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"ПРОГРЕССИВНЫЕ МЕТОДЫ ОБОГАЩЕНИЯ И КОМПЛЕКСНАЯ ПЕРЕРАБОТКА ПРИРОДНОГО И ТЕХНОГЕННОГО МИНЕРАЛЬНОГО СЫРЬЯ" – ПЛАКСИНСКИЕ ЧТЕНИЯ - 2014

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"КРАТКАЯ ИСТОРИЯ ПЕРЕРАБОТКИ ПОЛЕЗНЫХ ИСКОПАЕМЫХ"

Статья посвящена памяти академика Игоря Николаевича Плаксина (1900-1967), который является основателем советской научной школы в области обогащения полезных ископаемых и гидрометаллургии редких, цветных и благородных металлов.

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Комплексное использование минерального сырья. № 3. 2014

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A SHORT HISTORY OF MINERAL PROCESSING[1]

Crushing and grinding of ores and their beneficiation by washing away gangue minerals has been practiced since ancient times. Primitive crushing was done by hand pounding the ore with a hard stone then by using metallic hammers. The mortar and pestle was mechanized using a lever and when the size of operations increased in the middle ages, the stamp mill was introduced. The grindstone played an important role in grinding of ores. Panning for gold and hand sorting of minerals were two old methods of separation, now gave way to modern techniques. Flotation started in the middle of the nineteenth century by using oils to collect the mineral particles and float them on the surface of the aqueous slurry. It was only in the 1920s when it was discovered that organic compounds were affective floating agents. Textbooks written by distinguished engineers such as Rittinger, Rickard, Pryor, Taggart, Richards, Gaudin, and others contributed to the recognition of this field as a new discipline to be taught in Universities. In Russia I.N. Plaksin devoted his studies to the theory and technology of hydrometallurgical processes, concentration of minerals, and the history of metallurgy.

Key words: minerals processing, ore beneficiation, flotation, science history.

[1]*Dedicated to the memory of Igor Nikolaevich Plaksin (1900-1967)*

Introduction. The ancient Egyptians knew already that it would be easier to melt an earth rich in gold particles than another which is poor. As a result all efforts were made to enrich the gold by washing away the light gangue minerals (Figure 1). Another ancient method for enriching gold particles from a river stream was by means of fleece, hence the Greek myth of the "golden fleece". The present day Georgia was known in ancient times as Colchis and was a center for gold working. It was known to the ancient Greek as the land of Golden Fleece. The use of special cloth to catch gold particles was also described by Agricola in his 1555 book De Re Metallica (Figure 2).

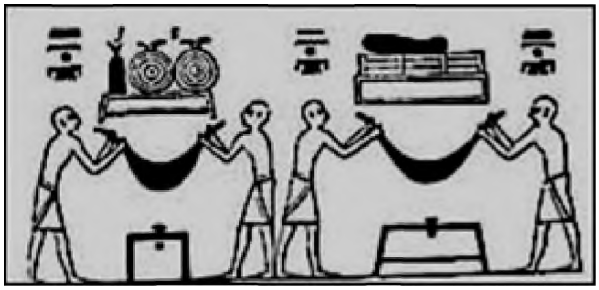

Figure 1 – Beneficiation of gold by washing. An ancient Egyptian wall painting

Figure 2 – A woodcut from Agricola`s De Re Metallica [1556] showing the use of fleece for concentrating gold particles from a stream [Book VIII, page 331, Hoover's edition 1912]

In the middle Ages, when trees in Europe were cut on a large scale to supply wood as a fuel for the smelting furnaces it was realized that, to economize the consumption of wood it would be necessary to remove as much as possible of the gangue minerals from the charge to the furnace. Hence more effort was directed to beneficiate the ores. The most important ores treated at that time were those of copper, iron and silver. In fact most of the silver was recovered from lead ores. To enrich an ore in its valuable minerals it was necessary to crush it into small fragments then pick up the mineral values and discard the valueless minerals. Hence crushing of ores became the first step in beneficiation.

