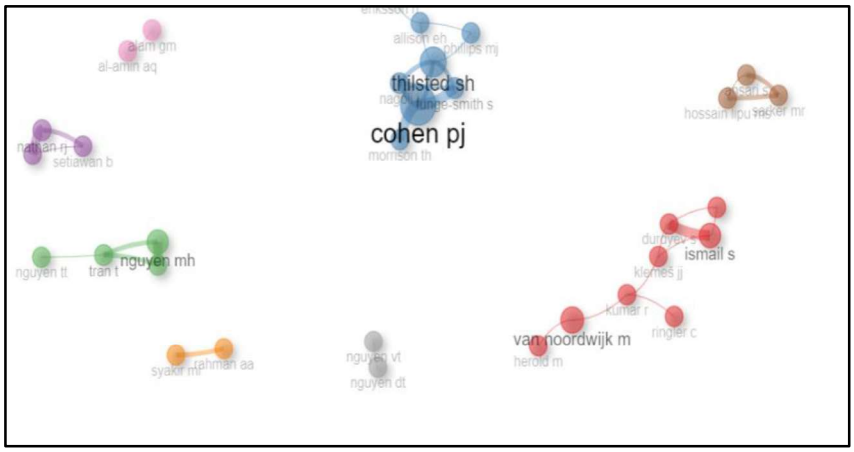

Figure 11. Collaboration between authors

Co-authorship networks presented patterns of scientific collaboration, revealing differences between subjects and over time (Newman, 2004). Based on the dataset that have been analyzed, there are 5102 authors involved in Sustainable development goals research. The network visualization can be seen in figure 10. Large nodes in the collaborative author visualization created with VOS Viewer signify researchers or research groups actively working together within a particular research cluster. The number of collaborations between the authors are divided into 8 clusters. The first big clusters (presented with blue color) consist of 7 authors, with the biggest node for this cluster "Cohen Pj".

(*Q4) Major keywords: What are the keywords that emerge and dominate the themes in the literature related to SDGs, especially in ASEAN?*

The graph (see Figure. 12) displaying a word's frequency over time from 2015 to 2023 in the field of Sustainable Development Goals research. By analyzing word frequency over time, it offers insights into the evolving landscape of a research field (Moral-Muñoz, 2020). Additionally, it can also help the identification of research trends within a field, by making it easier to distinguish between variations in keyword frequency and whether those variations indicate a rise or a decrease in applications.

Based on a line graph (Figure. 12), we might observe that the frequency of "Sustainable Development" is consistently high throughout the period, indicating its sustained importance in the literature. In contrast, "Planning" might show a stable or slightly increasing trend, suggesting that it is still relevant but not as important as "Sustainable Development." "Sustainable Development Goal" might reveal a rising trend, reflecting the increasing emphasis on tracking SDGs progress.

The frequency of specific countries like "Indonesia" and "Malaysia" could demonstrate variations, which may indicate changes in research focus or regional interest over time. Terms like "Climate Change" and "Environmental Protection" might show increasing trends, suggesting the significant increase of environmental issues in SDGs research. Moreover, "Economics" and "United Nations" could show relatively stable patterns, demonstrating that these ideas are still relevant in SDGs research

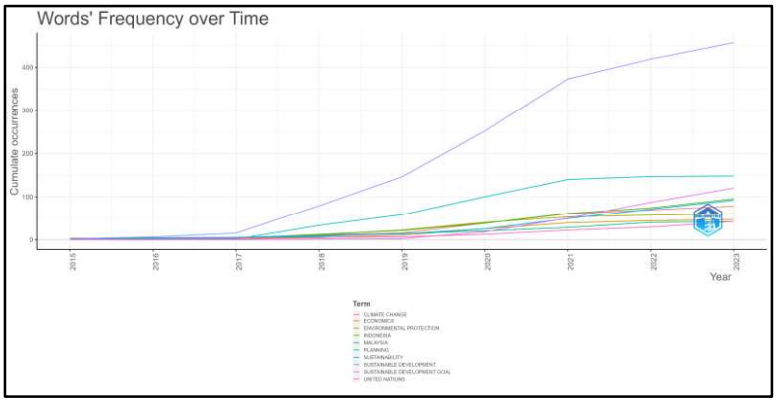

Figure 12. Word's frequency over time

Discussion

A collection of international objectives, the Sustainable Development Goals (SDGs) were created under the 2030 Agenda for Sustainable Development (Bank et al., 2015). This study aims to identify and analyze the development of research related to sustainable development goals (SDGs) in Indonesia from 2013 to 2023 using bibliometric analysis methods. The SDGs represent a global commitment to address the social, economic, environmental and scientific challenges faced by the world today. This study focuses on the main trends developing in SDGs research in Indonesia, including research productivity, collaboration between researchers, and dominant research themes. This article analyzes research trends related to SDGs themes obtained from Scopus data. In general, it is shown in Figure 13.

Figure 13. General information

(Q1) Evolution of publications: How is the trend of publication growth and trends of Sustainable Developments goals?

In the period 2015-2023, the number of published articles related to the topic of sustainable development goals (SDGs) generally increased. Except in 2019, this number decreased from 96 articles to 88 articles. Meanwhile, the average number of articles cited tends to fluctuate over time. The time slice between

2017-2023 in Figure 5 shows the direction of the quadrant of research topics for the SDGs theme. The quadrant with specific "niche" themes in the first cluster is "higher education", "environmental management", and "waste management". The second cluster consists of "attitude" and "sustainable tourism". The themes occupying the quadrant with the most central theme relevance in this theme are "sanitation" and "water".

The majority of research related to SDGs is dominated by basic themes such as those addressed by the first cluster "sustainable development", "sustainability", and "SDGs". Then the second cluster "economic growth" and "financial development". Finally, themes that are close to relevance are "food security" and "biodiversity". While the topics that are observed as trending topics 2018-2022 are about "sustainable development", "planning", "sustainable development goals" is the most researched topic followed by the topic "Indonesia", "sustainability", and "climate change". This shows that along with the development of science and technology, environmental issues become a branch of science that is still an issue.

(Q2) Country of literature source: What is the global trend in SDGs publications when compared to the trend in Indonesia and other ASEAN countries?

Figure 8 shows the development of productivity and publication trends in the period 2015-2021. As a result, Indonesia shows a significant increase over time compared to other ASEAN countries such as Malaysia and Thailand. Unfortunately, this is inversely proportional to the number of citations where Malaysia is the country with the highest number of citations ahead of Indonesia. If focused only among ASEAN countries, table 2 shows that the top three are Malaysia, Indonesia, and Thailand.

Table 4. Most cited countries among ASEAN

COUNTRY	TC	AVERAGE ARTICLE CITATIONS
MALAYSIA	2633	12,4
INDONESIA	858	2,5
THAILAND	276	3,5
VIETNAM	101	8,4
SINGAPORE	29	14,5
LAOS	22	22
CAMBODIA	21	7
PHILIPPINES	7	7
BRUNEI	1	1

Regarding productivity, Indonesia as a country in ASEAN that has the highest number of article production with the theme of SDGs, at the affiliation level, the University of Indonesia is the affiliation with the highest number of articles with 69 articles.

Table 5. Most relevant affiliations

COUNTRY	TC
UNIVERSITAS INDONESIA	69
UNIVERSITI TEKNOLOGI MARA	51
UNIVERSITI TEKNOLOGI MALAYSIA	50
IPB UNIVERSITY	39
UNIVERSITI KEBANGSAAN MALAYSIA	38
UNIVERSITI SAINS MALAYSIA	33
DIPONEGORO UNIVERSITY	30
HASANUDDIN UNIVERSITY	30
UNIVERSITAS GADJAH MADA	29
BINA NUSANTARA UNIVERSITY	27
UNIVERSITY OF MALAYA	27

UNIVERSITAS PADJADJARAN	23
UNIVERSITAS SEBELAS MARET	22
CHULALONGKORN UNIVERSITY	21
UNIVERSITI MALAYSIA TERENGGANU	21
CHIANG MAI UNIVERSITY	20
UNIVERSITAS AIRLANGGA	19
UNIVERSITI PUTRA MALAYSIA	19

(Q3) Collaboration network analysis: What are the collaboration trends and significant contributions?

The results of the data analysis in Figure 11 show the coauthorship relationship for SDGs-related themes with a significant number, meaning that this theme has its own uniqueness in addition to its urgency in the current global discussion focus. These big nodes denote a major influence and a central position within the cluster (Markovich, 2017). It means that the researcher is vital in fostering collaboration, frequently acting as pioneers or significant contributors in specific fields of study. Moreover, the red cluster also held a significant position for authors' collaboration in Sdgs research. There are 8 authors visualized with relatively similar-sized nodes, suggesting that the authors contributed to the network with approximately equal prominence (Newman, 2004).

(Q4) Major keywords: What are the keywords that emerge and dominate the themes in the literature related to SDGs, especially in ASEAN?

Even regionally in ASEAN, Indonesia and Malaysia appear to be actively discussing issues related to "sustainable development" in various aspects such as "sustainable biogas production" (Farobie et al., 2022); "Application of the SDG principles in interior architecture" (Affandi et al., 2022); "Sustainable interior economy planning" (Marsahala et al., 2023); "ecolabel and certification (Rais & Suzianti, 2021) and so on.

Table 6. Keyword trend development

YEAR	SUSTAINABLE	PLANNING	SUSTAINABLE DEVELOPMENT GOALS	SUSTAINABLE	CLIMATE CHANGE	ENVIRONMENTAL PROTECTION
2015	2	0	0	1	0	2
2016	6	0	0	4	0	3
2017	15	1	0	5	4	4
2018	79	33	1	9	11	11
2019	146	58	2	13	15	22
2020	252	100	18	25	38	40
2021	373	140	50	49	60	53
2022	419	147	87	71	69	57
2023	457	148	120	92	78	60

As we move towards the achievement of the SDGs by 2030, themes related to "sustainability" "climate change" and "environmental protection" are increasingly popular for study. This can also be influenced by conditions where the level of environmental pollution and exploitation of natural resources is increasing both related to forests, oceans, and food security (Azra et al., 2022; Levin et al., 2020; Malau et al., 2021; Prayitno et al., 2020; Roy et al., 2022; Suwarno et al., 2018). The development of research keyword trends on the topic of sustainable development goals over time, especially in Indonesia, indicates that sustainability issues are a priority and have an urgency to be studied more deeply in terms of science. This is indicated by the increasing number of scientific research productions in various fields related to sustainability. Even this still encounters obstacles in its implementation, therefore research related to SDGs still has the opportunity to be studied further as an evidence-based learning that can be used as a reference for decision makers.

The research trends presented in this article illustrate that sustainability topics are experiencing significant developments and still have opportunities to be further developed and researched in the future. The good thing is that the awareness of sustainable development goals in Indonesia and other ASEAN countries such as Malaysia and Thailand has initiated research in this field during 2015-2023 and beyond.

Conclusions

Based on the bibliographic review of research trends related to SDGs with a focus on Indonesia among ASEAN countries, it shows significant developments, especially on several topics such as "sustainable development" "SDGs". At a more specific level, the quadrant direction of research topics for the SDGs theme provides information that the quadrant with special "niche" themes in the first cluster is "higher education", "environmental management", and "waste management". The second cluster consists of "attitude" and "sustainable tourism". Indonesia as a country in ASEAN has the highest rate of scientific article production, indicating that Indonesia has a clear awareness of sustainability issues. This study illustrates that the best topics of SDGs have the potential to be further explored in the future, especially towards SDG 2030. Further research needs to be done to help catalyze issues around sustainability as scientific evidence and reference for decision makers.

