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NEW TRENDS IN THE DEVELOPMENT OF WORLD COPPER INDUSTRY

by

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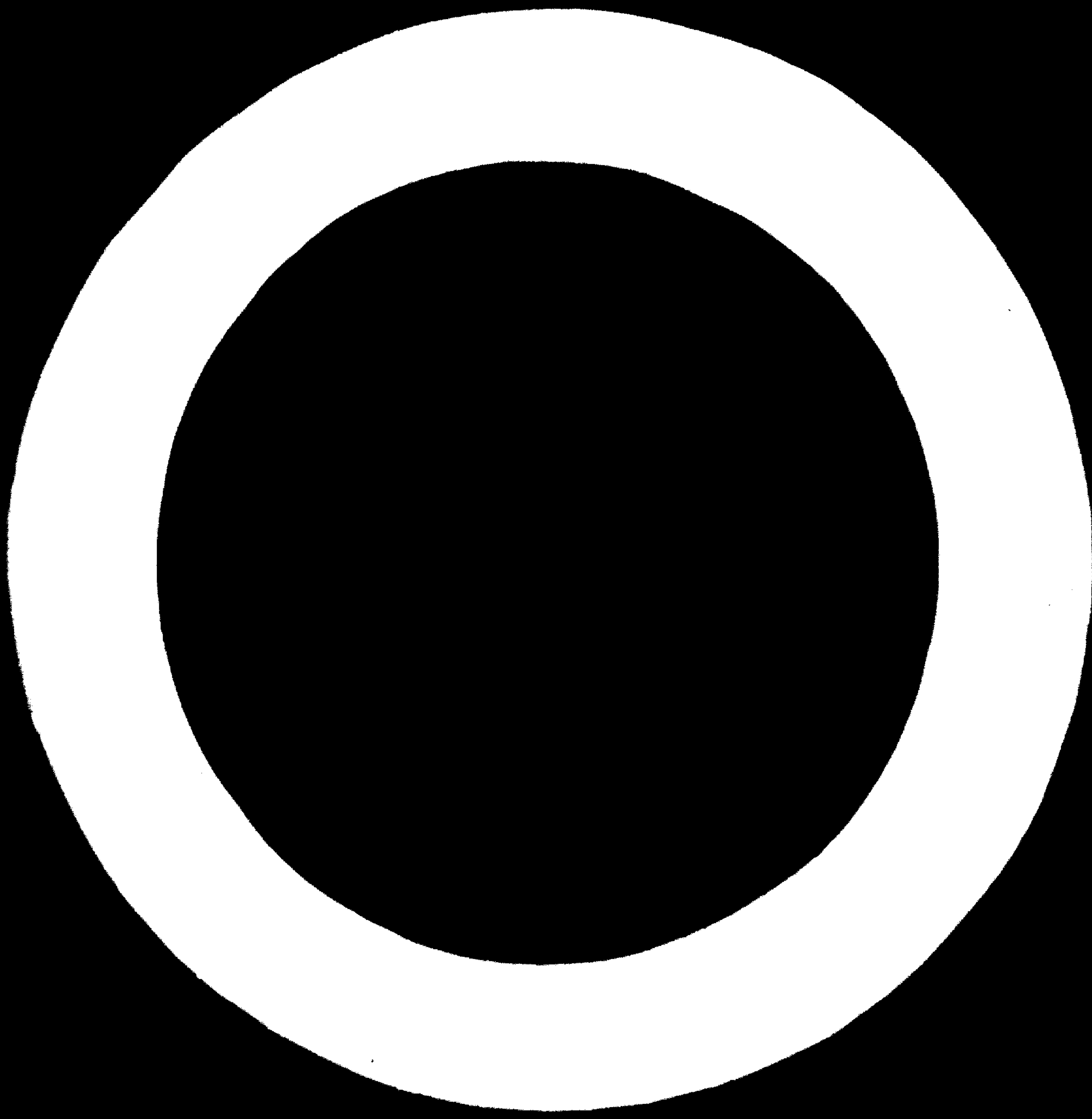


Theses

1. Copper production is one of the most important and rapidly developing branches of modern industries.

The development of copper industry in the developing countries has a number of features: it is based on relatively rich raw materials and on building new plants (this allows to effect the most advanced technical projects); a major part of copper is exported to other countries (this places more stringent demands on their quality). For the successful development and maximum efficiency of copper production it is necessary to take into consideration the main trends of world production the most interesting of which are: changes in raw materials base, the development of technological processes, changes in geographical distribution of plants and economic characteristics of production.

2. A main trend of changing raw materials base of copper industry is the lowering of an average copper content in ores concurrently with descovering and developing a small number of rich deposits.

It creates a need for increasing the volume of mining per unit of copper (by five times comparable to 1900), treating low-grade and hardly-dressed ores, showing interest in new raw materials and increasing the share of secondary materials sources.

3. The tendencies of developing copper production are

motivated by such factors as growing demands (and as a result increase of production), changes in a raw materials base, the technical advances in co-operating industries, index rise of labour, equipment and construction costs; changes in the fuel power balance and prices relationship for some types of fuel and power, a need for abating water and air pollution and others.

The main trends in technological advances under influence in these factors are given as an example in this paper, including:

- Application of continuous and integrated processes (continuous converting, flash smelting, etc.);
- Complex usage of raw materials (sulphur recovery from gases, including converter ones, metals recovery from dust and slags, using of silicates and iron contained in slags);
- Development of treating bulk (hardly treated) raw materials with combined operations of separating valubale components in a metallurgical cycle (hydrometallurgical treatment of copper-zink concentrates by methods, applied at Kosaka plant, KIVCET process, etc.);
- Expansion of hydrometallurgical treatment of ores and concentrates with appling extraction-sorption, autoclave and similar advanced processes;
- Intensification of production processes (fluid bed roasting, smelting with hot and oxygen enriched blast, increasing of current density, oxygen usage during converting sulphide concentrates, bacterial leaching of ores and dumps etc.);
- Use of new power and fuel sources, as well as secondary power

reserves (wide application of natural gas, solving the problem of using heat, generated in all types of smelting units and converters);