In the early years of the schools of mines, teaching of mining and metallurgy, and sometimes geology and mineralogy were usually taught by the same professor. Also, the tendency was to teach courses related to the exploitation of mineral resources. It was Peter von Rittinger (1811-1872) at the Schemnitz School of Mines in the Austrian Empire who first taught the subject of mineral dressing and wrote specialized books on this topic. Robert H. Richards (1844-1945) in USA was the first to organize a mineral dressing laboratory at Massachusetts Institute of Technology in Boston and published a series of books on the subject that started in 1903. However, the first chair in mineral dressing was founded in 1919 at Columbia School of Mines and was occupied by Arthur F. Taggart (1884-1959) who authored Handbook of Ore Dressing in 1927. Mineral dressing continued to develop when Antoine M. Gaudin (1900-1974) taught at Columbia (1924-1926), Utah (1926-1929), and Montana (1929-1939) before joining the MIT in 1939 (Figure 3). Most of the topics of mineral beneficiation, however, were divided between chemical engineering and metallurgy books until recently that the subject became well defined and an independent domain.

In Russia, Igor Nikolaevich Plaksin (1900-1967) (Figure 4) devoted his studies to the theory and technology of hydrometallurgical processes, the concentration of minerals, and the history of metallurgy. He created the modern scientific foundations of the hydrometallurgy and extraction of noble metals from ores, theoretically substantiated the process of amalgamation, and proposed an efficient method for increasing the productivity of the cyanide process.

Comminution. To the modern mineral processing engineer crushing of ores takes place in large jaw or gyratory crushers that can handle thousands of tons per hour. Similarly grinding is conducted in huge rotary equipment charged with steel rods or cast be attended by may be one worker who will only be watching a television screen in his control room to make sure that each equipment is

Peter von Rittinger
(1811-1872)

Robert H. Richards
(1844-1945)

Arthur F. Taggart
(1884-1959)

Antoine M. Gaudin
(1900-1974)

Figure 3 – Pioneers of mineral processing

working. How did the ancient people crush and grind ores when there were no electric motors and no robust equipment conceived or built to do such work?

Crushing. Rocks are crushed mainly by impact. The most primitive form was holding a hard stone in the hand and pounding the rock containing the valuable minerals (Figure 5). Archeologists have found many such stones. In Agricola's time, the ore was pounded with bats until the desired size of particles were obtained (Figure 6). Metallic hammers were also used by primitive people. The mortar and pestle is still used in everyday life (Figure 7).

The application of the principle of levers helped save some of the human effort. An ancient Chinese

Figure 4 - Igor Nikolaevich
Plaksin (1900-1967)

Figure 5 – Pounding
the ore with hard rock

Figure 6 – Pounding
the ore with bats

Figure 7 – Mortar and pestle

drawing shows the use of a lever to facilitate the operation of the mortar and pestle (Figure 8). A painting by Thomas Baines at Port Elizabeth Library in South Africa depicts a group of workers crushing ore particles using a granite boulder that is being balanced once to left and once to the right by two workers sitting on a tree trunk mounted on the top of the boulder (Figure 9). The method was also illustrated on a postage stamp issued by Botswana. When the size of operations increased in the middle ages, the stamp mill was introduced in which numerous pestles were powered by a water wheel (Figures 10 and 11) or by horses.

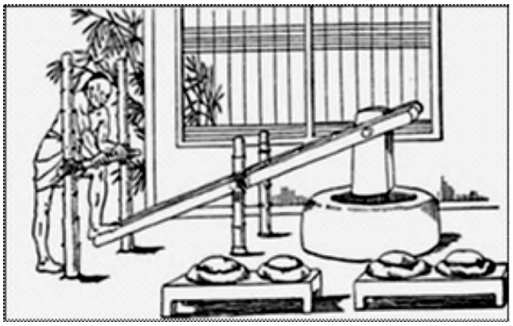

Figure 8 – Chinese drawing shows the use of a lever

Figure 9 – A granite boulder that is being balanced once to left and once to the right to crush ores

