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Invited review

Modern problems of mineral processing in Russia

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ABSTRACT

The contemporary state of the raw material base in the country is analyzed and a negative tendency is noted as a reduction in the extraction of mineral resources and worsening the quality of extracted ores. It is shown that in the near future the deposits developed will be mainly finely disseminated and rebellious ores and this requires new solutions in the technology of their beneficiation. Examples are provided of advanced solutions in technological mineralogy, directed changing in mineral and ore properties with different kinds of energy actions, and the use of pyro- and hydrometallurgical technologies that open definite possibilities for the rational and complex use of rebellious mineral raw material.

Keywords: Mineral processing; Mineral resources

1. INTRODUCTION

Analysis of the development of mineral resources beneficiation techniques and technology in recent years indicates considerable achievements in domestic fundamental science in the field of understanding the basic phenomena and regularities during separation of mineral complexes. This has made it possible to create highly efficient processes and technologies for primary processing of ores with a complex composition and as a consequence to provide the metallurgical industry with the required range and quality of concentrates.

At the same time in our country compared with the developed foreign states so far there have not been kept pace in developing the engineering base for producing beneficiation equipment, its quality, metal content, energy intensity, and wear resistance. As a result of insufficient automation and computerization for beneficiation processes of mineral resources the labor productivity in domestic concentration plants lags behind the world standards by a factor of three to five. It is natural that the specific consumption of material resources per ton of ore treated in plants is essentially greater compared with the world standards: in electrical energy consumption by 30%, for flotation reagents by a factor of two to three, and for metal worn in linings, grinding bodies and transport materials by a factor of 2.5.

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Apart from the negative tendencies listed above, the ecological situation in ore-dressing enterprises (threatening in a number of regions the existence of not only the biological world, but also humans) was sharply aggravated, a progressing reduction was noted in mining of coal, nonferrous and ferrous metal ores, mining and chemical raw material, and there was a deterioration in the quality of processed ores. As a consequence there was processing of rebellious ores of complex composition, high ash and sulfurous coals, characterized by a low content of valuable components, fine dissemination, and similar technological properties of minerals (Table l).

Table 1
Beneficiation indices for magnetite ores

Enterprise name	Processed volume, thou. t		Extraction, %		Concentrate quality, %	
	1990	1999	1990	1999	1990	1999
Lebedinsk DP*	43532.0	42265.9	79.28	79.03	68.44	68.47
Stoilenka DP	12090.0	12540.0	78.90	81.23	67.38	67.20
Mikhailovsk DP	29110.5	22359.1	54.12	52.76	64.21	65.90
Olenegorsk DP	16774.0	10249.0	79.84	80.52	65.40	65.78
Kovdor DP	16164.1	8350.0	91.26	91.11	63.73	64.15
Kostomuksha DP	23981.6	18525.7	79.45	78.40	67.60	68.19
Kachkanarsk DP	45153.9	34936.6	66.69	66.47	62.00	61.61
Korshunovsk DP	14428.7	9597.6	81.90	81.88	62.90	62.70
KMA - ore	3534.7	2665.6	82.61	84.67	66.08	66.06
Russia as a whole	251447.0	177696.4	74.32	74.14	62.04	63.45

* Dressing plant

From 1990 to 1999 the production of merchantable iron ore decreased by 34%. There was a sharp reduction in mining ore and production of nonferrous metal concentrates: rare metals by more than a factor of 30, tungsten by a factor of ten, tin and molybdenum by a factor of three, zinc and lead by a factor of two, fluorspar by a factor of 17.5, coal concentrates by a factor of five, and gold by a factor of 1.2-1.3.

In the last twenty years the content of nonferrous metals in ores has decreased by a factor of 1.3-1.5, iron by a factor of 1.25, and gold by a factor of 1.2, and the proportion of rebellious ore and coal increased by 15-40% of the total weight of raw material supplied for beneficiation. Besides, after the break-up of the USSR Russia lost commercial deposits of manganese, chromium, kaolin, and some other elements. On the other hand, in view of entry of Russia into the world market there is a sharp increase in the requirements for the quality of concentrates with respect to technological and ecological standards.