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Zulfa Safina Ibrahim
Yogyakarta State University
E-mail: zulfasafina.2022@student.uny.ac.id

Jumriani Sultan
Yogyakarta State University
E-mail: jumrianisultan.2022@student.uny.ac.id

Fina Rifqiyah
Yogyakarta State University
E-mail: finarifqiyah.2022@student.uny.ac.id

Heri Retnawati
Yogyakarta State University
E-mail: heri_retnawati@uny.ac.id

A Visualized Bibliometric Analysis for Mapping Research Trends of Machine Learning in Academic Research

Abstract: This study aims to conduct a comprehensive bibliometric analysis of machine learning research within the academic research from 2013 to 2023. The goals include comprehending how publication trends have changed over time, pinpointing important fields of interest, and clarifying how machine learning and scholarly research interact. This study's methodology combines a bibliometric framework with a qualitative descriptive approach. The data were collected from Scopus database, which consist of 4.655 documents for analysis. The analysis is executed using R studio and Biblioshiny. The result shows that the rise of machine learning in academic research between 2013 and 2023 suggests that this field of study will continues to be a trending area for academic exploration.

Keywords: Bibliometric Analysis, Machine Learning, Academic Research, Machine Learning in Education.

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Introduction

Evaluation of student achievement is the main focus in the world of education, especially in assessing student achievement in educational institutions. Educational institutions operate in a highly competitive and demanding environment. Most schools face difficulties in providing high-quality education, evaluating student performance, and understanding the future demands of their learners (Issah et al., 2023). Technological developments and information-based decision making have transformed our world over the past decades, bringing about the birth of the knowledge economy (Maphosa & Maphosa, 2023). One of them is the development of Artificial Intelligence itself (Zemel et al. 2013; Rohde et al., 2023). Advances in technology and data availability have enabled rapid developments in various aspects of machine learning, ranging from understanding basic concepts to implementing highly complex models. Along with these developments, it is important to understand academic research trends in the machine learning domain.

Machine learning has a crucial role in the exploration of educational data, enabling the ability to make predictions in the education sector. One of the advantages of this approach is its ability to identify questions that frequently arise (Pallathadka et al., 2023). Gaurav & Patel (2020) state, machine learning is a scientific discipline that aims to develop computer algorithms to turn data into intelligent actions. In recent decades, enormous growth in data and computing power has driven the development of statistical methods for analyzing complex data. Machine learning algorithms are needed to make machines understand and respond to data, with simulation of human learning processes, reasoning from incomplete data, exploration of new discoveries, and analysis of data trends being part of the process (Wu & Zheng, 2021).

The use of machine learning in higher education is experiencing significant growth. Some examples of its implementation in the world of education include the development of systems that can project student retention rates and provide students with feedback tailored to individual needs (Tahiru et al., 2023). In recent years, machine learning methods have been used to analyze student data, which is in line with efforts to improve information processing through data mining (Cardona et al., 2019a). For example, Machine Learning has been successfully applied to predict students who are at high risk of dropping out of school. Therefore, machine learning is very important in the world of education.

Bibliometric analysis is a very relevant method for the research questions in this study because it can highlight the quality of publications in a particular field (Tahiru et al., 2023). Bibliometric analysis has emerged as a highly effective tool in mapping and analyzing research trends in various scientific fields. In the context of machine learning, bibliometric analysis can provide valuable insights into the development and dynamics of academic research in this domain. This allows us to identify current research, influential authors, key concepts, and emerging topic trends.

Research using bibliometric analysis to describe the use of machine learning in higher education is limited. This could create further research opportunities to provide insight into future trends in higher education (Tahiru et al., 2023). The purpose of this article is to review research that has been conducted on machine learning-based academic research from 2013 to 2023. This article provides an in-depth bibliometric review that examines patterns and trends regarding key publications, country contributions, significant topics, and trends in the field this research. This study focused on answering the following research questions:

Q1. How has the publication output of machine learning research in academic research evolved based on bibliometric analysis of Scopus data from 2013 to 2023?
Q2. Which areas exhibit the greatest interest in research related to machine learning in the academic sphere over the last decade, as assessed through bibliometric analysis of the Scopus database?
Q3. Which areas exhibit the greatest interest in research related to machine learning in the academic sphere over the last decade, as assessed through bibliometric analysis of the Scopus database?

Research Methods

This research uses descriptive qualitative research with a bibliometric approach. Bibliometric analysis is a structural analysis of research results, and groups information obtained from metadata in the form of articles, books, conferences, reviews (Sri Rahayu & Sofian Hadi, 2023). The data used was sourced from Scopus with a period of 2013-2023 with the keywords "Machine Learning" and "Academic research" so that data was obtained for 4655 documents. The data obtained was analyzed using R studio and Biblioshiny. The following is the flow of the research

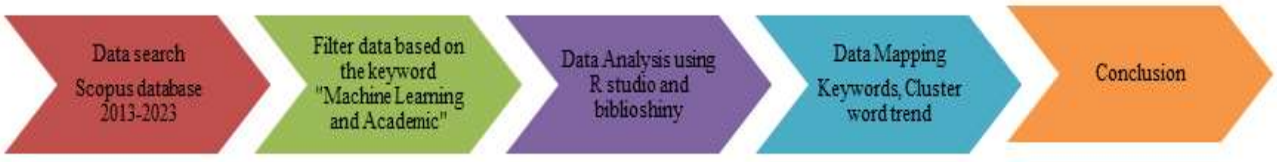

Fig 1. Flow Research

Literature search and Data collection

In total, 4655 papers were collected after refining based on the inclusion and exclusion criteria shown in Table 1. These data were exported for analysis. The search string for this study is made up of several keywords joining together "Machine Learning" AND "Academic". The search and retrieval of the data were conducted on November 5th, 2023.

Table 1. Inclusion and exclusion criteria for retrieving the dataset

	Code	Criteria	Data Extraction
Inclusion Criteria	IC1	Articles containing one of the keywords "Machine Learning" and "Academic"	6255
	IC2	Published articles between 2013 to 2023	5847
	IC4	Articles in journals and conferences papers	4864
	IC5	Documents written in the English language	4783
Exclusion Criteria	EC1	Articles with publication stage "in press."	128
		Total Articles	**4655**

Research Experiment

Results and discussion of findings are presented in this section to reflect (i) Data information and Overall Publications Growth; (ii) Countries and research institutions distributions; (iii) Most Relevant Keywords of Machine Learning in Academic Research.

Data information and Overall Publications Growth. In this section, this study will focus on scientific productions in the field of machine learning in academic research from 2013 to 2023. Analyzing annual scientific production helps researchers, institutions, and policymakers understand the trends and priorities in a particular field (Dou, 1985). The annual scientific production of articles is presented in Table 1. The data reveals a significant increase in the annual scientific production of articles in the field of machine learning over the past decade. In 2013, there are 42 articles which had been published within this field, and the number of publications increased steadily each year (see Fig. 2). By 2022, the production of the articles in this field reached an impressive number, with 1.124 documents, signifying a more than twenty-fold increase over the ten-year period. This substantial growth reflects the increasing attention, engagement, and investment in machine learning research among scholars.

Alongside the growth in the number of articles, the mean total citations per year per article exhibit dynamic patterns (see Table 2). In 2018, despite the significant increase in the number of articles (267), the mean total citations per year per article also showed a considerable surge, reaching 5.95. This suggests that the research output of that year had a remarkable impact and garnered substantial attention within the academic community. However, in the subsequent years, such as 2022 and 2023, while the number of articles remained high (1,124 and 989, respectively), the mean total citations per year per article declined to 1.96 and 1.04, respectively. This fluctuation indicates variations in the visibility and impact of research output, which is probably influenced by the evolving nature of the field and competition for attention.

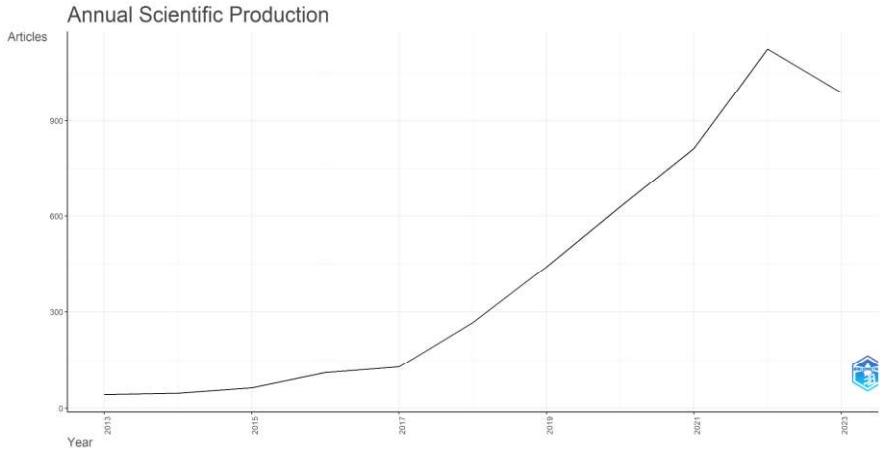

Fig 2. Annual scientific production over the years

Table 2. Articles production and average citation per year

Year	Articles	Average Citation PerYear
2013	42	2,89
2014	46	3,26
2015	63	3,64
2016	111	2,46
2017	129	3,49
2018	267	5,95
2019	441	3,82
2020	630	4,34
2021	813	3,27
2022	1124	1,96
2023	989	1,04

Countries and research institutions distributions

Distribution of articles by country. Every year, many countries conduct research in the field of differentiated instruction. However, when we examine the productivity of these countries, the top ten countries are their countries of origin. When research published by Scopus is displayed or presented based on the country conducting the research, the results can be seen in the chart in Figure 3.

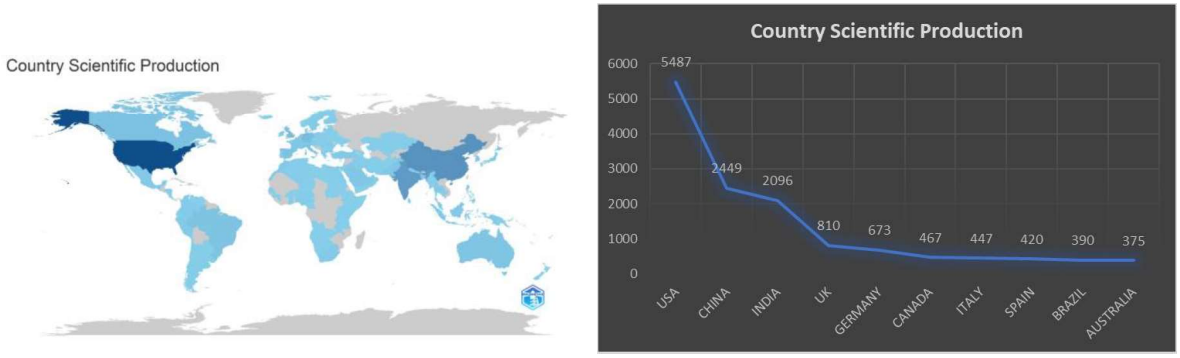

Fig 3. Distribution of articles by country

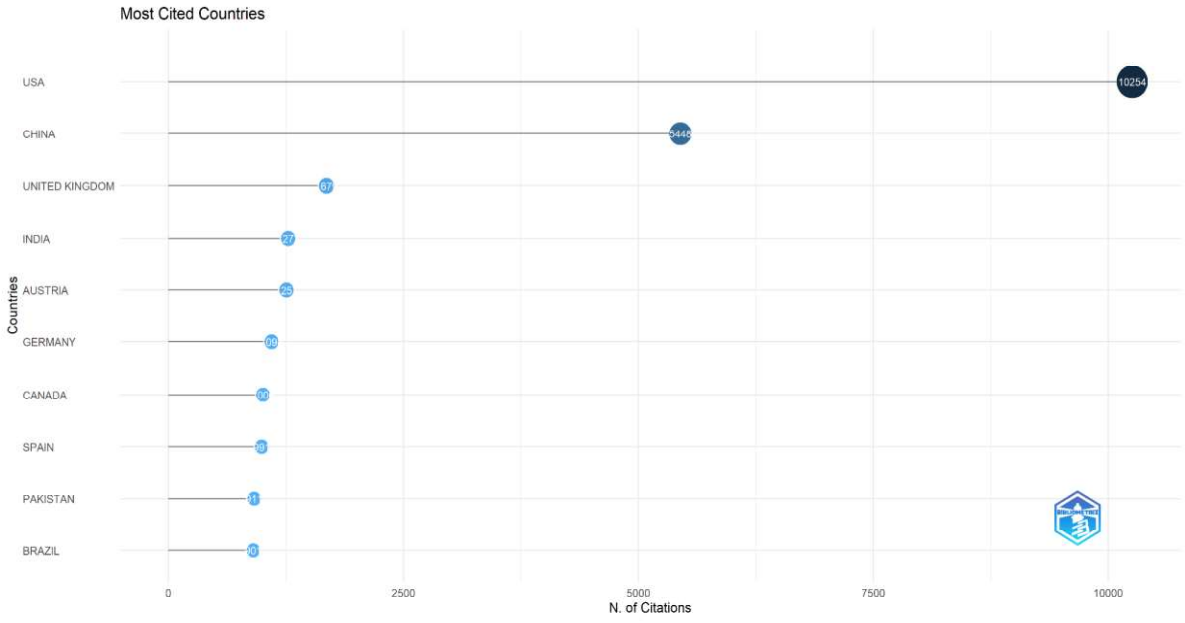

Fig 4. Most citation country

Providing data on the most productive countries in generating articles on machine learning in academic research. The data indicates that the USA is the most productive, with 5487 articles related to this topic. China is in the second position with 2449 articles, followed by India, the UK, and Germany as the top five most productive countries. This suggests that the USA holds a dominant position in machine learning research in academic studies when compared to other countries visible in Figure 4. The USA's most productive position may be influenced by several factors, such as a high number of universities and research institutions, research funding availability, and the early adoption of machine learning approaches in the country.