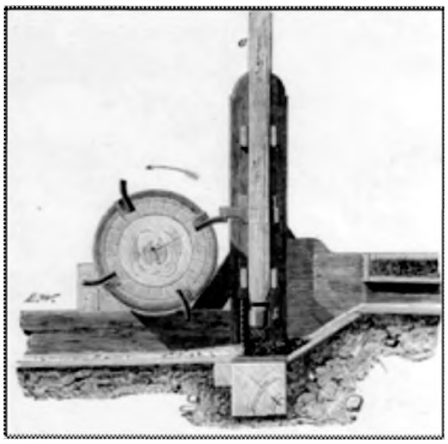

Figure 10 – Principle of the stamp mill

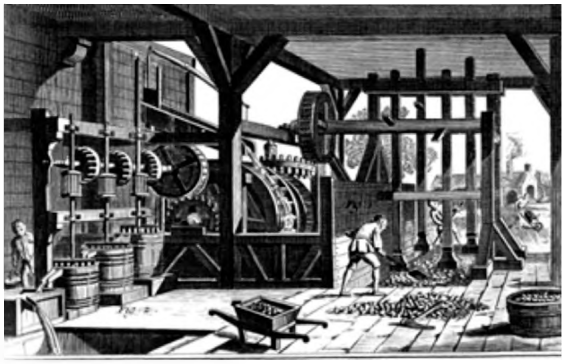

Figure 11 – A stamp mill used in an amalgamation plant [Diderot]

The stamp mill is closely related to the recovery of gold by amalgamation, a process now obsolete. The crushed ore leaving the mill was allowed to flow over an inclined copper plate covered with a thin layer of mercury. Large gold particles were immediately captured by mercury forming amalgam. From time to time the plate was wiped clean by a cloth, the amalgam recovered was saved for future distillation, and a fresh layer of mercury then introduced (Figure 12). Naturally the health hazard associated with handling of mercury and the amalgam resulted in abandoning this technology.

Figure 12 – Amalgamation table

When the stream engine was invented it replaced both. The modern crushing equipment was invented in the second half of the nineteenth century. The jaw crusher (Figure 13) by Joshua Hendy Blake in 1858, the gyratory crusher (Figure 14) by Gates in 1883.

Grinding. In many cases the crushed ore particles are not sufficiently small to permit liberation of the desired mineral so that separation can be achieved. Decreasing the particle size is usually conducted by applying a shearing force. A recent photograph taken in South America shows a boy grinding some material by balancing a small millstone by his hands (Figure 15). The technique was unproved by allowing the mineral particles to flow

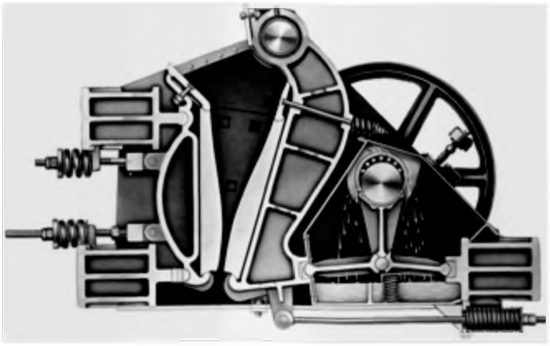

Figure 13 – Jaw crusher

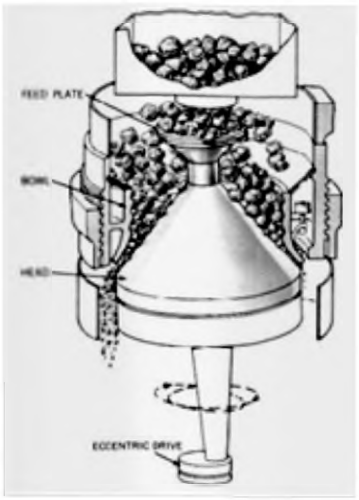

Figure 14 – Gyratory crusher

Figure 15 – A boy grinding material by balancing a millstone by his hands

Figure 16 – Millstones mechanized by the circular movement of an animal

between two horizontally laid grindstones, one on top of the other. The lower millstone has grooves on the side touching the upper millstone. The upper millstones can be rotated manually by a handle while the lower one is stationary. A hole is provided in the upper millstone to allow introducing the ore. The grinding action takes place between the two surfaces. The ground material falls from all sides and can be collected.