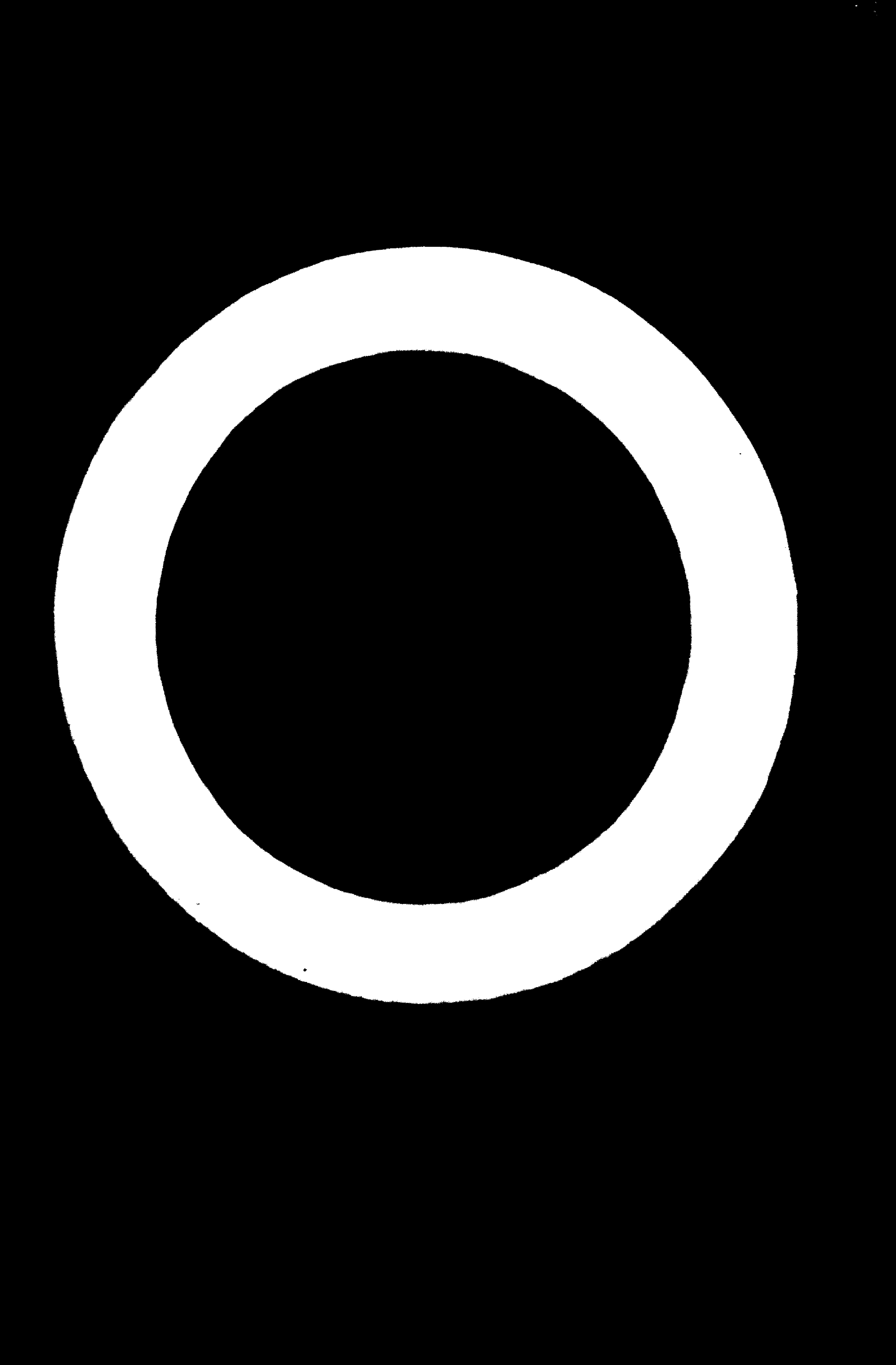
- Improvement and expansion of purifying gases and waste waters (application of new purifing methods, erection of costly air and waste water installations).

4. Technical advances in copper industry influence the changes in distribution of metallurgical plants. New plants are erected in the regions with favourable marketing conditions. This is determined by such factors as the decrease of concentrates consumption per unit of produced copper, increase of output per unit of raw materials due to their complex usage, production of less transportable by-products, creation of large complexes on the base of copper production (with the aim of producing fertilizers, construction materials, etc).

5. Trends in the changes of raw materials, economic conjuncture and technical progress cause definite shifts in operating results of copper production, namely: increase of costs and prices (in capitalist countries this is largley connected with market conjuncture and fluctuations of production), reduction of a working force and productivity growth with increasing of capital investments and rising of construction projects costs.

6. The above mentioned trends in the development of copper production are interconnected to a large extent and determined by the influence of such factors as demand growth, technical progress in co-operating branches of industry , depletion of raw materials sources.

An illustrated scheme, showing the formation of trends in copper industry, reflects these relationship.



The production and consumption of copper is a very important factor in the economic and industrial structure of the present--day society. A unique role of copper and copper alloys in solving of a number of the most important problems of technical progress, and in the first place, the electrification of industry has placed copper industry among such branches which defines the technical development and economical independance of some countries. And it is no wonder, that copper production increases more rapidly in the developing countries, which already account for about 1/4 of world output.

It is interesting to remember, that the rapid economical development of the Soviet Union and successfull electrification of the country may be explained among other reasons by the high rate of building copper plants in the period of first five year plans and radical changes in copper industry, which began during postwar years.

The development of copper industry in the developing countries has a number of features: it is based on relatively rich raw materials and on the building new plants (and this allows to effect the most advanced technical projects); a major part of domestic made products are exported to other countries and due to this factor , all shipped products must meet strict demands of the World market.

For the successfull growing and highest efficiency of copper production it is necessary to take into account those trends which prevail in the world copper production and at present determine the technical and economic aspects of this industry.

Some of these trends are considered in this paper. From our point of view the developing countries may be interested in the following problems: changing of raw materials for copper industry; improvement of technology at copper plants; changes of geographical distribution of plants; changes of operating results.

I. TRENDS IN CHANGING RAW MATERIALS OF COPPER INDUSTRY

A main trend of changing raw materials of copper industry is the increase of copper ore reserves at a steady decrease of the average copper content with developing some rich deposits, the share of which in raw materials amounts to 10-20%. At the present time an average content of copper in the mined ores is about 1%, and thus 50 times less than iron content in the mined ore and 50 times above the average copper content in the earth crust; copper content in some rich deposits 5-8 times higher than the average one. Given below are the data about downward trend of acceptable copper contents in the United States, which to some extent are characteristic for many industrial developed countries:

Year	1880	1902	1906-1910	1911-1920	1921-1940	1941-1950	1951-1956	1957-1968
Copper content, %	3.0	2.7	2.1	1.7	1.6	1.0	0.8	0.6

The lowering of the average copper content in mined ores is largely set off by technical progress in ore mining (decreasing costs per a unit of mined ore), in dressing (improvement of concentrate quality, reducing copper losses and producing pyrite and zinc concentrates), metallurgical processes (lowering of copper losses, increasing of metal quality, production of sulphuric acid, precious and rare metals, using secondary power resources). However about 50% of copper price rising during last 70 years may be explained by the lowering of the average copper content in ores and the necessity to treat 180-200 tons of ore to produce 1 ton of metal (in 1966-68) instead of 40 tons (in the early of 1900).

Due to the natural leaning of copper ores in several countries it was necessary to treat oxide and mixed ores, which are not easily milled by convential methods (floatation) and to use new copper resources, including underground leaching solutions, as well as waters of the world ocean in the future.

As a result of the unfavourable balance of raw materials and the growth of copper quantity, used in various industries, the share of secondary metal is steadily increasing . If in the developing nations it does not exceed several per cent , in the developed countries the share of secondary copper is amounted to 40% and shows an upward trend.