***Most citation country*.** The following provides information about the top 10 countries with the highest number of citations obtained from various sources and authors. Figure 4 presents the results of the bibliometric analysis. Figure 4 displays information about the countries and their highest number of citations tracked by Scopus. Based on the data in Figure 4 articles from the United States have received the highest number of citations (10,254) among all articles on the topic of machine learning in academic research. This is followed by articles from China, the United Kingdom, India, and Australia, which are among the most cited articles on this topic. The fact that the United States has the highest number of citations indicates that their research has had a significant impact on the field of machine learning in academic research. However, it should be noted that a high number of citations does not always reflect research quality, as other factors such as topic popularity or research availability can influence it. The presence of other countries on the list of the most cited articles in human resource management also suggests that their research has made substantial contributions to the field. Overall, the data presented in Figure 4 offers valuable information for researchers interested in machine learning in academic research, helping them identify key authors and articles in the field. Additionally, it can provide insights into research impact in the field and future research directions.

Most productive affiliate. The following information presents the most productive affiliations in the field of machine learning within academic research. The outcomes of the bibliometric analysis are depicted in Figure 5.

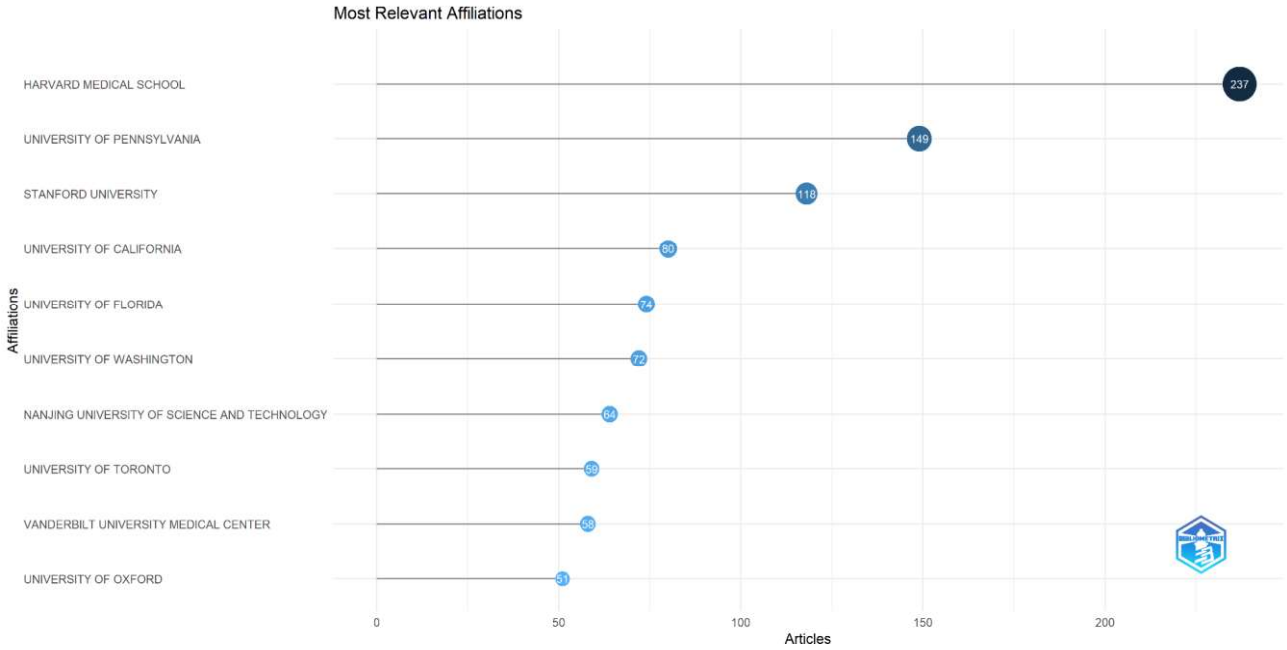

Fig 5. Most productive affiliate

As depicted in Figure 5, Harvard Medical School stands out as the leading institution in terms of publishing articles in the field of machine learning within academic research. With 237 articles to its name, it surpasses other institutions by a significant margin. This highlights Harvard Medical School's considerable involvement in this area, signifying its substantial contribution to advancing the knowledge of machine learning in academic research. Furthermore, the University of Pennsylvania also demonstrates notable activity in publishing articles on this subject, having produced 149 articles related to machine learning in academic research and securing the second position among affiliations with the most publications. In addition to these prominent affiliations, three others—Stanford University, the University of California, and the University of

Florida—also feature in the top five affiliations with the highest publication output in the realm of machine learning within academic research.

This indicates the widespread interest of researchers from various universities around the world in the field of machine learning within academic research. This data serves as a valuable resource for researchers and academics, enabling them to stay informed about the latest developments in the field of machine learning in academic research and facilitating the identification of potential research partners or collaborators in relevant universities. Furthermore, it offers insights into the global landscape of research and intellectual contributions in the field of machine learning within academic research. By identifying the most active affiliations in publishing within this field, researchers can make informed decisions about the direction of their research to further enrich the understanding of machine learning in academic research.

Table 3. Most productive sources

Sources	Articles
LECTURE NOTES IN COMPUTER SCIENCE (INCLUDING SUBSERIES LECTURE NOTES IN ARTIFICIAL INTELLIGENCE AND LECTURE NOTES IN BIOINFORMATICS)	130
ACM INTERNATIONAL CONFERENCE PROCEEDING SERIES	100
LECTURE NOTES IN NETWORKS AND SYSTEMS	84
IEEE ACCESS	81
COMMUNICATIONS IN COMPUTER AND INFORMATION SCIENCE	69
PLOS ONE	56
ADVANCES IN INTELLIGENT SYSTEMS AND COMPUTING	53
APPLIED SCIENCES (SWITZERLAND)	52
CEUR WORKSHOP PROCEEDINGS	46
SUSTAINABILITY (SWITZERLAND)	38

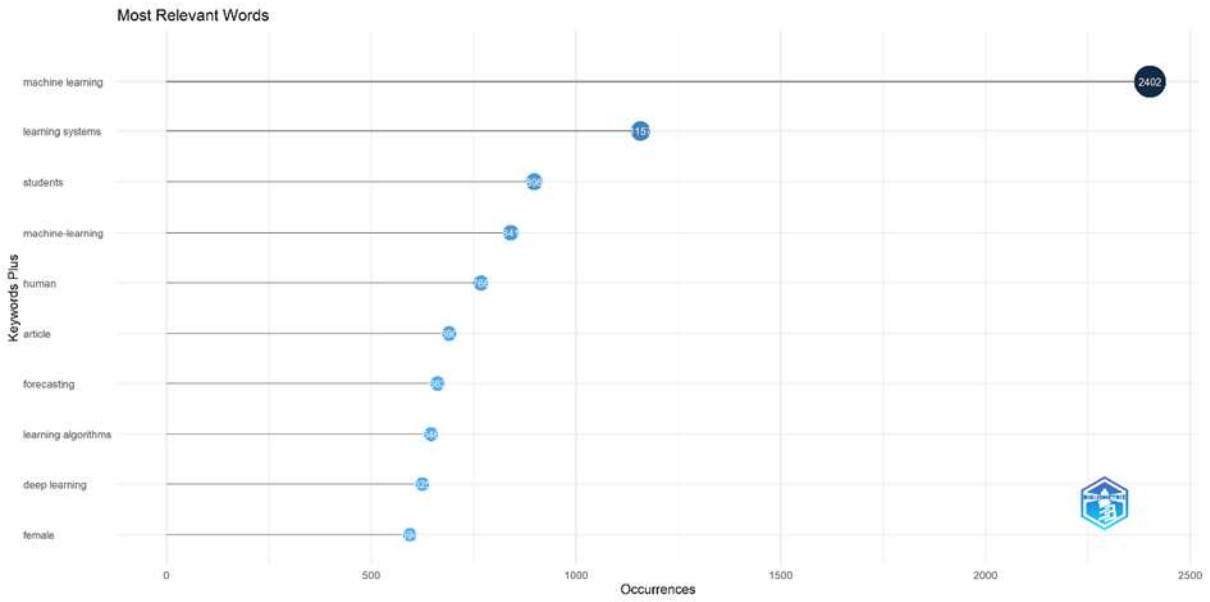

Fig 6. Most Relevant Words

The most productive sources. Table 3 provides information about the most productive journals and publication sources in terms of publications related to machine learning in academic research. From the table, "LECTURE NOTES IN COMPUTER SCIENCE (INCLUDING SUBSERIES LECTURE NOTES IN ARTIFICIAL INTELLIGENCE AND LECTURE NOTES IN BIOINFORMATICS)" is the most productive publication with 130 articles. It is followed by "ACM INTERNATIONAL CONFERENCE PROCEEDING SERIES" with 100 articles. Next, there is "LECTURE NOTES IN NETWORKS AND SYSTEMS" with 84 articles, "IEEE ACCESS" with 81 articles, and "COMMUNICATIONS IN COMPUTER AND INFORMATION SCIENCE" with 69 articles as the top five in the number of published articles. This table also provides important information about the most productive and influential publication sources in the field of machine learning in academic research.