The movement of the millstones was also mechanized by the circular movement of an animal as shown in Figure 16. The technique was developed furthers by having two millstones rotated at the same time (Figure 17). The equipment was re-designed by modern engineers and was described in chemical engineering textbooks in 1940s (Figures 18 and 19).

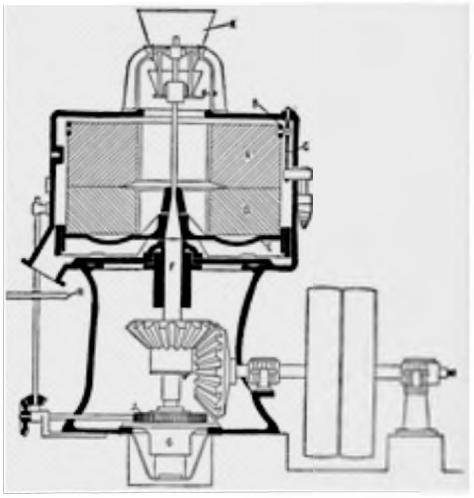

Figure 17 – Mechanized millstones

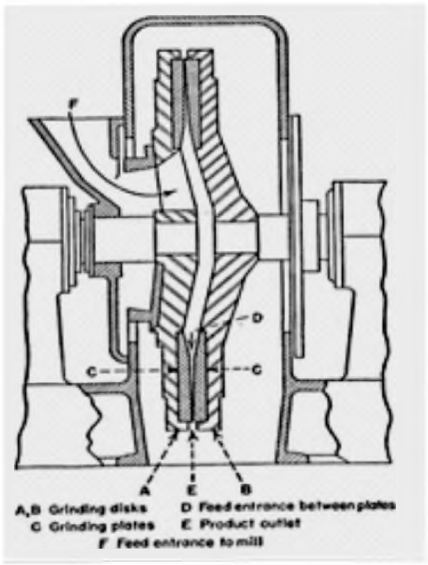

Figure 18 – Another version of mechanized buhrstone

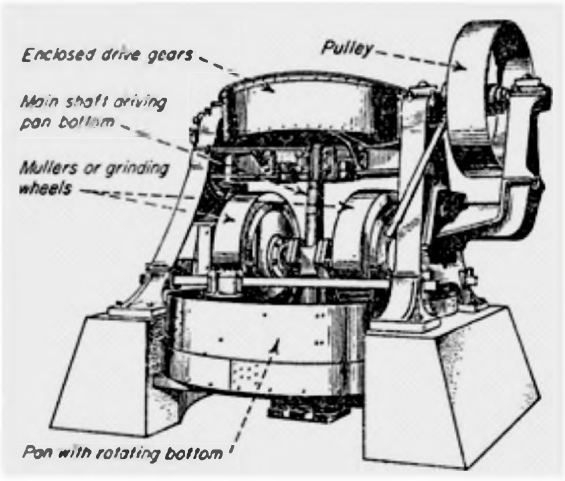

Figure 19 – A modern version of mechanized buhrstone

The millstone is a high strength quartz sandstone containing a small amount of clay or limestone as a binder. It is usually cut into discs about 2m diameter and 30cm thick; it weighs about 2 tonnes. A central hole is perforated through which a long log is mounted, and is then driven by animal power.

The millstone is usually cut into discs about 2m diameter and 30cm thick; it weighs about 2 tonnes. Figure 20 shows the partition of the pieces in the quarry, workers preparing the millstone, cutting it, sliding it out of the mine, and finally transporting it on a horse-driven chariot.

A primitive way for grinding ores was introduced in Mexico by the Spaniards in 1557 in connection with the amalgamation of silver ores. A heavy stone was dragged around upon a circular pad paved with stones and charged with the ore. It was cheaply constructed and worked by animal power It was known as arrastra.

The modern grinding equipment, i.e., the ball mill (Figure 21) was invented in Germany by Bruckner in 1876.