Thus the copper industry is confronted with the following major trends of changing a raw materials base:
- lowering of an average copper content
- treating low-grade and complex ores
- an interest to new copper sources
- increasing the share of secondary feed materials.

These trends greatly influence the technologies and economical effectiveness of copper production.

TRENDS OF ADVANCES IN TECHNOLOGIES OF COPPER PRODUCTION

The technical advances in production in the first place must ensure progress in ecobomy reducing the expenses of production, rising efficiency of capital investments, the growing of labour productivity, increasing an output of products. It is closely connected with definite tasks and working conditions of plants. In other words each scientific and technical idea or a new process is realized in industry only in the case if there are all necessary prerequisites, and the realization itself gives definite economical advantages. If the changes of technical progress prerequisites are not accidental and if a new process allows to improve economic effectiveness, we can speak about definite trends of technical progress in the given industry.

With this point of view it is necessary to consider the most important trends of technical development of copper metallurgy: the application of continuous and integrated processes, complex uses of raw materials the advances in the treatment of bulk materials, the expansion of hydrometallurgical methods of treating ores and concentrates, the intensification of production processes, using secondary power sources and new sources of power and fuel, the expansion of cleaning gases and waste waters. Here we do not consider the problems and trends of technical progress in mining production, as they refer to non-ferrous metallurgy in the whole.

a) The application of continuous and integrated processes

An interest to the development of continuous and integrated processes is determined by the possibility of reducing capital investments and operating costs, the improvement of using power and fuel, the decrease of metal losses, the reduction of the working force. The integration of two or several operations in a single unit basically changes physical and chemical principles of these processes, a heat balance and demands the radical changes and principal new design ideas. Thus for the application of continuous and especially integrated processes as a rule it is necessary to modernize operating facilities or to erect new plants.

As an example we can consider the processes of continuous converting and the integrated process of roasting and Smelting in a furnace for flash smelting of copper concentrates.

It is known that one of the essential shortcomings of converting matte is its batch type character. In this connection in recent years in various countries scientists carry out research work in the sphere of inventing a continuous process of producing blister copper. It is worth to mention the following main activities in this sphere: a process, which was at first developed in the Soviet Union by professor Diomidovsky D.A. in 1959 and later improved in Czechoslovakia with using a furnace of a reverberatory type; the WORCRA process, invented in 1963 in Australia; the process, developed at the Research Centre of Noranda Co. in Canada.

In Czechoslovakia the exploration of the continuous converting was carried out in a pilot furnace of a reverberatory type with a daily capacity of 6-7 tons of matte containing 41-44% copper. The investigations are being continued in the direction of creating conditions for recovering of by-product minerals.

The WORCRA process, proposed by the Australian scientist Dr. Worner is developed at Port Kembla. The process has a number of advantages. It gives the possibility to eliminate a roasting operation (though it is necessary to dry feed concentrates), to exclude the treatment of return converter slag, to reduce fuel consumption, to decrease a working force, to apply automation on a wider scale, to reduce losses of copper, contained in slag and dust; waste gases contain enough sulphur for producing sulphuric acid.

The process of Noranda Co. is somewhat different from the WORCRA process based on the same principle. It is carried out in a rotary converter with tuyres, located in the lower zone and the countercurrent flow of matte and slag. The WORCRA furnace is of a reverberatory type with tuyres located vertically above the bath; slag and matte flow in the opposite directions. It is expected that at the pilot plant of Noranda Co. blister copper, containing 98.6-99% Cu and slag with 0.2-0.3% Cu can be recovered from the concentrates, containing 26% copper. The process allows to reduce fuel consumption by 50 per cent, to decrease necessary facilities and personnel and to apply automation on a large scale.

A typical example of an integrated process is the so called flash smelting of copper concentrates. The process is one of simultaneous roasting and smelting. In this case it is possible to use heat of oxidizing sulphides with almost complete reducing heat consumption , and also to increase the efficiency of a unit and practically to recover all sulfur (excluding the quantity which is necessary for matte forming). As compared to ordinary mattes the costs of treating rich copper matte (45-60 percent copper) are reduced by two times. However this process demands carefull drying concentrates (0.5-0.3% moisture) and it is necessary to treat slags with a high copper content.

There are two methods of flash smelting: in the oxygen atmosphere (Copper Cliff plant in Canada and Almalick Copper Works in the Soviet Union) and smelting with hot blowing (Harjavalta Works in Finland, Ashio and Kosaka Works in Japan, Baia Mare in Rumania).

In the case of flash smelting in the oxygen atmosphere the erection of an oxygen plant and oxygen pipelines demands additional capital expenditure, however the process can be further intensified, and gases evolved during smelting, contain up to 90% of sulphurous anhydride.

Comparing with separate roasting and smelting and integrated process of flash smelting allows to cut operating costs per 1 ton of blister copper to 10-15%, taking into account of less costly converting rich mattes, to reduce the working force to 25-30%, to decrease capital investment by 10-15% and to increase sulfur recovery.

The advantages of the process mentioned above have attracted attention while modernizing operating plants as well as erecting new ones. In 1969 flash smelting units with hot blowing were operating at four copper smeltors in the World, but by 1972 the process is expected to be applied at 7 plant (2- in Japan, 2 - in Australia, 1 - in Turkey).

b)Complex using raw materials

Complex using feed materials is a typical trend in developing many braches industry due to the possibility to produce a large quantity of additional products (sulphuric acid, rare and precious metal, iron, construction materials) without new capital investments in increasing raw materials. In recent years in copper industry the following trend of complex using raw materials have become most typical:

- recovering zinc and pyrite into selective concentrates during the benefication of chalcopyrite and copper-zinc ores;
- recovoring molibdenum into concentrates during the beneficiation of copper-molibdenum ores;
- using sulphur of roaster, smeltor and converter gases for sulphuric acid production;
- recovering copper, zinc and associated elements from slags;
- using silicates of the slags for the production of construction materials;
- recovering selenium , tellurium and precious metals from sludge, formed during electrolysis;
- recovery germanium, indium, bismuth and other minor and rare metals from dust; formed during metallurgical processes.

At present bulk recovery of valuable components (copper, precious metals) is in the range of 80 per cent.

In the costs of raw materials the share of byproducts reaches 30-35 per cent and including iron and silicates it is about 50%. Practically only 10-15 per cent of these components are recovered into commercial products. This means, that there are considerable reserves of complex using raw materials and this problem can be considered as urgent for nearest years. Sulphur recovery and slags treatment have a very great importance. These processes account for highly profitable production of additional (10-20%) and as a rule deficient products such as sulphuric acid, fertilizers, construction materials, and in a number of cases iron in the form of cast iron and steel. These products are especially significant for the developing countries.

The experience and calculations show that at copper smelters about 85% per cent of all sulphur, charged with in feed materials can be used with a definite advantage. A relatively large quantity of sulphur passes into roaster gases (up to 55%), converter gases (up to 25%) and into gases, formed during cinder smelting (up to 15%). Technological losses of sulphur are in the range of 5-8 per cent, the quantity of sulphur, used in the sulphuric acid production is amounted to 93% per cent. Nowdays in the main producers use gases, formed during roasting sulphide copper concentrate and in a minor quantity gases, evolved during converting low-grade mattes.