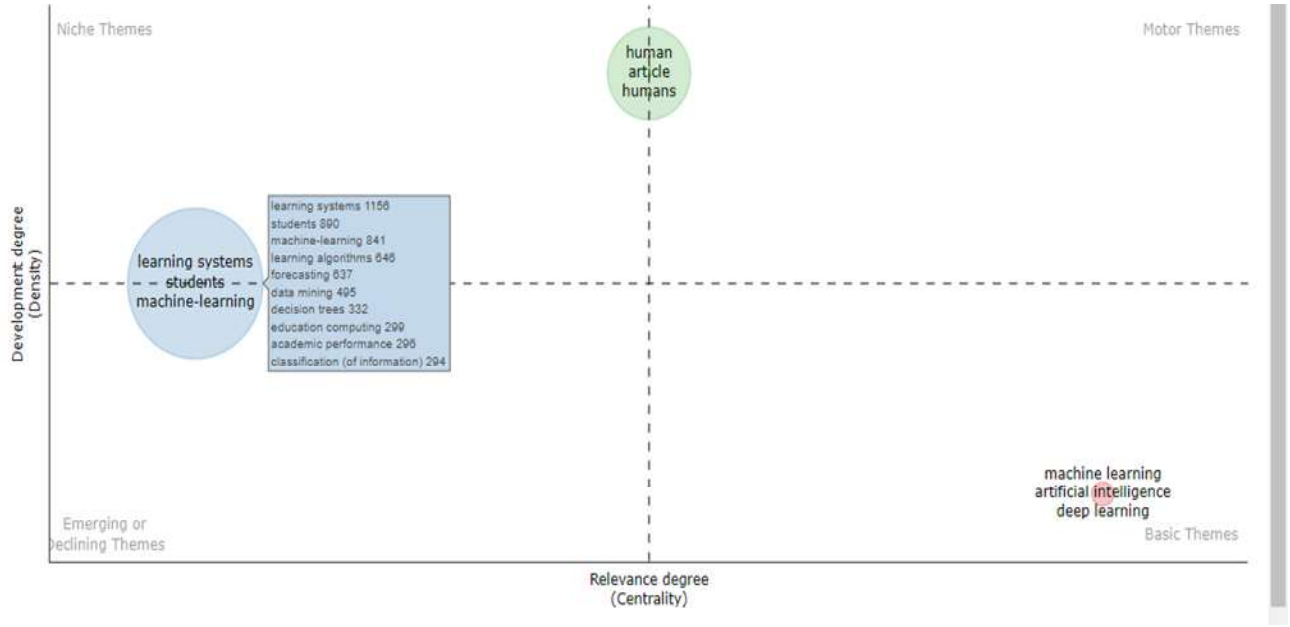

Fig 7. Thematic Map

Most Relevant Keywords of Machine Learning in Academic Research. The thematic map contains three clusters by binding to the author's keywords, with the variables author's name, publication title, keywords and number of citations. Special topics in the field of machine learning include human-computer interaction. Basic themes can be classified into learning systems, students, machine learning, human, artificial intelligence and deep learning. In the thematic map, a bibliographic index of the top three Machine Learning, Learning Systems and Students is obtained.

Fig 8. Word Map

The Word Map illustrates the relationship of the Machine Learning topic to other topics and depicts related research trends. In addition, it provides future research opportunities. The brighter and larger the font size of the keyword indicates that the topic is widely studied or of interest, such as "Machine Learning, and both learning systems and is followed by students with each document index like figure 7 of 2402, 1157 and 898. The smaller the font size of the keyword This means that the discussion regarding this topic is still not well studied so this could be a candidate for discussion that can be discussed in the future.

Research Discussions

Annual scientific publication. The data reveals a noteworthy trajectory in the annual scientific production of machine learning articles. From 2013 to 2022, there was a consistent upward trend in publication output, demonstrating the field's sustained growth and relevance (see Fig. 1). However, in 2022 and 2023, there is a notable shift, with a decrease in both the number of articles and the mean total citations per year per article. The correlation between publication growth and citation patterns highlights the need to consider both the quantity and quality of research output in understanding the dynamics of the field. While increased publication growth is a positive indicator of research activity, the impact and visibility of individual publications may vary, reflecting the evolving nature of the field and the competition for scholarly attention.

***Countries and research institutions distributions*.** In the context of academic research on machine learning, Figure 7 displays the categorization of relevant topics based on current research trends. In the first group, there are topics that are currently emerging in research trends, such as learning systems, students, learning algorithms, prediction, data mining, decision trees, educational computing, academic performance, and classification. In the second group, there are topics that are still under research scrutiny, related to humans and articles. Meanwhile, the third group comprises well-established and relevant topics in the context of machine learning in academic research, including machine learning itself, artificial intelligence, and deep learning. There are also topics situated between the first and second groups, indicating that these topics continue to be primary focuses in research and development of machine learning in an academic context.

Figure 7 and 8 provides valuable information for researchers in selecting research topics that align with current research trends and have the potential to contribute to the improvement of education. In bibliometric analysis, there is a method called conceptual structure mapping used to identify and analyze the relationships between concepts in academic literature. This method involves keyword mapping and cluster analysis of scientific documents in relevant databases. It helps researchers understand research trends and identify research opportunities that need further exploration.

Most Relevant Keywords of Machine Learning in Academic Research. *Bibliometric* analysis in machine learning in the academic field has a strong relationship. This can be seen in Figures 2 and 3 which indicate that machine learning and system learning in the last 10 years have become a highly discussed topic in the world, especially education. This is also supported by the opinion of Song & Wang (2020) that machine learning influences students' metacognition, emotions, motivation and learning skills. Machine learning has contributed to the academic field, especially the development of student-centered learning, increasing motivation and response or activeness in learning (Okagbue et al., 2023).

Thematic analysis shows a combination of bibliography and keywords of interest which are called clusters. Thematic clusters include; machine learning, learning systems and students. This finding is similar to the findings of (Akdeniz & Ozdine, 2021) who found that the terms "machine learning" and "student" influence a person's academics by changing the way of learning and better ways of teaching. Apart from that, the increase in research on machine learning from 2013 to 2023 has increased significantly, meaning that this is still a trend to be researched from various perspectives to provide a better academic impact.

Conclusions

This comprehensive bibliometric analysis of machine learning research within academic research from 2013 to 2023 yields valuable insights into the evolving landscape of machine learning within the educational context. The analysis covers multiple facets, including annual scientific publication trends, the categorization of research topics, and the thematic clusters that reflect the most relevant keywords in machine learning in an

academic setting. The results show the trajectory of annual scientific production in machine learning articles reveals a compelling narrative. From 2013 to 2022, there is a consistent upward trend, indicating the sustained growth and relevance of the field. The data underscores the field's sustained growth, emphasizes the importance of considering both quantity and quality in research assessment, and guides researchers in identifying relevant and impactful research topics. The thematic analysis highlights the enduring influence of machine learning and students in academia, paving the way for further exploration to enhance educational practices.

For future research, it is recommended to emphasize the quality of machine learning research in academic contexts, exploring emerging research topics in machine learning within academia and their influence on educational practices can guide the development of innovative pedagogical approaches. It also can enrich the understanding of machine learning's role in shaping the future of education.

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Zafrullah
Yogyakarta State University, Yogyakarta, Indonesia
E-mail: zafrullah.2022@student.uny.ac.id
ORCID ID 0009-0008-3752-8841

Atika Miftah Ramadhani
Yogyakarta State University, Yogyakarta, Indonesia
E-mail: atikamiftah.2022@student.uny.ac.id

Xu Wenxin
Abai Kazakh National Pedagogical University, 050010,
Almaty, Dostyk ave., 13, Kazakhstan
E-mail: xuwenxin0124@163.com

Anugrah Arya Bakti
Yogyakarta State University,
Yogyakarta, Indonesia
E-mail: anugraharya.2022@student.uny.ac.id

Abzal Kuanyshuly
Institute of Metallurgy and Ore Beneficiation JSC,
Satbayev University, 050010, Almaty City,
the Republic of Kazakhstan. Shevchenko str., 29/133.
Email: AbzikSabir@gmail.com

Application of Critical Thinking in Mathematics Education: Bibliometric Analysis (1991-2023)

Abstract: Critical thinking is an important skill in the 21st century and plays a major role in learning. This bibliometric research evaluates previous academic work on the use of Critical Thinking in mathematics education. Through Scopus analysis, research uses RStudio Biblioshiny and VosViewer to map research trends and search for new keywords. The results show an increase in publications of approximately 10.58% annually, reflecting growing interest in this topic. The Indonesian University of Education stands out as a productive research center in this field, with more than 25 related articles. "Journal of Physics: Conference Series" and "International Journal of Instruction" stand out as the most prolific publications, with "Soter et al. (2008)" having the highest number of citations, reaching 217 citations. Keywords such as systematic reviews, critical mathematics education, science technologies, and e-learning stand out as key trends, providing potential for further exploration in future research. This underscores the importance of continued research in applying Critical Thinking in mathematics education, indicating growing interest as well as areas requiring further focus for the development of critical skills in this context.

Keywords: Critical Thinking, Mathematics Education, Bibliometrics

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Introduction

The end of the Second World War was a trigger for all countries in the world to undertake extensive recovery efforts (Zetriuslita, Nofriyandi, & Istikomah, E., 2020; Zetriuslita & Ariawan, 2021). Countries are committed to repairing damaged infrastructure, rebuilding their economies, and increasing human resources through various reconstruction and development programs. One aspect that has received great attention is the education sector, where many countries have launched programs to increase access to education for all levels of society and improve the quality of education to ensure a brighter future (Fitriani, 2023; Hakim & Angga, 2023; Rezeki et al., 2020).

Education is an integral part of human life where each individual is considered the greatest investment in overall human development and formation (Arraniri et al., 2021; Saputra, 2021). Education can also be explained as the process by which individuals acquire the knowledge, skills, and values necessary for their growth and development in society (Rahmadania et al., 2021). So, educational position is very important for a

person because it can make a greater contribution to the journey of life (Zafrullah, Bakti, et al., 2023; Zafrullah, Suyanto, et al., 2023; Zafrullah & Zetriuslita, 2021). One thing that is experiencing development is mathematics learning.

Mathematics plays a vital role in the realm of education and has experienced significant development as a scientific discipline that continues to develop to this day (Asdar et al., 2021; Priyatna & Wiguna, 2021). Mathematics is an integral foundation for various scientific disciplines, because it penetrates every aspect of knowledge, and as a substantial science that has broad uses in various areas of social life (Nurulaeni & Rahma, 2022; Yahya, 2022). So it can be concluded that mathematics is a crucial foundation that cuts across various scientific disciplines, provides an important foundation and has a substantial role in continuity and understanding in various fields of life and human knowledge. One of the important things in learning mathematics is the application of Critical Thinking.

Critical thinking ability itself is a systematic skill in evaluating information, explaining reasons, and analyzing, which is an urgent need in facing the impact of the dynamics of life in the era of information flow (Kurniawan et al., 2021; Kusumawati et al., 2022). Critical thinking is not only a cognitive aspect that allows identifying problems and finding solutions, but also a process that aims to enable rational and reasonable decision making in dealing with various situations and complexities that occur in everyday life (Fitriyah & Ramadani, 2021; Rahmad et al., 2022). Thus, critical thinking as a high-level thinking skill that is important in developing 21st century skills, becomes very essential in the learning process because it increases students' thinking abilities in learning practices (Rahardhian, 2022; Salamudin & Amelia, 2022).

Much research has been conducted regarding the application of Critical Thinking in mathematics education. Therefore, researchers are interested in conducting bibliometric analysis to see the latest trends and innovations in this research. Through this analysis, it is hoped that research development trends and novelties in the application of Critical Thinking in the context of mathematics education can be understood. This can provide a more comprehensive view of how critical thinking concepts are integrated into mathematics learning and how this approach continues to develop to improve students' understanding and mastery of mathematics material.

Research Methods

This bibliometric research aims to evaluate previous academic work that has been carried out in the context of the use of Critical Thinking in Mathematics Education. Bibliometric analysis is an approach to examining the evolution of a research domain, including topics and authors, based on the social, intellectual, and conceptual structure of scientific disciplines (Supinah & Soebagyo, 2022). Bibliometric analysis is commonly used in scientific disciplines and focuses on the quantitative study of journal papers, books, or other types of written communication (Sidiq, 2019). The overall analysis of the article mapping was carried out through R-Studio, which is the Bibliometric platform used (Saifudin, 2013).