Separation of minerals. Panning of gold is probably the oldest way of separating mineral particles by gravity (Figure 22). The attraction of iron particles to a certain kind of a naturally-occurring rock near the village of Magnesia near Izmir in Asia Minor was also known since ancient times. However, it was William Gilbert (1544-1603) the physician to Queen Elizabeth I, who described this phenomenon as magnetism and the naturally-occurring rock possessing this phenomenon, as magnetite. With the discovery of electromagnetic induction in 1831, it became possible to have strong magnets capable of separating magnetic from non-magnetic minerals.

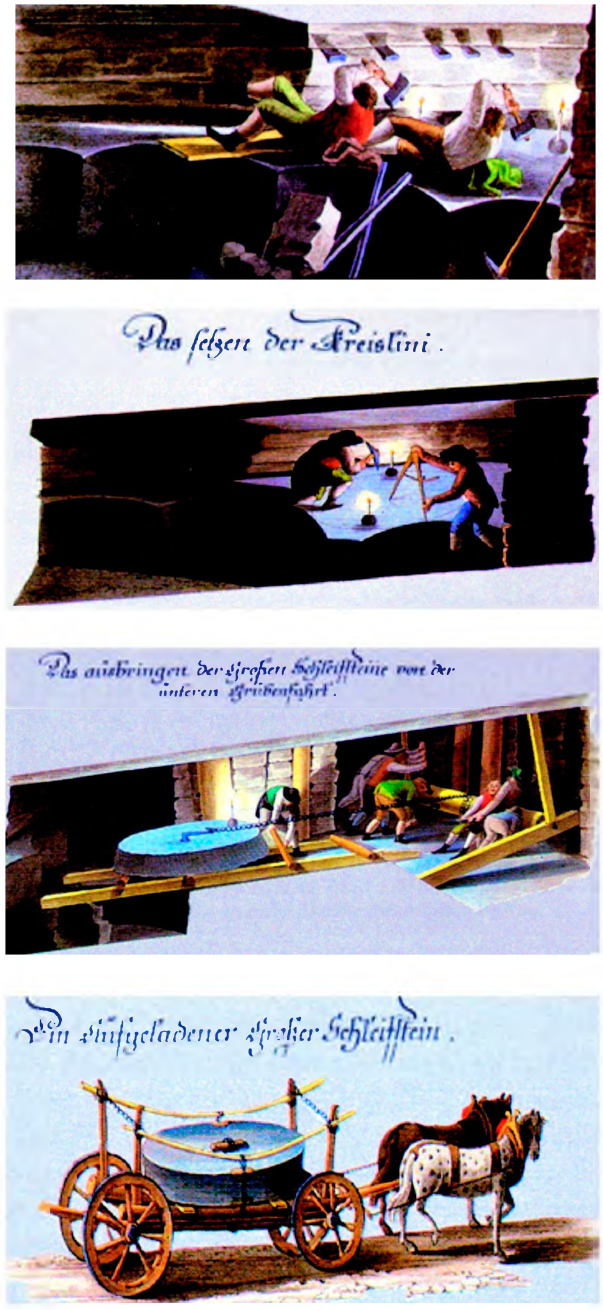

Figure 20 – Quarrying, cutting, and transportation of grindstones from an 1806 German manuscript

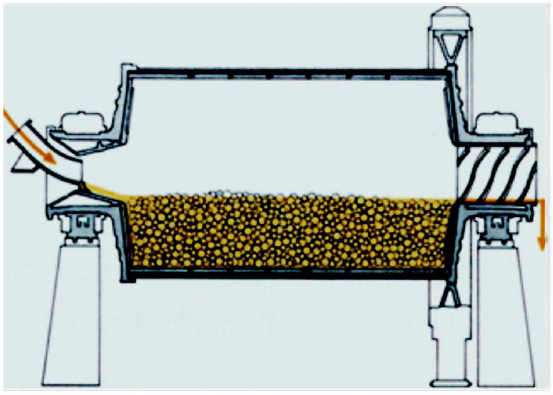

Figure 21 – Ball mill

Figure 22 – Panning for gold

Flotation. Flotation is now the most important mineral beneficiation method. Froth flotation as practiced at present was preceded by many attempts to float minerals using certain oils such as pine oil: certain mineral particles clinged to the oil layer which is lighter than water, hence it was floated. For example, the process used by William Haynes in England in 1860. At the beginning of the twentieth century it was recognized by Elmore in 1904 and Sulman et al. in 1906, that the use of large amounts of oil was unnecessary and even objectionable and that the replacement of some oil by air as the buoyant medium was more advantageous.