Consequently, at the present time a number of irresolvable conflicts between a change in the nature of the mineral-raw material base has developed, i.e. the requirement for processing ores and deposits that are not easy to enrich, an ecologically severe situation in the mining regions, and the state of the technology and organization for primary treatment for mineral raw materials.

In addition, the majority of ore deposits in Russia incorporated by the state is run-of-mine or lean ores, and in a number of cases these are rebellious ores or ores occurring at great depths. In view of this in the majority of cases they are not competitive compared with foreign deposits. Preliminary calculations indicate that for many forms of mineral resources, within the ore category where the content of useful components is less than in the balanced ores, may be from 30 to 70% of valuable deposits, since considering the world prices for final product, mining them, using traditional technologies, is not profitable.

Re-evaluation of deposits taking account of world prices for finished products showed that below mine grade ores are as follows: 34% of Pb ores, 49% of Sn ores, 34% of magnetite ores, from 15 to 30% of Ti, Cu, W, apatite ores, and coal. Under these conditions increasing the completeness and complexity of mineral resources beneficiation, and the development of highly effective, ecologically safe technologies is of primary importance. It should be based on intensification of existing methods and creating new ones for extracting components from rebellious ores and technogenic deposits, based on the latest achievements in fundamental sciences, and combination of beneficiation and chemical-metallurgical processes with application of modern pyro- and hydrometallurgical technologies.

2. PROCESS MINERALOGY

A change-over to a new strategy for primary processing is only possible on the basis of new technological and mineralogical evaluation of deposits. Currently, technological mineralogy has in its arsenal a number of modern precision methods of physical and physical-chemical analysis for substance and with appropriate computerization and development of software it is possible to obtain rapid and reliable information not only about the chemical and mineral content of mineral resources, but also about the technological properties of mineral associations (Figure 1) (Chanturiya and Bashlykova, 1998; Alcover Neto et al., 2000).

At present in Russia, on the basis of computer analysis of images (Institute of Comprehensive Exploitation of Mineral Resources (IPCON), Russian Academy of Sciences, NVP "Tsentr", "Mekhanobr" Int. Stk. Co.) and approaches developed for predicting the technological properties of different raw material objects, a universal express-method has been developed for mineral-technological evaluation of mineral raw materials using an image analyzer based on an IBM PC and special software orientated towards the problems of technological mineralogy.

The first studies of gold-containing, rebellious manganese ores and high-sulfurous coals by image analysis point to the considerable promise, efficiency of this method, and the possibility of predicting the beneficiation potential of a raw material (Chanturiya and Bashlykova, 1998).

The main morphometric characteristics and prediction parameters for desulfurizing coals of Rostov region obtained on the basis of using the computer method of image analysis, which made it possible to substantiate the main technological regimes for thorough coal beneficiation, are given in Table 2.

Table 2
Results of morphometric analysis of coal samples in the image analysis system and parameters predicted for desulfurizing

Sample	Natural beneficiation factors			Predicted beneficiation factors					
	average mass size of pyrite inclusion μm	amount of unextractable pyrite inclusions %		optimum crushing size mm	theoretically possible extraction of sulfur %		sample original sulfur content	content of organic sulfur in sample	theoretical sulfur content of concentrated coal
		lean aggregates	micro-inclusions		bonded with pyrite	from coal (taking account of organic sulfur)	%		
"Sholokovsky" mine (central beneficiation plant feed)	37	7	11	-0.1	82	58-60	1.94	0.24	0.80
"Gornyatsky" mine (screenings -25 mm)	59	11	14	-0.2	75	65-67	2.18	0.5	0.74
"Krasnodonetsk" mine (screenings -25 mm)	61	6	9	-0.2	86	76-78	2.05	0.29	0.66
"Donetsk" mine (screenings -25 mm)	87	2.4	8	-1.5	87	50-55	5.73	2.4	2.58
"Izvarinsk" mine (screenings -25 mm)	70	4	12	-1.0	83	40-45	3.54	1.64	1.94
"Sholokovsky" mine (screenings -25 mm)	53	10	15	-0.5	70	59-62	2.15	0.49	0.82
"Sadkinsk" deposit	73	11	9	-0.3	80	42-45	1.46	0.41	0.88