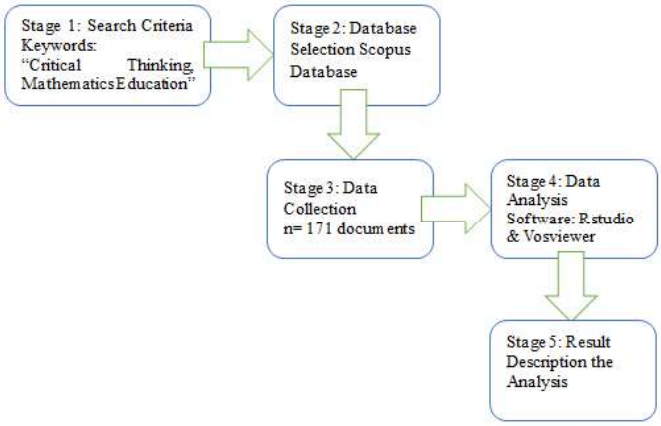

Fig 1. Bibliometrics Flow of Critical Thinking in Mathematics Education

This research describes a series of structured steps that begin by using keywords related to Critical Thinking in the context of mathematics education to ensure focus and relevance in the search. This was

followed by a search in a database that was considered to have a high reputation, namely Scopus, where 171 documents were obtained that were ready for analysis. The next stage involves evaluating the selected documents with bibliometric methods using open source software such as R Bibliometrix. In addition, researchers utilized VOSviewer to map innovations in the research. The final step focuses on presenting the results, conclusions and quantitative evaluation of the research after the data has been processed and analyzed. This process displays an explanation of the findings along with a visual representation of the research results. This research approach is outlined in clear stages, starting from keyword selection, leading databases, document analysis, to presentation of results, which not only focuses on the search process but also on evaluation and use of software that supports bibliometric analysis to obtain comprehensive research results.

Research Results and Discussion

Research Results

Main Information. Once the relevant data is transferred to RStudio, the software's initial interface displays basic information about all articles that have been uploaded and are ready for analysis. Main information about documents to be analyzed using bibliometric methods can be accessed via Figure 2.

Fig 2. Main information about Critical Thinking in Mathematics Education

Figure 2 provides general information about research that looks at Critical Thinking in mathematics across 171 documents. These documents come from a variety of sources, including journals, proceedings, and books, for a total of 92 sources in the Scopus database. Interestingly, there is an increase in publications of around 10.58% each year, indicating increasing interest in Critical Thinking research in mathematics education. The analysis results also show the author's contribution and international collaboration in this research. Of the total 450 authors, 76 of them wrote themselves. Although there is variation in authorship, only about 9.942% of author collaborations involve international collaboration with an average of 2.87 authors per document. There are also 380 keywords and 5750 references related to this topic, indicating the diversity and depth of research regarding Critical Thinking in mathematics in the world of education.

Publication Trends. Of course, Critical Thinking research experiences a trend in the number of publications each year. Table 1 will explain publication trends from 1991 to 2023.

Table 1. Publication Trends

Year	TP	Percentage	TC	NCP	h	g
1991	1	0.58%	8	1	1	1
1992-2004	-	-	-	-	-	-
2005	1	0.58%	1	1	1	1
2006-2007	-	-	-	-	-	-
2008	1	0.58%	217	1	1	1
2009	4	2.34%	56	4	4	4

2010	3	1.75%	46	3	3	3
2011	3	1.75%	6	1	1	2
2012	2	1.17%	12	2	2	2
2013	2	1.17%	36	2	1	2
2014	3	1.75%	48	3	2	3
2015	4	2.34%	30	4	3	4
2016	7	4.09%	111	7	3	7
2017	7	4.09%	76	7	4	7
2018	9	5.26%	34	7	3	5
2019	17	9.94%	111	15	7	10
2020	37	21.64%	185	27	8	12
2021	21	12.28%	30	10	4	4
2022	24	14.04%	64	13	5	7
2023	25	14.62%	13	6	2	3
Total	171	100%				

TP= Total Publications, TC= Total Citations, NCP= Number of Citation Publications, h= h-index, g=g-index

The data contained in Table 1 clearly shows that between 1991 and 2018, only 17 publications were recorded that discussed Critical Thinking in the domain of mathematics education. However, from 2019 to 2023, there was a significant increase in the total number of publications, with the addition of 124 articles, meaning approximately two-fold growth. This reflects a substantial change in interest in research related to Critical Thinking in the context of mathematics learning. The peak of the increase in the number of publications was recorded in 2020, with 37 articles (21.64%). The Citations trend can be seen from the NCP value, where the highest NCP occurred in 2020 with an NCP value = 27, followed by 2019 with an NCP = 15. However, if we look at the total citations (TC), the publication in 2008 is in the spotlight with the highest number of citations, reaching 111 citations, making the publication in 2011 the most influential in this field.

Most Productive Affiliates. Below is presented data regarding the most productive affiliations in the Critical Thinking theme in the field of mathematics education. The results of the bibliometric analysis can be seen in Table 2.

Table 2. Affiliates with the highest number of publications

Affiliation	Country	Articles
Universitas Pendidikan Indonesia	Indonesia	25
University of Groningen	Netherland	8
University of Southern Queensland	Australia	8
University of Salamanca	Spain	7
Universitas PGRI Madiun	Indonesia	6
Universitas PGRI Semarang	Indonesia	6
Western Philippines University	Philippines	6
State University of Malang	Indonesia	5
The Chinese University of Hong Kong	China	5
Universitas Negeri Yogyakarta	Indonesia	5

In continuation of the data analysis presented, it can be concluded that the Indonesian Education University stands out as a very productive research center on the topic of Critical Thinking in mathematics education. With more than 25 articles related to this topic, the university shows consistency in contributing knowledge regarding critical approaches to mathematics learning. Meanwhile, the University of Groningen

and the University of Southern Queensland, although with lower numbers than the Indonesian University of Education, still have significant contributions in this field with more than 8 articles. This indicates a strong commitment from these universities to participate in the development of the concept of Critical Thinking in the context of mathematics education.

It is important to note that five affiliates from Indonesia, with a total of 47 publications, show that collaborative efforts in developing Critical Thinking knowledge in mathematics education do not only come from one institution, but from a number of academic institutions in Indonesia. This reflects a positive trend in the development of critical approaches in the field of mathematics education at the national level. From these data, it can be concluded that cross-institutional and international collaboration plays an important role in developing the concept of Critical Thinking in the context of mathematics education. This opens up opportunities for the exchange of ideas, methodologies and best practices among various affiliates, enriching the understanding and application of these concepts in educational settings.

Most Productive Source. Citation analysis begins with the ten main sources that have the largest number of publications in the field of Critical Thinking in mathematics education listed in the Scopus index.

Table 3. Sources with the highest h-index

Journal Name	SQ	NP	h_index	TC
Journal Of Physics: Conference Series	-	32	5	79
International Journal of Instruction	Q2	4	4	48
Sustainability	Q1	6	4	50
Eurasian Journal of Educational Research	Q3	3	3	48
Journal on Mathematics Education	Q2	3	3	84
ASEE Annual Conference and Exposition, Conference Proceedings	-	6	2	16
Canadian Journal of Science, Mathematics and Technology Education	Q2	4	2	8
Eurasia Journal of Mathematics, Science and Technology Education	Q2	2	2	15
Mathematics	Q2	2	2	9
Participatory Educational Research	Q3	2	2	14

SQ= Scopus Quartile, NP=Number of Publication, TC=Total Citation

Table 3 presents information about the most productive journals and publication sources in terms of the number of publications and citations related to critical thinking in mathematics education. From this table, "Journal of Physics: Conference Series" is the most productive publication with 32 articles and 79 citations. This is followed by "International Journal of Instruction" with 4 publications and 48 citations. Apart from that, information from this table also shows that the higher the number of citations to a journal or source, the higher the h-index value. This indicates that journals or sources with a high number of citations have a significant impact in the field of critical thinking in mathematics education and are highly recognized by researchers in this field.

Articles with the Most Citations. Below are presented the ten most cited articles obtained from various sources and authors. The table below reveals the results of a bibliometric analysis highlighting the articles that have received the highest number of citations in various sources.

Table 4. Top 10 Most Article Citations

Paper	DOI	Affiliation	TC	TC/Y
(Soter et al., 2008)	10.1016/j.ijer.2009.01.001	The Ohio State University	217	13.56

(Holmes & Hwang, 2016)	10.1080/00220671.2014.979911	Hope Collage	67	8.38
(Dewolf et al., 2014)	10.1080/00220973.2012.745468	Katholieke Universiteit (KU) Leuven	45	4.5
(As' ari et al., 2017)	10.22342/jme.8.2.3961.145-156	Universitas Negeri Malang	41	5.86
(Gal et al., 2020)	10.1007/s11858-020-01155-9	University of Haifa	37	9.25
(Palinussa, 2013)	10.22342/jme.4.1.566.75-94	Universitas Pattimura	35	3.18
(Ülger, 2016)	10.16986/HUJE.2016018493	Sivas Cumhuriyet University	31	3.88
(Aizikovitsh & Amit, 2010)	10.1016/j.sbspro.2010.03.596	Ben Gurion University	29	2.07
(Erdogan, 2019)	10.14689/ejer.2019.80.5	Fırat Universitesi	27	5.4
(Sriraman & Knott, 2009)	10.1007/s10780-009-9090-7	University of Montana	26	1.73

The information in Table 4 highlights the authors and highest number of citations of the articles tracked by Scopus. These data show that the article written by (Soter et al., 2008) received the highest number of citations, namely 217, among all articles discussing critical thinking in mathematics education. This article is followed by papers from (Holmes & Hwang, 2016), (Dewolf et al., 2014), (As'ari et al., 2017), and (Gal et al., 2020), which are included in the five the most cited article on the topic. This data highlights that (Soter et al., 2008) is the author who received the highest citations, indicating that his research has a significant impact regarding critical thinking in the context of mathematics education. It should be noted, however, that a high number of citations is not always the sole determinant of the quality of a study, given that other factors can influence this, such as the popularity of the topic or the availability of access to the research.

Author with the Most Articles. Below is presented data regarding the most productive writers on the Critical Thinking theme in mathematics education. The results of the bibliometric analysis can be seen in Table 5.

Table 5. Top 10 Authors of the Most Articles

Authors	Affiliation	Articles
Abdur Rahman As`ari	Universitas Negeri Malang	5
Sufyani Prabawanto	Universitas Pendidikan Indonesia	4
Herawati Susilo	Universitas Negeri Malang	4
Darhim	Universitas Pendidikan Indonesia	3
Agung Purwanto	Universitas Negeri Jakarta	3
Arief Agoestanto	Universitas Negeri Semarang	2
Giovannina ALBANO	University of Salerno	2
Hugo Bronkhorst	University of Groningen	2
Jose Mª Chamoso Sánchez	Salamanca University	2
Robertas Damaševičius	Kaunas University of Technology	2

In Table 5, it can be seen that Abdur Rahman As'ari from the State University of Malang is the most productive writer with 5 articles on Critical Thinking in mathematics education. Meanwhile, Sufyani Prabawanto from the Indonesian University of Education and Herawati Susilo from the State University of Malang were ranked second with 4 articles. Of the ten authors listed, six come from universities in Indonesia. This indication shows the strong interest and involvement of researchers in Indonesia in exploring aspects of Critical Thinking in the context of mathematics education, which in turn can reflect the interest in developing innovative methods in mathematics education that focus on critical aspects of thinking. This can also encourage collaboration between researchers in the country to develop a deeper understanding of the topic.

Research Focus and Keyword Novelty. Apart from using RStudio, researchers also use Vosviewer to map research focus and see the novelty of keywords. The research focus can be seen in Figure 3.

In the image above, there are different colors according to the cluster. This shows that there are several clusters of keywords that are often linked to others. There are five clusters in Figure 3. The first cluster (red) contains the words calculations, data handling, education computing, learning models, learning systems, mathematics education, problem-based learning, realistic mathematics education, and undergraduate students. The second cluster (green) contains the words curriculum, pre-service teachers, problem solving, teaching, problem solving skills, sustainable development, and stem (science, technology, engineering, and mathematics). Cluster three (blue) consists of the word's critical mathematics education, critical thinking, education, higher education, and student. Cluster four (yellow) contains the words e-learning, engineering and mathematics, engineering education, robot programming, and science technologies. Cluster five (purple) contains the words mathematical thinking, physics, and systematic review.

The overlay visualization depicts various keywords with color groupings, where dark colors indicate keywords that have long been the focus of research, while light colors indicate keywords that have recently been used in research. From the data depicted, it can be seen that in 2022, keywords such as systematic review, critical mathematics education, science technologies, and e-learning appear in yellow. From this it can be concluded that for further research, these keywords can be used as recommendations because they became trends or the main focus of research in that year, providing potential for further exploration.