In 1909, Greenway, Sulman, and Higgins advanced the art through their discovery of soluble frothing agents such as ketones and alcohols, which permitted still further reduction of the quantity of oils formerly required for flotation. From 1913 to 1922, flotation may be said to have first attained commercial success, particularly in the United States. The first commercial plant of importance

Figure 23 – Ore sorting in 1500s

Figure 24 – Ore sorting in 1900s

Figure 25 – Arthur Redman Wilfley

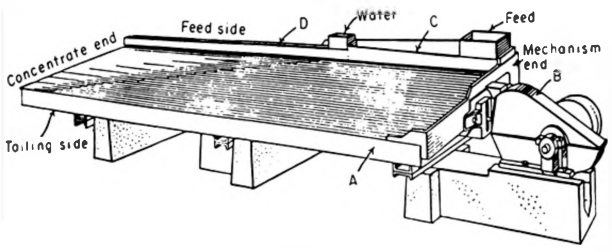

Figure 26 – Shaking Table

being that of the Butte & Superior Company placed in operation in 1913.

A wide variety of oils, such as wood and coal-tar creosotes, were used as collectors in conjunction with frothers, such as pine oils and rosin oils, for the sulfide minerals. It is to be noted that all these collectors were of indefinite chemical composition. Bulk sulfide concentrates were recovered as much as it was not possible to separate sulfide mineral

from another with the known flotation reagents of that era. The modern era in this technology may be marked by Perkin's discovery in 1921 of the effectiveness of definite chemical compounds such as alpha-naphthylamine and thiocarbanilide in promoting the flotation of sulfide minerals. This was followed by the discovery of Keller and Lewis in 1924 that water-soluble xanthates are effective flotation agents (Figure 27). Since then other discoveries followed such as the use of cyanide as depressant for pyrite and sphalerite in alkaline solution, etc.

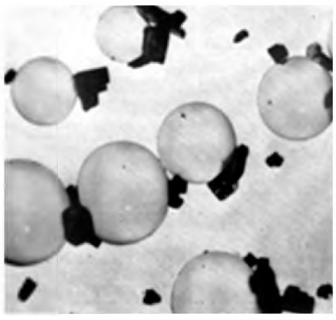

Figure 27 – Mineral particles that adsorbed water-soluble collectors cling on air bubbles and float

Figure 28 – Irving Langmuir (1881-1957)

The theory of flotation was first advanced by Irving Langmuir (1881-1957) (Figure 28) in 1920 as an absorption phenomenon on the surface of the mineral and the adhesion of the mineral to the bubbles of air forming a froth. Langmuir graduated as a metallurgical engineer in 1899 from Columbia School of Mines. He conducted graduate work under Walther Nernst in Gottingen, Germany then taught chemistry at Stevens Institute in Hoboken from 1902-1909 before joining the newly established General Electric Research Laboratory in Schenectady, NY. His work at GE was concerned with adsorption phenomena. Langmuir was awarded the Nobel Prize in 1932

The theory was elaborated further by L.J. Christmann of the American Cyanamid Company in USA in 1930. Application of flotation to non-sulfides has been increasing. Satisfactory results have been obtained in the treatment of mineral phosphates, of cement rock, of crude salines (such as potassium ores), and also of impure fluorite and barite. Another field of application of flotation is to the making of high-grade iron concentrates from low-grade primary ores and the cleaning of coal.