The results obtained are entirely confirmed by technological studies on desulfurizing coals of the Sadkinsk deposit (Chanturiya et al., 1995, 1997). Thorough coal beneficiation made it possible to obtain a high quality coal concentrate with an ash content of 11.4% and sulfur of 0.93% with a yield of 68%. Economic evaluation of the efficiency of thorough coal beneficiation with calculation of the expenditures from mining to obtaining the electric energy in a thermal power station indicates that the potential saving in electric energy production is from $2.44 to $9.98 in relation to the thoroughness of run-of-mine coal beneficiation (Table 3).

Thus, technological mineralogy should become a foundation of information for a unified theoretical approach to primary processing of mineral and technogenic raw material.

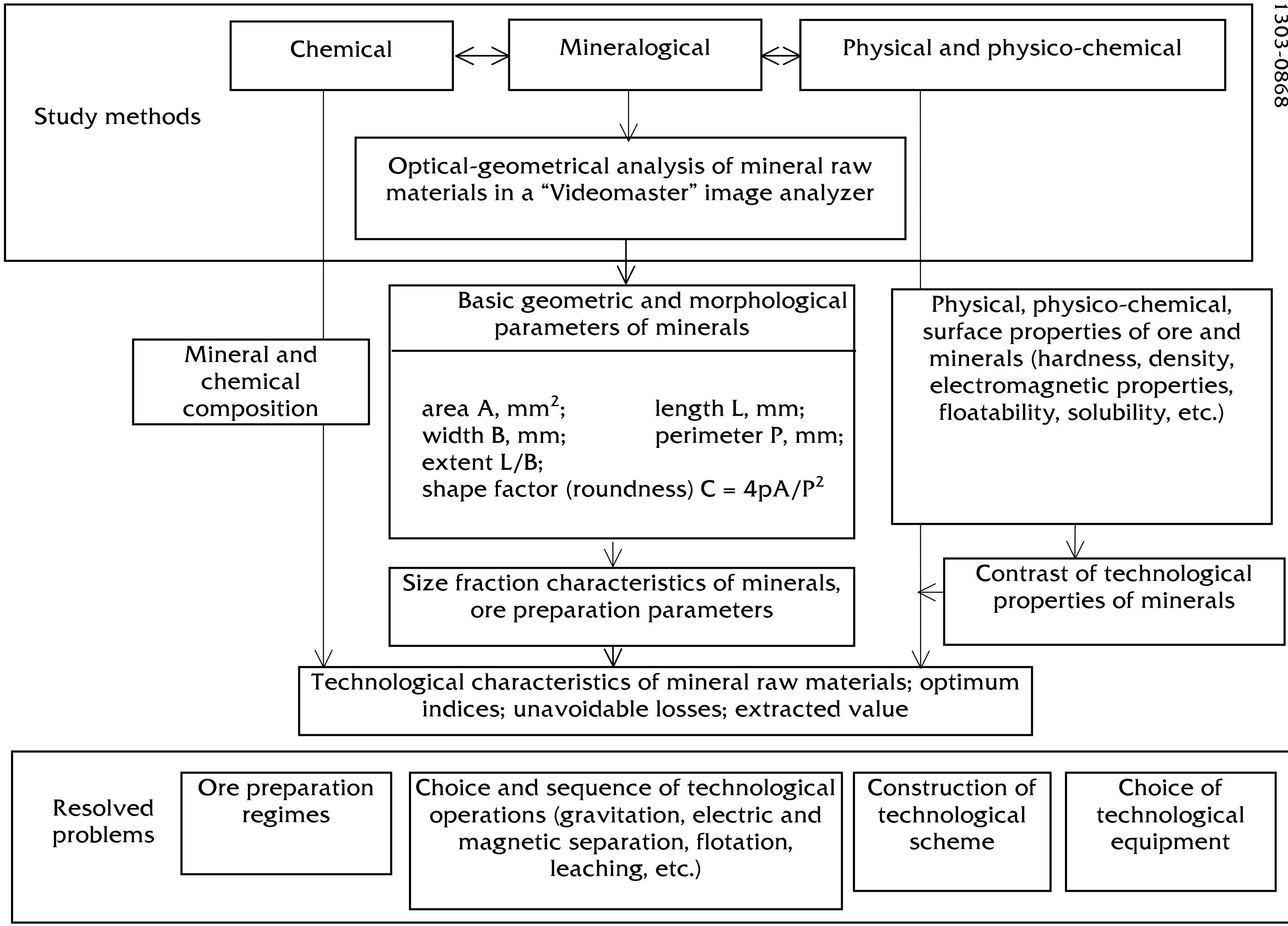


Figure 1. Scheme for preliminary evaluation of mineral raw material beneficiation

Table 3
Comparative expenditure indices for producing electric energy in relation to burnable fuel quality (sadkinsk deposit)

Fuel quality	Run-of-mine coal A* = 33.7%		Concentrate: existing technology, coal beneficiation, % A* = 25.6		Concentrate: thorough technology, coal beneficiation, % A* = 12	
	versions of delivery distance, km					
Items of expenditure	80	1270	80	1270	80	1270
	total expenditures, $/MW.h					
Original coal acquisition	22.59	23.03	21.94	22.35	20.93	21.35
Coal beneficiation (cost)	—	—	2.85	2.90	5.62	5.73
Transport outlay	8.16	17.28	6.71	14.22	5.17	10.69
Thermal power station operating expenditures						
including:						
amortization of "dust preparation" mills	0.75	0.75	0.62	0.62	0.47	0.47
treatment of thermal power station cinder waste	3.89	3.89	2.45	2.45	0.90	0.90
Specific expenditures for producing electric energy	35.41	34.97	34.58	42.54	33.11	39.41
Saving from beneficiation, $/MW·h	—	—	0.83	1.43	2.30	4.56
Burnable fuel, $/t	—	—	1.42	2.44	5.03	9.98

* Ash content

3. ORE PREPARATION