An additional quantity of sulphur can be produced by applying the integrated processes of roasting and smelting, using oxygen-enriched blowing, smelting copper concentrates in reverberatory furnaces (in this case sulphur concentration in gases is enough for its profitable usage), as well as by using converter of new design (such as converters, used at the Onahama in Japan, Hobocken in Belgium and others).

Sulphur recovery is the most profitable in the system of complex using copper raw materials. At relatively equal capital investments in sulphuric acid production operating costs of producing acid are much less when using sulphur pyrite or elemental sulphur as receiving sulphur containing materials does not demand any expenses.

Raw materials	Costs of producing 1 ton of H_2SO_4, %	Capital investment per 1 ton of H_2SO_4, %
Sulphur pyrite	100	100
Elemental sulphur	175	30
Copper smelter gases	30-80*)	20-90*)

Slags are re-treated on a wide scale at the plants, where feed concentrates have a high zinc concent. Zinc and copper are recovered from these slags mainly by fuming process. In some cases rich slags (those of flash smelting and converting) are treated by beneficiation with floatation copper recovery. Technical feasibility and economic expedience of complex treatment of slags make no doubt. Experience and economic calculations show that iron recovery in the form of iron powder or cast iron and production of various building materials from silicates make it possible to supply these products for the plant itself and for a neighbouring region, and economic advantages of slag treating

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*) Depending on sulphur concentration in gases and the quantity used.

increase up to 30-40%. Enough to say, that the costs of slag cement production are 25-30 per cent less than those of producing ordinary cement.

c) Advances in treating bulk raw materials

Rising costs of raw materials and treatment of complex ores explain a new trend in metallurgical treating of bulk feed materials: copper pyrite, copper-zinc, lead-zinc-copper and etc. In this case it is possible to eliminate valuable components losses while producing selective concentrates and to pay more attention to solving the problem of separating valuable elements in metallurgical processes.

At present monometallic concentrates are not produced by floatation, as they contain definite quantity of associated elements, which can be recovered as a result of complex treatment of feed materials as all plants receiving those concentrates. If zinc, copperand pyritic concentrates are recovered from copper-zinc ores, copper in produced not only at copper plants, but at zinc smelters; zinc is recovered not only at zinc but at copper smelters, sulphur is recovered from copper and zinc concentrates as well as from pyrites.

Production of bulk concentrates ensures a 3-3% increase in the recovery of valuable components, and able all the reduction of operating costs and capital expenditure:

	Bulk floatation	Selective floatation
Capital investments	100	117
Production expenses	100	138

Bulk materials are treated by hydrometallurgical methods (roasting, leaching, zinc and copper production by electrolysis), and pyrometallurgical methods (for a example, KIVCET process).

Both schemes (pyrometallurgical and hydrometallurgical) are rather efficient. Compartable to reverberatory smelting as a result of treating copper-zinc concentrates from one of the deposits it is possible to receive additional commercial products valued at 23 M.roubles with capital investments decrease by 9.4 million and operating costs reduced by 8.9 M.roubles a year. In this case capital investmonts can be justified in two years. The treatment of such concentrates by methods, applied at the Kosaka works is also efficient enough, though costs are somewhat higher; capital expenses are compensated during three years.

It is likely that the trends of treating bulk raw materials for some complex ores will remain in the future and this will be facilitated by developing methods of separation of valuable components in solutions, gaseous phase, melts etc.

In this connection enough attention is paid to investigations of ion exchanging processes, pyrometallurgical methods with sublimation of some components and their condensation in the form of metals, as well aschloridyzing volatilization, "segregation" processes and others.

It is necessary to note, however, that using direct metallurgical methods of treating bulk materials (bulk concentrates, ores and so on) will be efficient only in those cases when valuable minerals losses and operating costs of metallurgical processes such raw materials are much less comparing with the complete cycle of beneficiation and metallurgical treatment of all selective concentrates. At present these methods are used for treating extremely complex ores. The recovery of valuable minerals from such materials is relatively low and the production of clean selective concentrates is connected with considerable difficulties and generally is unprofitable.

d) Expansion of hydrometallurgical treating ores and concentrates

Due to copper deficiency and lowering its content in mined ores much attention is being given to low-grade oxide and mixed ores, which up to date were not considered as important raw materials for copper production. At present copper produced by direct hydrometallurgical recovery from such ores is about 10 per cent of the world output . Such methods hold great promise in connection with re-treating highly efficient ion-changing materials (extracting agents, sorbents) possessing good selectivity.

Hydrometallurgical methods of copper recovery from primary raw materials are used for treating mixed ores, oxide, sulphide dumps, overburden and ores from mine.

Technologies of treating mixed sulphide oxide ores are developed in the Soviet Union (the so called "Mostovitch method"), this method, widely applied in the U.S.A. as known as "LPF" process (leach - precipitation - floatation).

Now both treatment of old dumps and heap leaching becomes more important for processing oxide ores. The advantages of heap leaching are relatively low expenses, but operating costs are higher comparing to leaching in tanks; acid consumption increases by 2-3 times, the cycle continues for a longer period of time.

In view of the above mentioned data some producers are greatly interested in a project of copper are mining by nuclear explosion, the information being published by Kennecott Copper Corp. and United Nuclear Corp. Investments into the project, including leaching of mined ore in the region of explosion initially estimated at 13-15 million dollars.

The operating costs of producing and treating solutions, with copper content of about 1.2 g per liter with a total circulation of 7500 cubic meters and cement copper smelting are in the order of 40 cent per 1 kg of copper.

It is planned to recover copper from solutions by extraction (instead of cementation) followed by electrolysis. Extraction is shown to be effective in separating copper from ruthenium and other products of radioactive delay, however, radioactive contamination of surrounding regions and seismic effects remained to be an unsolved problem.

The technology and economics of hydrometallurgical methods of copper production can be qualitatively changed by ion-exchanging processes, including extraction methods, which are widely being investigated in various countries as well as sorption processes, tested in the Soviet Union. The application of these processes are justified above all by high copper recovery and by the possibility of its direct recovery from stripping solutions by electrolysis (in this case the operation of cement copper smelting is eliminated). This determines an efficient copper recovery from various dilute solutions, which is confirmed by some data given below.

In 1966 at Colorado Springs (USA) General Mills Co. put into operation a unit with a capacity of 1140 l/min; the solution contained 1.1-1.6 g copper per liter. Costs amounted to 2.1-3.8 cents per pound against 3.75 cents per pound in the case of cementation by iron.

Israel Mining Industries (at Timna) have produced 15,000 tons of copper from low-grade ores. Feed solutions contain 5 g copper per liter. Recovery is over 99 per cent. The costs are in the range of 1.5 cents per pound.