Flotation was always conducted in agitated tanks (Figure 29). The suggestion to use columns in

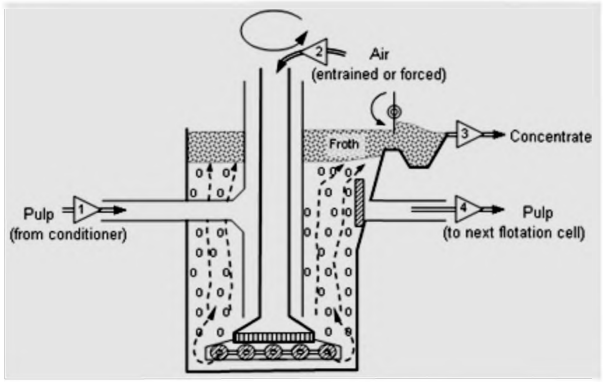

Figure 29 – Flotation tank

flotation was proposed by P. Poutin and R.J. Tremblay in a US patent issued in 1967. It was in 1980 when columns were installed for the first time at Mine Gaspe in Quebec, Canada. It was found out that two columns: one 45.7 cm and another 91.4 cm replaced 13 stages of cells in a molybdenite circuit. Few years late, the copper industry in Chile adopted column flotation cells in some of its operations and since then their use became wide spread. The major advantage of the columns is the absence of moving parts hence they are nearly maintenance free (Figure 30).

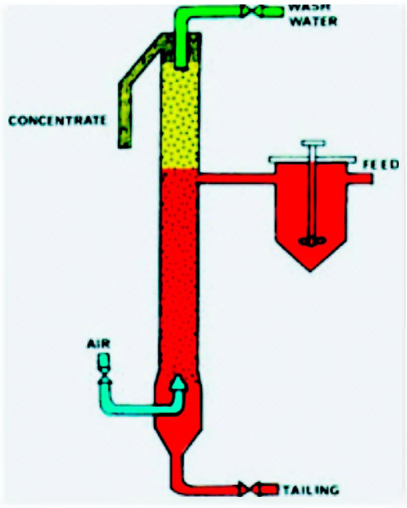

Figure 30 – Flotation column

Solid Liquid separation. At the beginning of the twentieth century, cyanidation process became widespread worldwide. Hundreds of thousands of tonnes of ores were treated by a solution of sodium cyanide to extract gold into solutions. There was a need to separate the pregnant solution from the gangue minerals. The invention of the classifier in 1904 and the thickener in the 1906 by John Van Nostrand Dorr (1871-1962) (Figure 31) was the

Figure 31 – John Van Nostrand Dorr (1871-1962)

solution to the problem. Now these equipment are huge, well constructed and fully instrumented. These inventions had a huge impact on mining and beyond by hastening the transition from intermittent to continuous processing. Dorr began his career in the laboratories of Thomas Alva Edison at the age of 16. After graduating from Rutgers University he worked as an assayer, and metallurgist in the gold mills of South Dakota and Colorado.

Mineral processing and economics. Rich ores usually will first be exploited because the economics will be favourable. Such ores, however, have been practically exhausted and the metallurgist is now faced with ore deposits containing low metal content from which the metal has to be recovered by economical means. This became only possible as a result of the discovery of efficient ore beneficiation methods. This resulted not only in treating ores at an unprecedented high tonnage but also in treating deposits that were not considered ores some years ago. For example, in 1900 copper ores treated in a beneficiation plant averaged 600 tons/day at a copper content of about 2%. In the 1980's a copper ore beneficiation plant processed about 100,000 tons/day at a copper content of about 0.5% (Figure 32). Today, the size of flotation cells has increased (Figure 33) and the size of the processing plant increased even further. The engineering problems associated with material handling and control can well be imagined.