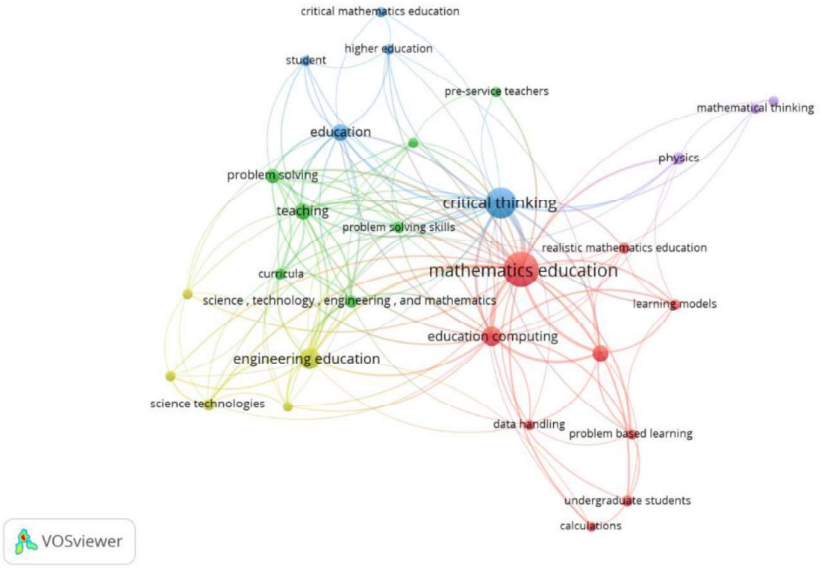

Fig 3. Network Visualization (Keyword Occurrence ≥ 3)

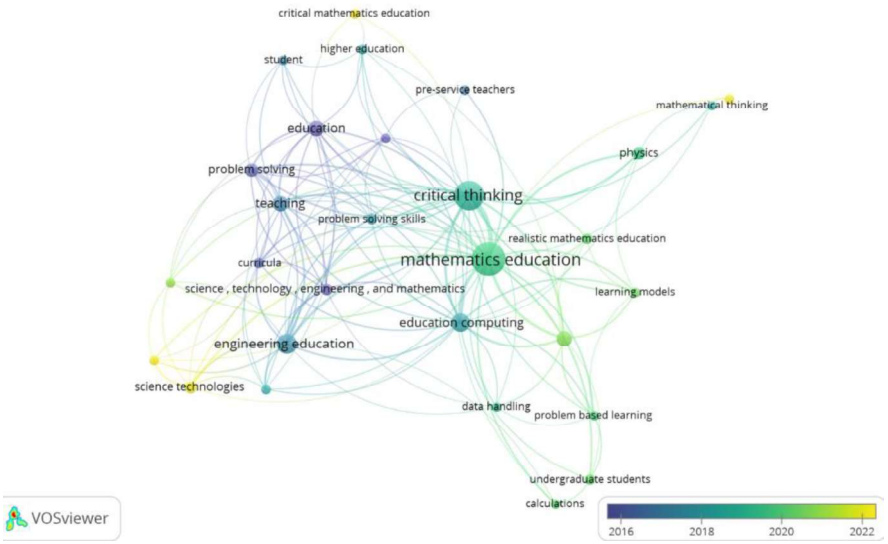

Fig 3. Overlay Visualization

Research Discussion

Rapid developments in the realm of education have brought changes in various aspects, including evolution in learning styles (Andrian, 2019; Andrian et al., 2020). In this era of ever-growing educational transformation, the increasing emphasis on critical thinking skills is crucial because it not only encourages students to master information, but also to be able to understand, analyze and carefully evaluate the information obtained (Lismaya, 2019; Warsah et al., 2021). Thus, Critical Thinking becomes the center of attention in providing the skills needed to face complex challenges in an era of education that continues to develop, especially mathematics education.

The results of the analysis of main information from 171 documents examining Critical Thinking in the context of mathematics education, came from various sources including journals, proceedings and books. This research shows an increase in publications of around 10.58% every year, indicating increasing interest in the study of Critical Thinking in mathematics education. Detailed data shows that between 1991 and 2018, there were only 17 publications discussing the topic of Critical Thinking in mathematics education. However, from 2019 to 2023, there was a significant jump in the total number of publications, adding a total of 124 articles, reflecting almost double the previous growth.

The Indonesian University of Education stands out as a very productive research center on the topic of Critical Thinking in mathematics education with more than 25 related articles. Although the University of Groningen and the University of Southern Queensland had fewer contributions, they still played a significant role with more than 8 articles. Interestingly, five affiliates from Indonesia, with a total of 47 publications, show strong collaboration in developing Critical Thinking knowledge in mathematics education, beyond the contribution of one institution alone.

Regarding the source with the highest number of publications, "Journal of Physics: Conference Series" was recorded as the most productive publication with 32 articles and 79 citations in the context of critical thinking in mathematics education. Meanwhile, "International Journal of Instruction" followed with 4 articles and 48 citations. Information from this table also shows the correlation between the number of citations to a journal or source and its h-index value, where the higher the number of citations, the higher the h-index value. The authors and the highest number of citations from articles listed in Scopus show that (Soter et al., 2008) is the author with the highest number of citations, reaching 217 citations, among all articles discussing critical thinking in mathematics education. Abdur Rahman As'ari from Malang State University is the most productive writer with 5 articles discussing Critical Thinking in mathematics education. Meanwhile, Sufyani Prabawanto from the Indonesian Education University and Herawati Susilo from the State University of Malang were ranked second with 4 articles each.

The first cluster emphasizes improving mathematics education by utilizing technology, innovative learning strategies, and efforts to involve students in mathematics learning experiences that are more real and appropriate to their context. Meanwhile, the second cluster discusses the development of problem solving skills in the context of continuing education, especially for prospective teachers with a focus on STEM disciplines (science, technology, engineering and mathematics). The discussion centered on the integration of problem solving skills into the educational curriculum, aiming to prepare prospective teachers to teach students to be able to solve problems related to sustainable development.

The third cluster discusses the importance of developing critical thinking skills at the higher education level, especially in mathematics, with a focus on critical approaches in mathematics learning. The fourth cluster highlights engineering and science education with an emphasis on e-learning, seeking to develop innovative learning methods to improve student understanding. Meanwhile, the fifth cluster explores the relationship between mathematical thinking and physics through a systematic approach, to understand the influence and essential connection between the two.

The latest keywords consisting of systematic review, critical mathematics education, and science technologies, e-learning describe a substantial role in supporting the development of critical thinking skills in mathematics education. Systematization in the research approach, seen from the use of systematic reviews, shows a commitment to analyzing information in a structured manner, which is essential for strengthening critical aspects in mathematics education. The focus on critical mathematics education highlights the urgent need to promote critical thinking in mathematics learning, while the emphasis on science technologies and e-learning offers opportunities to utilize technology to enhance mathematics learning in ways that encourage critical thinking. Thus, the combination of these three keywords provides a strong foundation for the

development of mathematics education that considers critical thinking in an effort to improve the quality of student learning in mathematics.

Conclusions

From the results of the analysis, it can be concluded that research highlighting Critical Thinking in the context of mathematics education shows an increase in publications of around 10.58% every year, reflecting the increasing interest in this topic. The Indonesian University of Education stands out as a highly productive research center in this field, with more than 25 related articles. Regarding the highest publication sources, "Journal of Physics: Conference Series" is the most productive publication with 32 articles and 79 citations in the context of critical thinking in mathematics education, followed by "International Journal of Instruction" with 4 articles and 48 citations. Additionally, authors Soter et al. (2008) recorded the highest number of citations, reaching 217 citations, indicating the significant influence of their work in the literature discussing critical thinking in mathematics education. In line with the analysis, keywords such as systematic reviews, critical mathematics education, science technologies, and e-learning stand out as key trends in research in that year, providing potential for further exploration in future research.

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e-ISSN 2707-9481 Institute of Metallurgy and Ore Beneficiation, Satbayev University, Almaty, Kazakhstan
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A.V. Panichkin
National Scientific Collective Use Laboratory
Institute of Metallurgy and Ore Beneficiation JSC
Almaty, Kazakhstan.
ORCID ID: 0000-0002-2403-8949
Email: a.panichkin@satbayev.university

B.B. Kshibekova
Institute of Metallurgy and Ore Beneficiation JSC
Almaty, Kazakhstan.
ORCID ID: 0000-0002-5944-7865
Email: b.kshibekova@satbayev.university

Assessment of the flux composition effect on the removal efficiency of non-metallic inclusions in high-chromium cast iron

Abstract: The problem to refine high-chromium cast iron melts obtained with the use of a large proportion of scraped metal and scrap is considered herein. Since fluxes containing calcium fluoride are currently considered to be environmentally polluting, it is required to reduce the use of fluorides, or completely replace them. It was shown that a decrease in the melting point of the flux can be achieved with the use of a mixture of calcium and magnesium fluorides or by the introduction of boron oxide into the composition of the fluxes. However, the efficiency of these fluxes, as well as silicocalcium additives and vacuum remelting in the high-chromium cast iron melting when a high proportion of scrap in the charge is used, has not been previously considered. In this regard, the effect of these refining methods on the removal of non-metallic inclusions in high-chromium cast iron of Grade 340X18HML was experimentally assessed. Thermodynamic calculations were performed for the interaction of magnesium and calcium fluorides with non-metallic oxide inclusions typical of high-chromium cast irons and with oxides used for neutral lining of induction furnaces. It has been shown that fluxes based on boron oxide, magnesium and calcium fluorides and their mixtures effectively remove oxide and sulfide non-metallic inclusions; however, they have a destructive effect on the lining of furnaces, significantly reducing its service life. The addition of silicocalcium reduces the content of sulfides but does not affect the content of non-metallic inclusions in the form of oxides and nitrides. Vacuum remelting effectively reduces the number of nitride inclusions.

Keywords: high chromium cast iron, HCCI, flux, calcium and magnesium fluorides, boron oxide, non-metallic inclusions

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Introduction

White high-chromium cast irons are important industrial alloys used in the manufacture of parts subject to abrasive wear. Their use in the manufacture of parts for mills, crushers, pumps intended to pump pulp and other equipment determines their high demand in the mining, metallurgical and energy industries. Due to the high cost of such cast irons during production of castings from them, it is economically justified to use a high proportion of scraped metal and scrap in their melting. It results in an increase in non-metallic inclusions in castings. In industrial conditions, it leads to an increase in defects caused by cracking of castings both during cooling and during subsequent heat treatment, as well as a decrease in their wear resistance. Economic considerations, as well as the desire to increase the wear resistance of castings, justify the increasingly widespread use of high-chromium cast irons of hypereutectic composition. If non-metallic

inclusions are introduced during melting the proportion of defects increases even more since these cast irons are prone to the formation of cracks by their nature.

Studies for castings made of hypereutectic high-chromium cast irons produced under industrial conditions have shown that cracks propagate both through primary carbides $(Cr, Fe)_7C_3$ and through oxide non-metallic inclusions and pores (Panichkin et al., 2021). At the same time, castings obtained without use of a large proportion of scrap during cast iron melting have predominantly MnS and TiN inclusions. It indicates the need for effective refining of these cast iron melts. It is known (Kudryavikh, 2012) that many non-metallic inclusions are contained in the form of extremely thin formations of colloidal size in alloyed cast irons and in cast irons containing impurities of non-ferrous metals (1 cm^3 of ordinary gray cast iron can contain up to 5 million stable oxide inclusions, including about 70 % inclusions ranging in size from 0.2 to 1 micron; about 43 million sulfides; about 5 million carbonitrides). These endogenous inclusions, existing in liquid cast iron and formed during crystallization, can have a noticeable, and often decisive, effect on the physical properties of the metal, the processes of structure formation of cast iron and its properties in castings, and in the greater extent, the higher these properties are.