According to calculations copper recovery from oxide and mixed ores by applying sorption processes without filtration may be rather advantageous. With increasing copper recovery by several per cent against Mostovitch method (this is achieved by complete leaching of copper in the presence of sorbent) and the recovery of the same quantity of precious metals the process is more profitable and capital investments are justified in 2-3 years.

e) Intensification of production processes

The intensification of technological processes is aimed at producing more copper or treating more raw materials; other things being equal this facilitates the reduction of capital investments and operating costs per 1 ton of copper produced. However intensification of production processes in copper metallurgy has some negative aspects: increase of copper content in slags, dust losses rise, rapid wear of equipment and lining. And beside this it is necessary to invest additional capital for intensification (erection an oxygen plant, increase of blowers, erection of units for preheating air itc). The efficiency of intensification is determined by the ratio of above mentioned factors.

It is worth to note that intensification of production processes by modern means (by using oxygen) has a number of other favourable effects. Thus oxygen-enriched blowing alongside with intensification of smelting allows to decrease coke consumption, to produce concentrated sulfur gases and to cut dust losses.

In recent time the achievemnts of science have increased the role of favourable factors of intensification of production processes, and decreasing costs of capital construction and labour made these processes especially attractive.

In this connection intensification of production processes can be considered as a steady tendency of present day copper production.

As most promising for the nearest years we can consider the following tendendes:fluid bed roasting of concentrates, flash smelting*), concentrates smelting in converters with oxygen

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*) Described in the section, Development of continuous and integrated processes.

enriched blowing , increasing current density during electrolysis of copper, applying bacterial leaching of ores and dumps.

Fluid bed roasting is being developed in the Soviet Union. The efficiency of fluid bed roasting furnaces as compared with multi-hearth ones is increased 1.5-2 times, the process can be effectively controlled, maintenance and repair costs can be sharply reduced and technological processes are properly stabilized. Applying fluid bed roasting it is possible to cut operating costs by 15-25 per cent and capital investments in the reconstruction and erection of furnaces are compensated during 1.5-2 years.

The experience of using oxygen for agglomeration of copper concentrates and reverberatory smelting raw concentrates also showed the efficiency of the intensification of these processes.

The particular an increase of oxygen content in the blast of a reverberatory furnace by 1 per cent makes it possible to rise speed of smelting by 2.5 per cent and to decrease specific fuel consumption to 2.2%; with the considerable reduction of dust losses; sulphurous anhydride content rises up to 2.5-4 per cent and it can be used for making sulphuric acid.

In recent years in the USSR the density of current , used in electrolysis of copper was considerably increased to intensify this process and to rise the output of electrolytic copper. Thus at one of the plants current density was raised from 189 a/m^2 in 1957 to 240 a/m^2 in 1964.

Increase of current density along with rising the efficiency of electrolytic copper production causes definite difficulties in technological processes (current output declined from 93% in 1959 to 91.5% in 1964, power consumption increased by 38 per cent). Economics of intensifying electrolysis are improved by current reversing. A number of plants where oxygen-enriched blasting is being applied for treating concentrates in converters instead of reverberatory smelting increases every year. Aside from rising the efficiency of converter this method facilitate to increase sulfur content in converter gases and to produce more sulphuric acid.

At Hitachi works (Japan) dried concentrates pellets are smelted in a converter using air enriched with oxygen to about 35%. T The introduction of this method instead of agglomerate smelting in a shaft furnace gave the possibility to rise the efficiency of production more than by two time.

At the Copper Cliff (Canada) copper concentrate is being smelted in the converter, blown by air, enriched with oxygen up to 29-30%. The efficiency of the convertors has increased by 50%, and as a result one of the electric furnaces and a special converter were shut down. Labour and materials requirement have reduced accordingly.

As a result of detailed economic calculations Kennecott Copper Corp. at its Harfield works decided to operate an oxygen unit with a capacity of 363 ton of technical oxygen a day. Technical oxygen(227 tons/day) will be fed to the converters to increase its concentration in the blast up to 23%. This will allow to rise copper output without the installation of new converters, as well as SO_2 content in converter gases (from 2 to 4-6%), and sulfuric acid production increases from 1270 to 1542 tons a day without reconstruction of the plant.

Charging of concentrates into the converter is aimed to increasing the weight of one melt, taking about 10-hours from 60 to 68-72 tons, decreasing the quantity of raw materials fed to a reverberatory furnace, operating two furnaces instead of three units and reducing sulfur losses in reverberatory furnaces gases.

Oxygen-enriched blast is also applied at the american works Hayden (Arizona) and Chino (New Mexico). At Hayden works one of the converters produces matte and in another this matte is blown to blister copper; at the Chino works blister copper from concentrates is produced in the same convertor.

An oxygen unit, which is being built at the Nkana Copper smelter (Zambia) will daily produce 544 tons of technical oxygen (93.5%), costs of the project are in the range of 4.5 million dollars.

Since 1969 it was supposed to feed oxygen-enriched blast to reverberatory furnaces and converters, and this was to rise the plant efficiency to the level, for the achievement of which by usual methods would be spent about 28 million dollars. It is the second among the largest units in the world which operate at the plants of non-ferrous metallurgy.

The experience of treating pelletized concentrates in converters has been gained in the Soviet Union, where one of the plants is successfully operating a unit which ensures about 15 per cent of copper output with a saving over 500,000 roubles a year as compared to concentrates smelting in a reverberatory furnace.

The problem of intensifying production processes of hydrometallurgical treatment of ores and dumps is of particular interest, as one of the main shortcomings of the natural leaching is that this process is taking much time.

In recent years the investigations conducted in various countries, show that in natural oxidizing and leaching sulphide ores one of the main factors is a bacterial process in natural conditions. In particular it is found that per every ton of sulphuric acid, made by chemical methods, up to 4 tons of acid are produced by bacteria.

A pilot plant for bacterial underground leaching at one of the mines was designed by the institute "Uralmehanobr". A monthly productivity of a precipitation plant was about 20 tons of copper. During the first month it increased up to 31 t, during the second - up to 33 t, and during the third - up to 34 tons.

As a result of the tests the efficiency of the unit has been increased by 63 per cent. Cost price of one ton of copper was much less as compared to that produced from copper concentrates.

f) Uses of new sources of fuel, power and secondary power resources

Deficiency and high costs of solid metallurgical fuel (coal, coke), the occurence of relatively cheap and more available gaseous fuel due to the discovery of new gas fields and advances in chemistry caused an active search for decreasing fuel consumption in pyrometallurgical processes and uses of low priced fuel and power. In principle copper production does not require consumption of fuel and power in large quantities (excluding the production of refined copper). Depending on current density in electrolysis the total power consumption is 200-330 kw-hr, and fuel consumption in the order of 12-20 per cent of charge weight. However in copper production on a wide scale fuel and power consumption is rather great. For a plant with a capacity of 200,000 tons of refined copper coal consumption totaled 200,000-250,000 tons and power requirements in the range of 50 million kw-hr.

A share of fuel and power costs in the expenses for metallurgical processes is amounted to 30-40% and in the total price costs of blister copper is about 6-10%.

At present natural gas is being used at copper smelters of the Soviet Union and the United States.