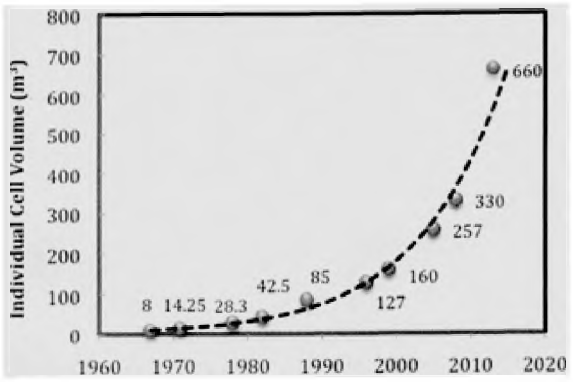

Figure 32 – Increase in size of flotation cells

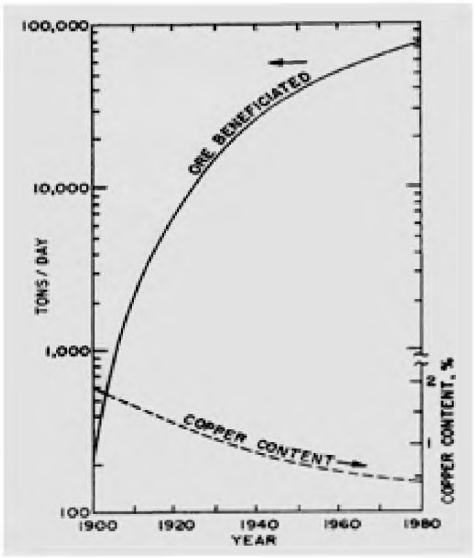

Figure 33 - Changing in the copper industry due to improved mineral processing technology

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Түйіндеме

Кендерді бос жыныстардан шаю арқылы ұсату мен ұсақтау және оны байыту ежелгі заманнан қолданылған.Кендерді жұпыны ұсатуда тас кемегімен, кейін темір балғалармен қолмен атқарған. Келі мен келсап иінтірекпен механикаландырылған, ал орта ғасырларда операция масштабы ұлғайған кезде ұсақтау зауыттары салынған. Диірменнің тасы кендерді ұсақтауда өте маңызды рөл атқарған. Алтынды науашада шаю мен пайдалы қазбаларды қолмен іріктеу - екі ескі ажырату тәсілдері болған, кейін олар қазіргі заман әдістеріне жол берді. Флотация әдістерін қолдану он тоғызыншы ғасырдың ортасында, мұнай өнімдерінің қолдануымен минерал бөлшектерін су суспензиясы - шламға жинақтаумен басталған. Бұл әдіс 1920 жылдары органикалық қосылыстардың тиімді флотациялық уәкілі екендігі анықталған соң қолданыла бастады. Аса көрнекті инженерлер Rittinger, Rickard, Pryor, Taggart, Richards, Gaudin және т.б. жазған оқулықтары ғылымның осы саласын жаңа дербес пен ретінде көпшілікке танытуда өз үлестерін қосты, қазіргі кезде Университеттерде оқытылады. Ресейде И.Н.Плаксин өз зерттеулерін гидрометаллургиялық процестердің теориясы мен технологиясына, пайдалы қазбаларды байытуға, металлургия тарихына арнаған.

Түйін сөздер: пайдалы қазбаларды өңдеу, кен байыту, флотация, ғылым тарихы.

Резюме

Дробление и размол руд и их обогащение путем отмывания от пустой породы проводились начиная с древних времен. Примитивное дробление осуществляли вручную, измельчением руды твердым камнем, затем с использованием металлических молотков. Ступка и пестик были механизированы с помощью рычага и когда в средневековье масштабы операций увеличились, были введены в действие дробильные заводы. Жернов играл важную роль в размоле руд. Промывка золота в лотке и ручная сортировка полезных ископаемых были двумя старыми методами разделения, которые теперь уступили место современным методикам. Использование методов флотации началось в середине девятнадцатого столетия с использованием нефти для сбора минеральных частиц на поверхности водной суспензии – шлама. Это произошло только в 1920-ых годах, когда было обнаружено, что органические соединения являются эффективными флотационными агентами. Учебники, написанные выдающимися инженерами, такими как Rittinger, Rickard, Pryor, Taggart, Richards, Gaudin, и другими внесли свой вклад в признание этой области как новой дисциплины, которая преподается в Университетах. В России И.Н. Плаксин посвятил свои исследования теории и технологии гидрометаллургических процессов, обогащению полезных ископаемых и истории металлургии.

Ключевые слова: переработка полезных ископаемых, обогащение руд, флотация, история науки.

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