Treatment of cast iron with limestone reduces the contamination of alloys with non-metallic inclusions, especially sulfide ones, reduces their size, globularization and transfers them deep into grains, as well as incurs chopping and smoothing of the structure (Kolokoltsev, Shevchenko, 2011). A slag mixture is usually used in the acid melting process. This mixture consists of fireclay and glass breakage, freshly burnt ground lime and fluorspar. The authors of (Ri et al., 2015) recommend to treat chromium cast iron with slag-forming mixtures containing CaF_2, $CaCO_3$, SiO_2, C coke, CaC_2 to improve its quality. These mixtures are proposed in a crushed state (2-3 mm or less) to be poured onto the surface of the melt immediately after addition of ferroalloys. The main components of fluxes used in melting high-alloy cast irons in furnaces with a main lining are lime (CaO) and CaF. It can prevent contamination of the melt with non-metallic inclusions containing silicon oxide in contrast with melting in an acid-lined furnace.

Another source for the formation of non-metallic inclusions is the process of deoxidation of cast iron melts. Thus, deoxidation of the melt with ferrotitanium reults in contamination of cast iron with titanium carbonitrides and carbosulfonitrides. During deoxidization with aluminum or ferrotitanium containing up to 10% Al and 7% Si, dispersed compounds $nAl_2O_3mSiO_2$(aluminosilicates) that do not have time to float are formed in the structure of the castings and crumble during impact-abrasive wear (Goldstein & Mizin, 1986; Kolokoltsev et al., 2007; Taran, 1967; Orekhova. 2010;). The authors of (Ri et al., 2015) consider the use of ferrosilicon for deoxidation of cast iron unacceptable due to the formation of silicates. The authors of (Rozhkova, et al., 2005) believe that the most effective is the deoxidation of chromium cast iron with the alloy FCM-6 containing, %: 40 – 50 Ce; 5 – 7 Mg;18 – 25 La; 10 – 12 Nd; 5 – 7 Pr; not more than 10 of Fe. The optimal amount of FCM-6 additive was 0.2 – 0.3% of the liquid metal mass. The introduction of a large amount of master alloy causes contamination, since REM and Mg, which are part of the master alloy, form complex compounds with oxygen and sulfur located in the form of a continuous front along the boundaries of eutectic chromium carbides, and form intercrystalline layers of non-metallic inclusions of REM and Mg oxides.

The study of the effect of silicocalcium on non-metallic inclusions in high-chromium cast irons is of great interest. Thus, it is known that calcium is slightly soluble in iron-based melts and does not form solid solutions with iron; this feature allows it to be used as a deoxidizing element. The formation of calcium oxides in the melt volume during deoxidation can lead to their direct interaction with dispersed silicate inclusions and their removal. At the same time, the process of interaction of silicocalcium with the melt will promote the dissolution of silicon in the melt volume, which can also interact with oxygen in the melt volume, forming silicates.

Being a part of fluxes, calcium fluoride significantly reduces the viscosity of highly basic slags Al_2O_3 - CaO-MgO-SiO_2 (-CaF_2) (Wu et al., 2011). However, CaF_2 has a negative effect on the refractory lining, and its effect on the physical and chemical properties of slags is short-lived due to the high volatility of environmentally harmful fluorides.

One of the ways to increase the efficiency of fluxes and reduce the release of harmful fluorides is to lower the melting point of slags by adjusting the composition of the fluxes. As follows from the information presented in Table 1, boron oxide and mixtures of calcium and magnesium fluorides have a significantly lower melting point compared to fluorspar. It allows us to predict the possibility of reducing the amount of fluorides in the composition of fluxes or completely replacing them with boron oxide.

Table 1 - Melting and boiling points of compounds considered as components of fluxes for melting wear-resistant chromium cast irons

Characteristic name	Compound				
	CaF_2	MgF_2	CaF_2+ MgF_2 (2/1 by wt.)	B_2O_3	CaF_2+ 14.5 wt.% CaO
Melting point,°C	1418	1263	980	480	1368
Boiling point, °C	2533	2239	-	1680	-

It is known (Babenko et al., 2020; Babenko et al., 2020) that replacing CaF_2 with boron oxide allows not only to improve the physical properties of the slag but also the environmental situation. Work (Babenko, 2020) presents the results of experimental studies of the effect of chemical composition and temperature on the viscosity of slags of the CaO-SiO_2-Cr_2O_3 system containing 8 % MgO, 3 % Al_2O_3 and 6 % B_2O_3. It has been established that slag containing no chromium oxide with a basicity of 1.0 has a fairly low viscosity of 0.2–0.6 Pa·s in a wide temperature range of 1200–1350 °C, due to the high concentration of low-melting phases, reaching 22% ($CaO·B_2O_3$, $2CaO·B_2O_3$ and $CaO·MgO·2SiO_2$), and only 11% refractory ($2CaO·SiO_2$, $CaO·Cr_2O_3$, $MgO·Cr_2O_3$, CaO, Cr_2O_3 and MgO). Slag with 18% Cr_2O_3 with the same basicity retains a low viscosity of 0.1–1.0 Pa·s but at a much higher temperature of 1450–1570 °C due to an increase in the content of refractory compounds to 27% and an almost unchanged amount of fusible phases (21%). It is obvious that the use of a high proportion of scraped metal and scrap in the high-chromium cast iron melting sharply increases the risk of contamination with a large amount of chromium oxide, and it requires to take measures to reduce the melt viscosity.

The purpose of this work was to assess the efficiency of the use of fluxes from calcium and magnesium fluorides and their mixtures, boron oxide and its mixture with calcium fluoride, silicocalcium additives and vacuum remelting to remove non-metallic inclusions from a melt of high-chromium cast iron with Grade 340X18HML during melting in an induction furnace with a neutral lining.

Experimental part

With the purpose to assess the possibility to use fluxes CaF_2, MgF_2, a mixture of 56 wt.% CaF_2 + 44 wt.% MgF_2 of eutectic composition, B_2O_3 and mixture 50 wt.% B_2O_3+50 wt.% CaF_2, silicocalcium with Grade SK20, a series of laboratory experiments were performed to melt wear-resistant chromium cast iron with Grade 340X18HML (Table 2). The results were compared with castings obtained from cast iron smelted without the use of flux during the melting process. The mass of the cast iron sample melted during each experiment was 1300 g, the total proportion of scrap in the charge was ~70%. The flux sample was 50 g. The silicocalcium sample was 10.3 g. The melting was carried out in a normal atmosphere, in a corundum crucible with a neutral lining of the Insetag-86XT brand (84.7 wt% Al_2O_3, 14.6 wt% MgO). The charge used was Grade 3 steel (Grade C), ferrochrome FeCr60C70LSLP, cast iron shavings, AISI210 steel scrap (manganese steel), and H-2 nickel. When the steel scrap and cast iron shavings were melted, ferrochrome was added to the melt, then nickel and AISI210 steel scrap. Next, the alloy was deliberately kept at 1500-1550 °C without protective flux in a normal atmosphere for 10 minutes to oxidize it. After that, flux was added, and the melt was kept for another 15 minutes at the specified temperatures. Melting was performed in an induction furnace UIPV-0.001. Casting was carried out in a ∅ 40 mm graphite mold. Before casting, a layer of slag was mechanically removed from the surface of the melt.

Vacuum remelting was carried out using cast iron previously melted in a normal atmosphere. Remelting was performed in a vacuum induction furnace UIPV-0.001 at residual pressure (50-100 Pa). Heating was also carried out to 1450-1500°C and it was held for 0.5 hours. The melt was cast into a ∅40 mm graphite mold.

Table 2 - Composition of casting samples made of wear-resistant chromium cast iron after refining

Alloy	Chemical composition, wt.%											
	Fe	Cr	C	Mo	Ni	Mn	Si	P	S	Ti	Ca	Mg
340X18HML	base	17-20	3.3-3.6	≤1	≤1	0.6-1.2	0.6-1	≤0.1	≤0.06	-	-	-

The size and quantity of non-metallic inclusions were studied by metallographic analysis using a Leica DM IRM inverted optical microscope and the VideoTest-Metal software package. The surface of the sections was examined without etching. The content of sulfur and carbon in cast iron after refining was determined with the use of a Bruker G4 ICARUS TF analyzer. The phosphorus content was assessed by X-ray fluorescence analysis with an Axios wave-dispersive combined spectrometer. The number and proportion of non-metallic inclusions were determined under GOST 1778-80 by method P1. The composition of nonmetallic inclusions was studied with the use of a JEOL JXA-8230 microprobe analyzer.

Thermodynamic calculations of the interaction of magnesium fluorides, calcium and boron oxide with oxides characteristic of high-chromium cast iron, including the furnace lining, were performed using the HSC Chemistry 8.14 software package. The thermodynamic calculations made indicate that fluxes based on a mixture of magnesium and calcium fluorides will not enter into a chemical reaction with the lining of an induction furnace based on $MgO*Al_2O_3$ and with the oxides Cr_2O_3, SiO_2 located in the melt volume according to the reactions considered (Figures 1-3). The disadvantage of such fluxes will be the inability to use limestone or burnt lime to desulphurize the cast iron melt due to the development of reaction 11 with the formation of magnesium oxide that will significantly increase the viscosity of the melt. Based on this, it is possible to conclude that silicon and chromium oxides dissolve in fluoride-based fluxes, and the lining of the induction furnace will also be dissolved.

$CaF_2(l)+MgO=CaO+MgF_2$ (1)
$3MgF_2(l)+Al_2O_3=3MgO+2AlF_3$ (2)
$3CaF_2(l)+Al_2O_3=3CaO+2AlF_3$ (3)
$4CaF_2(l)+MgO*Al_2O_3=4CaO+MgF_2+2AlF_3$ (4)
$4MgF_2(l)+MgO*Al_2O_3=4MgO+MgF_2+2AlF_3$ (5)
$3CaF_2(l)+Cr_2O_3=3CaO+2CrF_3(g)$ (6)
$2CaF_2(l)+SiO_2=2CaO+SiF_4(g)$ (7)
$3MgF_2(l)+Cr_2O_3=3MgO+2CrF_3(g)$ (8)
$2MgF_2(l)+SiO_2=2MgO+SiF_4(g)$ (9)
$3MgF_2(l)+MgO*Al_2O_3=4MgO+2AlF_3$ (10)
$MgF_2+CaO=MgO+CaF_2(l)$ (11)

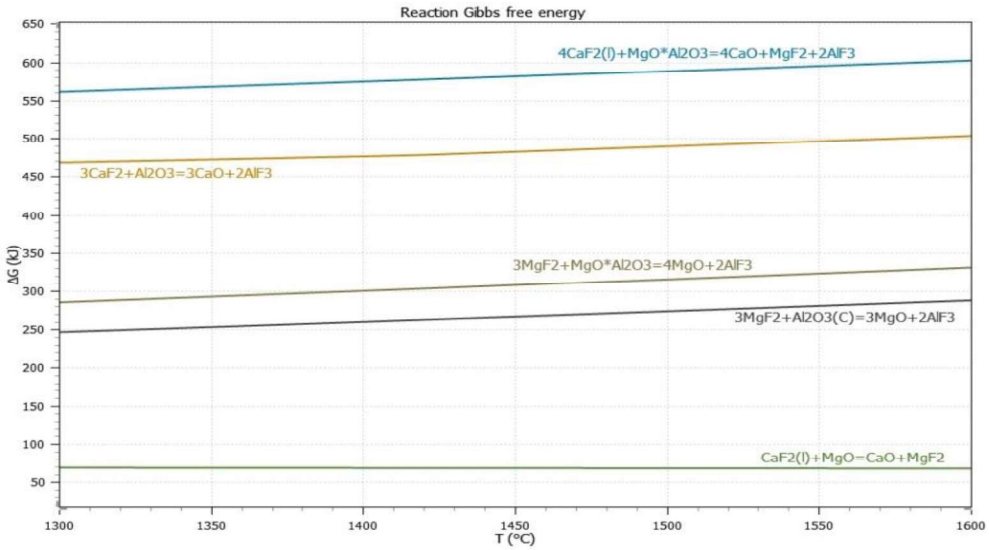

Figure 1 - Temperature dependence of the Gibbs energy of the reactions of calcium and magnesium fluorides with the furnace lining