The results of investigations and the experience of applying natural gas in industry show the accnomic expediency of using natural gas instead of oil for firing reverberatory, refining and other furnaces of copper smelters. Natural gas, used for reverberatory smelting makes it possible to prolong a furnace compaign, to reduce fuel costs and favours the solution of dust collection problems.

In the sphere of fire refining the investigations are aimed at the application of natural gas for firing refining furnaces and for technological purposes.

Currently a final stage of fire refining (reduction) is still performed with the aid of expensive wood (wood poles) which requires the application of manual labour and a large quantity of wood. The investigations, on the changing of wood by less expensive reducing agents (natural gas) gave positive results.

In recent time great attention is focussed on the utilisation of secondary power resources of copper smelters. Now waste heat boilers are being installed behind reverberatory furnaces, converters and units for flash smelting. The calculations show that the usage of flue gas heat for power and steam generation, as well as for preheating air is favourable in all cases, when a period of stable heat emission is not less than 60-70%. of the operating time of the main unit. Most effective is the complex application of heat when steam, power and air are used for the needs of the plant. It opens up possibilities of reducing primary fuel consumption by 70-80%.

It is relatively simple to solve the problem of heat emission from gases of reverberatory smelting which is a continuous process with stable heat conditions and low dust content of gases. The problem of using heat from the waste gases formed during flash smelting with relatively stable heat conditions was also successfully solved by means more advanced methods.

A problem of using converter gases heat remained unsolved for a long time.

It was explained by the shap changes of gas volumes, its corrosive nature and the high contomination of gases with dust and particles of liquid metals.

For achieving of the high efficiency in using heat it is necessary to prevent an infiltration of cold air into waste gases. At Onahoma plant it is reached due to a special construction of a converter hood. Under such conditions it is possible to increase sulfur concentration in waste gases and to produce additional quantity of sulfuric acid. After three year operation of waste-heat boilers there was no corrosion of heated surfaces. Waste-heat boilers generate about 10.4 tons of steam an hour at 250°C and under the pressure of 38 atm. Turbo-blowers require about 80% of steam, generated in waste-heat boilers of converters.

At the Boliden plant (Sweden) a waste-heat boiler for converter gases has been in operation for several years and produces about 100 tons of steam a day. 0.3 tons of steam is generated per 1 ton of blister copper.

The experience of these and other copper smelters shows that the problem of heat and sulfur gases utilisation can be successfully solved.

g) Improvement and Expansion of gases and waste water purification

Until the recent time little attention was given to the problems of air and natural water pollution, as air and water resources were considered to be practically unexhaustable.

However in the course of time the air pollution of industrial centres and states as well as pollution of fresh water basins have become so great that at present the solution of the problem is of vital importance. In recent years countries, companies and separate enterprises invested great capital in creating more advanced air and water purification systems at operating and new plants. This can be considered as a steady tendency in the development of many industries, including copper production.

At copper smelters generated gases and waste waters contain valuable components (copper, gold, silver, rare metals) and impurities (arsenic, chlorine, fluorine). Aside from this gases contain much sulfur, which on one hand is of great interest in an economic aspect and from the other it is a real danger of contaminating surrounding atmosphere with a sulphurous gas.

At the plants, operating without water recirculation, during beneficiation its consumption amounts to 200-250 m^3 per 1 ton of copper and during metallurgical treatment of ores and concentrates - 130-150 M^3. The volume of waste waters, which are to be purified is about 300-350 m^3 per 1 ton of copper.

At metallurgical plants air, consumed per 1 ton of copper is in the order of 25-65 m^3.

The total quantity of gases passing to atmosphere including a number of raw materials components (such as sulfur) reaches 30-70 m^3 per 1 ton of blister copper.

Gases and waste water are purified with the following purposes:

1) valuable components recovery;

2) improvement of working conditions at the plant;

3) prevention of air and fresh-water basins pollution.

The methods of solving these problems may be different, though in a number of cases they can be solved simultaneously.

The difference in overcoming these problems may be shown by the following example.

For profitable production of sulfuric acid from flue gases the minimum content of sulfurous anhydride should be in the range of 4-5%. In the air of production buildings sulphurous anhydride content should not exceed 20 mg/m^3. At this content a harmful influences on the personnel is not detects. On the other hand in populated areas the concentration of sulphurous anhydride in the air in the order of 1-2 mg/m^3 is considered to be undesirable, as the inhabitants stayed there all day round and at the concentration of 1.6 mg/m^3 they feel unpleasent smell.

Contents of harmfull matter in gases and waste water exert an adverse effect on the whole biosphere.

All this causes to errect at the enterprises complexes of air and waste water purifing installations, using new materials, equipment and processes. Ion-changing methods of waste water purification, biochemical, electrophysical and electrochemical methods of air cleaning find expanding application in industry. Of great interest are sorption methods of purifying gases from some harmful impurities; these methods are being developed by "Ginztvetmet" institute.

Air and waste-water purifying installations become an integral part of each concentrator and metallurgical plants, processing raw materials, containing copper. Costs of such equipment are amounted to 10-20 per cent of total capital investment in industrial enterprises and show an upward trend.

III. Trends in Geographical Distribution of Copper Industry Plants

Technical development of copper production and increasing its role in the structure of industry determine the changes in the distribution of copper industry plants. In recent time metallurgical plants are being built in the regions, located in immediate proximity to the products consumers.

The choice of construction site has a great economic significance and errors, made at this stage in contact to the errors made in choosing the technology , are impossible to correct and they adversely influence the operating results of a plant during the whole period of its work.

At present a number of copper smelters consume raw materials supplied from far sources Great transportation costs are largely compensated by the concentration of production , decreasing of costs per a ton of copper to 12-15 roubles ensures raw materials transportation for a distance of 800-1200 km. The problem of feed materials transportation is essentially facilitated by the advances in ore dressing. For example, in the Soviet Union during the period of 1945-1968 concentrate consumption per 1 ton of copper has decreased twofold.

A character of expenses on raw materials and products transportation is also changing to the considerable extent. At present in the Soviet Union expenses on the transportation of copper smelter products exceed raw materials, alongside in connection with the expansion of complex using raw materials the output of copper smelters is steadily rising. By 1965 at a number of copper smelters 600 kg of final products were produced from every ton of raw materials. Now this ratio is about 1:1; and less transportable sulfuric acid is a great portion of the total quantity of the products.

In the nearest future, when iron will be recovered from the slags, and silicates will be used for construction materials, production quantity of products (metals, acid, iron) would exceed processed raw materials, containing copper nearly by two times.

A very interesting tendency is the erection of large chemical - metallurgical complexes in the regions of copper smelter location. Aside from conventional products these complexes will produce high quality fertilizers, salts, chemicals, construction materials etc. Transportation expenses for shipping these products are much higher as compared to shipping of raw materials.

If the tariff for concentrate transportation is taken as a unit, the tariff for metal shipping will average 2; for sulfur acid - 1.7-1.8; for products, made from slags - 1.1-1.2. The total costs of the products are sharply increasing when they are transported for a long distance; thus if the costs of concentrates, shipped for distance of 1000 km rise only by 1.3%, sulfuric acid costs increase by 40-50, and those of the products from slags by 80-100 per cent.

As a result of this metallurgical plants are becoming less dependable on raw materials transportation and may be situated at considerable distances from mines and concentrators in the regions with more favourable conditions as related to fuel, power and climate and in immediate proximity to the consumers of the products.

IV. Trends in the Changes of Operating Results

(costs, prices, capital investments, productivity)

The changes of operating results reflect the tendencies of changing raw materials, consumption, technological schemes, economic and political conjuncture, as well as a general approach to the problems of scientific and social progress. Despite the fact that these results are subjected to considerable changes, their analysis for a number of years allows to determine the relatively steady trends of these changes.

a) Costs of copper production

The costs changes are effected by the two opposite factors: rising the costs of production (decrease of metal content in ores, depletion of mines reserves, increase of labour costs, rising of land and water costs, increasing capital investments in construction and equipment) and lowering the costs of production (technical progress, improvement of industrial engineering and technological processes, reduction of the working force, development of co-operation and specialization of production, complex uses of raw materials, treatment of waste products). In capitalist countries the costs of copper production during some periods are essentially rising due to the strikes of working people.

According to the data for 2/3 of the copper producers in the capitalist countries the average costs of copper smelting are in the range of 400-800 dollars per 1 ton, and under the fixed prices copper production may be considered as profitable.

Given below is the character of copper production costs according to the available data:

Mine production	41%
Ore beneficiation	33%
Smelting and refining	26%

Considering these data it is essential to stress a major role of the capital invested in mine production. Technical progress in mining (application of highly efficient mining systems, usage of self-propelled equipment, application of effective explosives, mechanization of mining works, application of nuclear explosions etc., probably may essentially reduce costs per unit of mined ore. However due to an expected lowering of copper content in ores (according to the estimates in the USA in 1985 an average copper content in mined ores will decrease up to 0.5%) it is likely that the costs per unit of mined metal will remain at the same level or may be somewhat higher.

It is necessary to take into account a steady trend of rising labour costs (during [illegible] index rise was about 17%) and of increasing equipment and construction expenses (index rise - [illegible] year). This is explained by the need of satisfying demands of the workers and of the erection of auxilary objects ([illegible] and waste water purification etc.).

On dressing and metallurgical treatment of ores and concentrates technical progress, the main tendences of which were mentioned above, will allow to cut the expenses per a unit of copper at stable indices of labour, equipment and construction costs by 5-15%. The total costs will be at the old level or decrease only slightly. It may be considered that in the nearest years the technical development of copper production will in the main off set the deterioration of raw materials balance of this metal and rising of labour, equipment and construction costs.

b) Prices

During last 10 years copper prices show a steady upward trend in connection of rising demand for metal and increasing of production costs (rising in prices of raw materials, and in capitalist countries the instability of production due to financial crises and strikes at the big plants, producing this metal and other reasons). Copper prices (in dollars per 1 ton) were 678 in 1960, 1127 - in 1967, 1242 in 1968 and 1467 in 1969. In the Soviet Union prices of refined copper also rose to some extent (in [illegible] they were higher by 25 per cent).

As mentioned above the costs of copper smelting are not expected to rise essentially in the near future, especially as the increase of copper output in the developing countries will be based on relatively rich raw materials and advances technological processes. Thus the tendencies of costs changes as the basis for the objective price determination will facilitate the stabilization and even the reduction of prices, the further increasing of which in the future can be caused by the considerable conjunctive changes.

e) Capital investments

In recent years copper plants are being built and reconstructed on a wide scale, and this allows to define some tendences of changing the capital investment and the total costs of new plants construction.

The main funds of copper production show an upward trend. During 1960-1970 the funds of the major copper producers (Kennecott Copper Corp., Phelps Dodge and Anaconda) have increased by 1.5 times. In the Soviet Union and socialist countries the main funds of copper industry were rising at the high rate. Mine production accounts for about 60% of the main funds. A share of the capital, invested in the mines is rising more rapidly.

Comparing the data of the costs of building new facilities during 1950-1960 to the data concerning the construction costs during 1960-1968 one can find a 20-30% total rise of capital investment per ton of copper. In the first place it is connected with raising the index of equipment costs and lowering copper content in mined ores (this is of particular importance due to the increasing of capital investments in mining facilities).

According to the data, published for a number of mines in capitalist countries in 1969, the average capital investment per a unit of production for mining and dressing were 1900 dollars per 1 ton.

At the average investments in metallurgical treatment (smelting and refining) in the order of 400-600 dollars the total investments per one ton of copper are in the range of 2,500 dollars for new plants and about 2000 dollars for the plants, built in the early fifties.

By comparison capital investments per unit of production in aluminium industry are amounted to 800 dollars per ton, and in the complete cycle of nickel production 4,000-9,000 dollars per ton.

Technical progress in mining is likely to have the same effect on stabilizing the capital investments and the costs. In metallurgy due to the introducing of continuous and integrated processes and intensification the capital investments in the major metallurgical operations essentially decrease and this despite of the action of some factors, facilitating costs rise, may result in the stabilization or reduction of capital investments per a unit of production.

d) Productivity

One of the main reflections of the trends in the development copper production is a decrease of labour content of technological processes and the growth of labour productivity. Usage of high capacity equipments, increase of funds, a wide application of automation and mechanization , intensification of production processes, wide usage of mordern forms and methods of industrial engineering, management and control, improvement of workers skill - all these factors lead to a steady rise of the share of labour costs. It is necessary to note that the considerable copper output at the operating plants in the Soviet Union and capitalist countries is achieved without an essential increase of a working force.

There is a tendency of stabilizing or even reducing working force in copper industry as a whole, despite of the wide building and placing in operation of new facilities.

During the period of 1960-1967 the labour content in the production of refined copper in the USA reduced by 15 per cent, in mining more than by 10%, in dressing by 1/3 and in metallurgical processes by 10%. At many copper smelters in the Soviet Union labour productivity growth for the same period was much higher.

At the same time it is necessary to note that the labour content practically remaines unchanged. In the late fifties and at present the structure of labour contents in the copper industry of the Soviet Union and the United Stated according to our calculations was characterised by the following data (%):

	USSR	USA
Mines	57	50
Concentrators	18	18-21
Metallurgical plants	25	28-31
Total	100	100

These date are similar to the structure of labour content in copper industry of other capitalist countries.

Mining is accounted for a major part of labour content and a share of this content can be reduced by radical technical advances. It is likely that the trends of technical progress will only off set the lowering of metal content in ore. Thus as a major tendency in chaning of labour productivity we should consider a further decrease of labour content in copper production with the relatively stable labour requirements and some rising of labour content in mine production.

V. Conclusion

Without the claim on the embracing of all present and future trends in the development of copper industry this paper shows that the main of these trends are interrelated and not accidental. So one can clearly see the influence of the demand for copper and the changes of raw materials on the development of technological processes, the effect of technological processes on the distribution of the plants and determination of operation results, the influence of prices and demands for copper and the advances in the treatment of ores on the requirements placed upon raw materials sources etc.