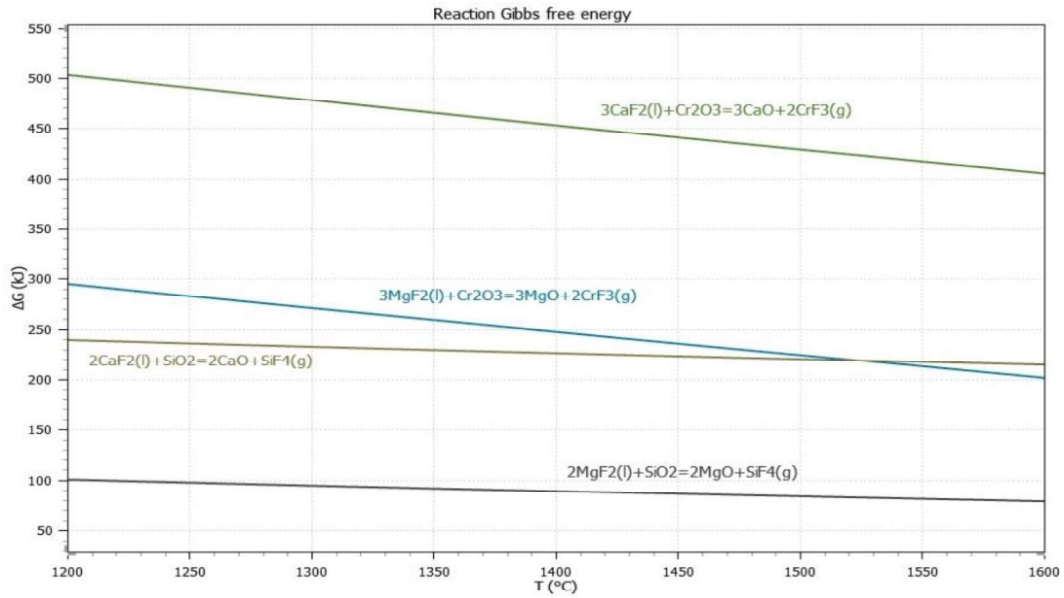

Figure 2 - Temperature dependence of the Gibbs energy of the reactions of calcium and magnesium fluorides with oxides in the melt structure

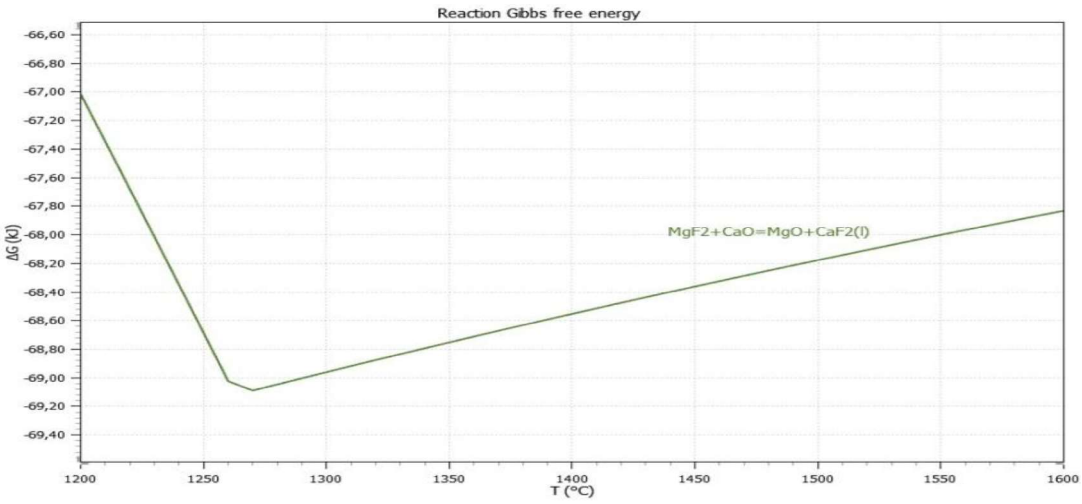

Figure 3 - Temperature dependence of the Gibbs energy of the reactions of magnesium fluoride with calcium oxide

Results and Discussion

Analysis of the composition of the alloys after refining with all types of fluxes showed a decrease in sulfur content (Table 3) compared to the alloy not treated with flux. The introduction of silicocalcium also led to a significant reduction in the sulfur content in the alloy. Vacuum remelting had little effect on the content of this element in cast iron. None of the melt processing methods used caused a decrease in the phosphorus content in it.

The metallographic analysis of the resulting castings showed a decrease in sulfide inclusions in the structure of cast irons melted using fluorides and boron oxide as fluxes and with the addition of silicocalcium (Table 3). In this case, the maximum reduction in the amount of sulfides to 0.09 vol.% occurred during use of a flux of 50 wt.% B_2O_3+CaF_2 and in case of introduction of silicocalcium into the melt. A good result in melt desulfurization is also achieved during use of B_2O_3 flux.

The most effective way to reduce inclusions of titanium nitrides turned out to be vacuum remelting. It ensured a reduction in their amount by ~80%. The effect of fluxes on the volume fraction of inclusions of titanium nitrides and carbonitrides in the obtained samples is significantly less, however, a decrease in their

quantity is also noted by an amount ranging from 33% for CaF_2 flux to 45% for 50 wt.% flux B_2O_3+CaF_2. It is explained by the fact that the flux protects against the penetration of nitrogen into the melt from the atmosphere during the melting process but does not refine it from this element.

Table 3 - Effect of refining cast iron on the content of sulfur, phosphorus and non-metallic inclusions in their structure

Flux composition	*Content, wt.%*		*Nitrides, vol.%*	*Sulfides, vol.%*	*Oxide inclusions, vol.%*
	P	S			
Alloy without flux	0.02	0.052	0.37	0.298	0.63
CaF_2	0.03	0.028	0.249	0.175	0.26
MgF_2	0.03	0.027	0.234	0.187	0.34
56 wt.% CaF_2 + 44 wt.% MgF_2	0.03	0.028	0.245	0.174	0.32
B_2O_3	0.03	0.017	0.205	0.148	0.19
50 wt.% B_2O_3+CaF_2	0.02	0.017	0.203	0.07	0.22
Ferroalloy SK20	0.03	0.014	0.312	0.09	0.55
Remelting in vacuum (50-100 Pa)	0.019	0.033	0.074	0.267	-

All tested fluxes clean the wear-resistant high-chromium melt well from oxide inclusions, with the best results obtained with the use of B_2O_3 flux, which reduces the number of oxide inclusions by ~70%. This is due to the lowest melting point and, accordingly, the viscosity of slags formed during interaction with oxides of chromium, iron, and silicon. Analysis of the composition of slags formed on the surface of molten cast iron during its treatment with flux 56 wt.% CaF_2 + 44 wt.% MgF_2 shows (Table 4) that it contains large amounts of oxides of iron, chromium and silicon.

Meanwhile, it has been discovered that the use of all fluoride- and oxide-based fluxes causes accelerated destruction of the furnace lining. It is due to the fact that fluxes gradually penetrate into lining material through the pores and react due to their low viscosity and good wetting of its surface. It is confirmed with the results of analyzes for the composition of the slag taken from the surface of the lining after melting cast iron using a flux of 56 wt.% CaF_2 + 44 wt.% MgF_2 (Table 4). They indicate the dissolution of aluminum oxide by flux. The least influence was found during use of CaF_2 flux. It is due to the formation of more refractory eutectics with lining components. B_2O_3 has the most significant effect on the lining; its use reduces the service life of the lining up to 2-3 heats.

Table 4 - Composition of slag after melting the wear-resistant high-chromium melt under a layer of flux of 56 wt.% CaF_2 + 44 wt.% MgF_2

Slag sampling location	**Chemical composition, wt.%**										
	O	**F**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**K**	**Ca**	**Ti**
From the lining surface	17.770	22.888	0.388	12.451	6.015	5.227	0.004	0.028	0.074	12.260	0.518
	Cr	**Mn**	**Fe**	**Sr**	**Y**	**Zr**	**Ba**	**Pb**	**Co**	**Ni**	**Zn**
	0.030	0.485	0.292	0.018	0.006	0.015	0.242	0.040	-	-	-
From the surface of the melt	**O**	**F**	**Na**	**Mg**	**Al**	**Si**	**P**	**S**	**K**	**Ca**	**Ti**
	10.088	25.859	0.109	14.958	0.168	0.782	0.013	0.012	0.022	15.110	0.055
	Cr	**Mn**	**Fe**	**Sr**	**Y**	**Zr**	**Ba**	**Pb**	**Co**	**Ni**	**Zn**
	6.953	0.154	13.292	-	0.004	-	0.302	0.029	0.026	0.052	0.007

Thus, it has been established that replacing CaF2 flux with fluxes B2O3 and 50 wt.% B2O3 + 50 wt.% CaF2 promotes deeper purification of the melt from sulfide (by 75%) and oxide (by 70%) non-metallic inclusions. The effect of melt desulfurization from the use of flux 50 wt.% B2O3 + 50 wt.% CaF2 is comparable to modifying the alloy with silicocalcium CK30 in an amount of 1%. Fluxes CaF2, MgF2, 56 wt.% CaF2 + 44 wt.% MgF2, B2O3 and 50 wt.% B2O3 + 50 wt.% CaF2 protect the melt from dissolving nitrogen in it, but do not refine it from nitrogen impurities. Meanwhile, the use of these fluxes reduces the service life of the furnace lining. The least effect on the lining was found when using CaF2 flux; the most significant effect is exerted by B2O3, which is associated with the interaction of this compound with the components of the lining with the formation of low-melting eutectics. Vacuum remelting is an effective way to clean cast iron

from nitrogen dissolved in its volume. Based on the results obtained, we can conclude that it is necessary to search for more effective refining fluxes that provide comprehensive cleaning of high-chromium cast irons from sulfide and oxide non-metallic inclusions and have minimal impact on the furnace lining.

Conclusions

- The thermodynamic calculations made indicate that fluxes based on a mixture of magnesium and calcium fluorides enter into a chemical reaction with the lining of an induction furnace based on $MgO*Al_2O_3$ and with the oxides Cr_2O_3, SiO_2 located in the melt volume. Analysis of phase diagrams indicates that these fluxes will form melts with these oxides. The disadvantage of these fluxes is the inability to use limestone or burnt lime to desulphurize the cast iron melt.

- Replacement of CaF_2 flux with fluxes - $B_2O_3$and 50 wt.% B_2O_3+50 wt.% CaF_2 promotes deeper purification of the melt from sulfide (~75%) and oxide (~70%) non-metallic inclusions. The effect of melt desulfurization from the use of flux 50 wt.% B_2O_3+50 wt.% CaF_2 is comparable to alloying of the alloy with silicocalcium CK30 in an amount of 1%.

- Fluxes CaF_2, MgF_2, 56 wt.% CaF_2 + 44 wt.% MgF_2, B_2O_3 and 50 wt.% B_2O_3+50 wt.% CaF_2 protect the melt from dissolution of nitrogen in it but does not refine it from nitrogen impurities.

- The use of fluxes based on CaF_2, MgF_2 and B_2O_3 and their mixtures shortens the service life of the furnace lining due to active dissolution. The least effect on the lining was found during the use of CaF_2 flux; B_2O_3 had the most significant effect on the lining.

- Vacuum melting at 50-100 Pa for 30 minutes is effective to remove nitrogen from a melt of high-chromium cast iron but it does not have a significant effect on the sulfur content in the alloy.

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Content

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Issue VI

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Institute of Metallurgy and Ore Beneficiation JSC, Satbayev University, Almaty, Kazakhstan
Address: 050010, Almaty, Kazakhstan. st. Shevchenko corner ch. Valikhanova, 29/133

Tel.: +7 (727) 298-45-19, +7 (727) 298-45-20, +7 (727) 298-45-22
Web сайт: http://kims-imio.com; URL: https://kims-imio.kz/en/
E-mail: conference@kims-imio.kz