A general scheme of the trends in the development of copper industry is shown in fig. 1. The scheme outlines the following problems:

- main factors, concerning the development of copper industry (a growth of demand; depletion of raw materials sources; technical advances in co-operating branches; a growth of demands for by-products: an index rise of labour, equipment and construction costs);
- general trends in the development of industry (a growth of output; capital investments; and copper prices; construction, modernization and expansion of plants; the development of technical processes; treatment of new raw materials etc.);
- trends in technical progress (intensification of production processes, complex uses of raw materials, development of hydrometallurgical processes etc.) as well as examples of the effects of these trends;
- effects of trends in technical progress (growth of copper production, compensation of raw materials balance, decrease of construction costs, rise in labour productivity etc.).

The scheme shows that the determination of the trends in the development of copper industry are mostly influenced by the growth of the demands for copper, technicql advances in co-operating industries and the changes of raw materials. It is necessary to note that the effects of the trends in the technical progress directly meet the main demands of the industry.

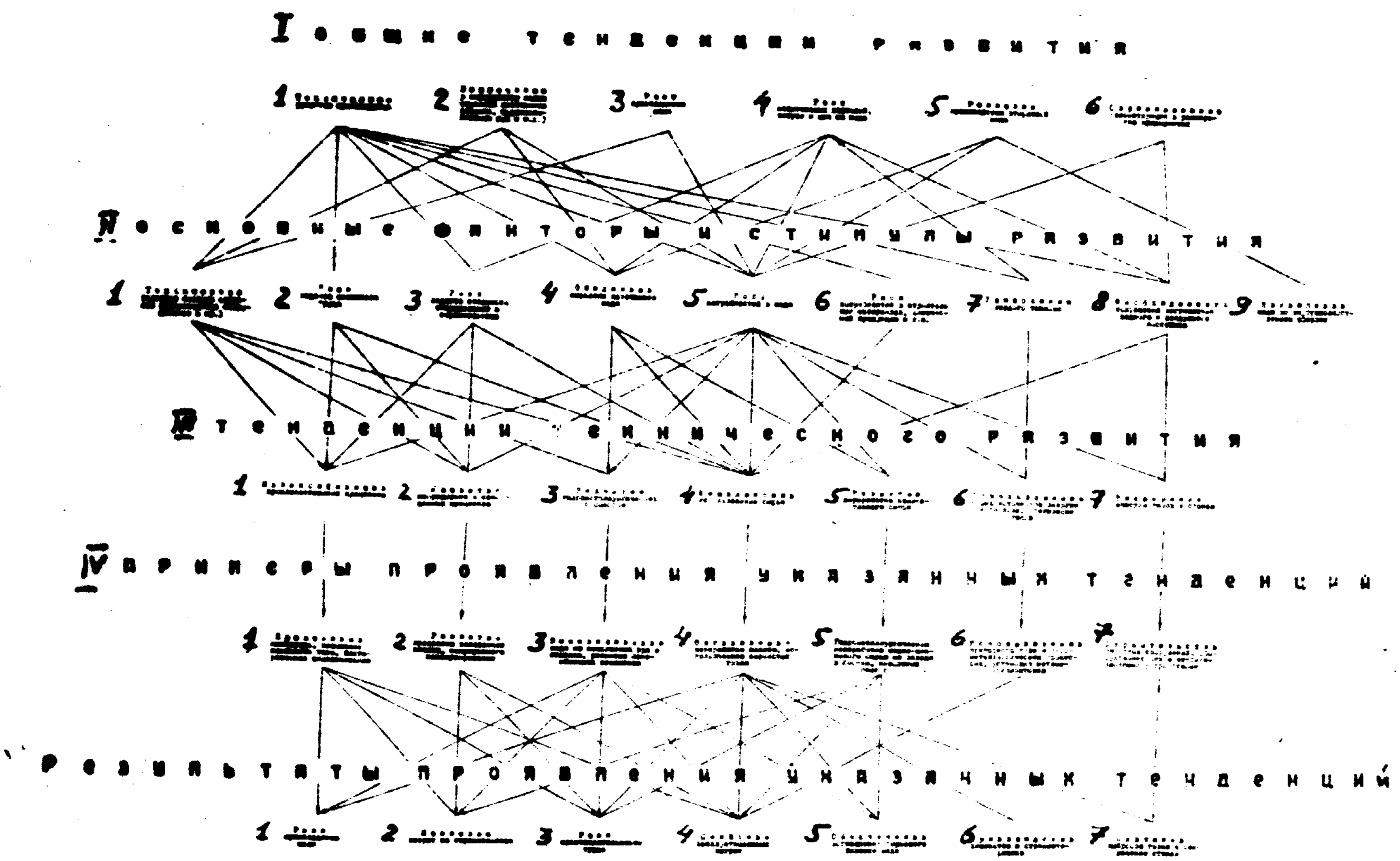

Fig.I Determination of trends in copper production.

Fig. 1 Determination of trends in copper production.

I. General trends.

1 - Development of technical processes;

2 - Treatment of new raw materials (low-grade, hardly treated ores etc.);

3 - Growth of copper production;

4 - Growth of capital investments, costs and copper prices;

5 - Development of secondary copper production;

6 - Construction, modernization and expansions of plants.

II. Main factors and stimulation of development.

1 - Technical development of co-operating branches (equipment production etc.);

2 - Increase of labour costs index;

3 - Increase of equipment and construction costs index;

4 - Depletion of raw materials sources;

5 - Growth of demand for copper;

6 - Growth of demand for construction materials, chemicals, etc.

7 - Rising in prices of solid fuels;

8 - Necessity of abating air and water pollution;

9 - Increase of copper used in various industries of the country.

III. Trends in technical progress.

1 - Intensification of production processes;

2 - Development of continuous and integrated processes;

3 - Development of hydrometallurgical processes;

4 - Complex uses of raw materials;

5 - Advances in treatment of bulk feed materials;

6 - Uses of new power and fuel sources;

7 - Expansion of gas and waste water cleaning.

IV. Examples of reflecting these trends.

1 - Uses of oxygen, increase of current density, bacterial leaching;

2 - Advances in flash smelting and continuous converting;

3 - Copper leaching from oxide ores and dumps development of ion-exchanging processes;

4 - Treatment of slags, and uses of sulphur containing gases;

5 - Hydrometallurgical treatment of copper-zinc containing raw materials at Kosako plant, KIVCET process;

6 - Usage of natural gas for pyrometallurgical processes, installation of waste heat boilers;

7 - Construction of equipment for cleaning gases and waste water.

V. Effects of these tendences.

1 - Growth of copper production;

2 - Decrease of construction costs;

3 - Rise of labour productivity;

4 - Reduction of operating costs;

5 - Compensation of raw materials balance;

6 - Production of chemicals and construction materials;

7 - Decrease of gases emission and volume of waste water.

[redacted]

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