The evaluation of technological-mineralogical information will make it possible to depart from the principle of mining a deposit as a single ore source. For this purpose it is more expedient in the scheme of primary processing to develop ore preparation as a set of operations for treating lump rock mass with the aim of converting it into one or several technological types of standard ore for subsequent beneficiation or use it as a finished product.

Currently preliminary concentration of rock mass at dressing plants is performed by separation in heavy media and by dry magnetic separation. However, ore preparation based on radiometric methods of sampling, sorting, and separation is more promising. In this case all of the operations of the cycle are built on a single base, i.e. use of the nuclear-physical properties of a mineral substance as a recognition criterion for composition and separation. Within the arsenal of radiometry there are more than twenty different methods with respect to physical base (from gamma-radiations to radio-waves) from which the most effective may be selected for each ore (Mokrousov and Lileyev, 1979; Tatarinov et al., 1995).

A study of the beneficiation of nonferrous, ferrous, and rare-metal ores, and mining-chemical raw material showed that radiometric separation may remove 20-50% of waste product which may be used as a building material, and it increases by a factor of 1.3-1.9 the content of valuable components supplying for beneficiation, it reduces the amount of waste by a factor of 1.2-1.5, and it involves ores with low content of useful components in processing (Table 4).

Table 4
Results of radiometric ore separation

Ore type	Separation method	*Number of objects*	Contrast index	Tailings output, %	Beneficiation level
Copper-nickel, gold-containing, cobalt	Radio-resonance	14	1.5-1.6	50	1.9
	Photometric	1	1.4-1.6	40	1.6
Tungsten, molybdenum	X-ray radiometric	13	0.6-1.0	35	1.45
Lead-zinc, tin	—" —	25	1.1-1.3	30	1.4
Mining-chemical raw material	X-ray luminescence, neutron absorption				
Rare metal, apatite-magnetite, chromite	X-ray radiometric, X-ray luminescence, radio-resonance	21	0.6-1.0	20	1.3

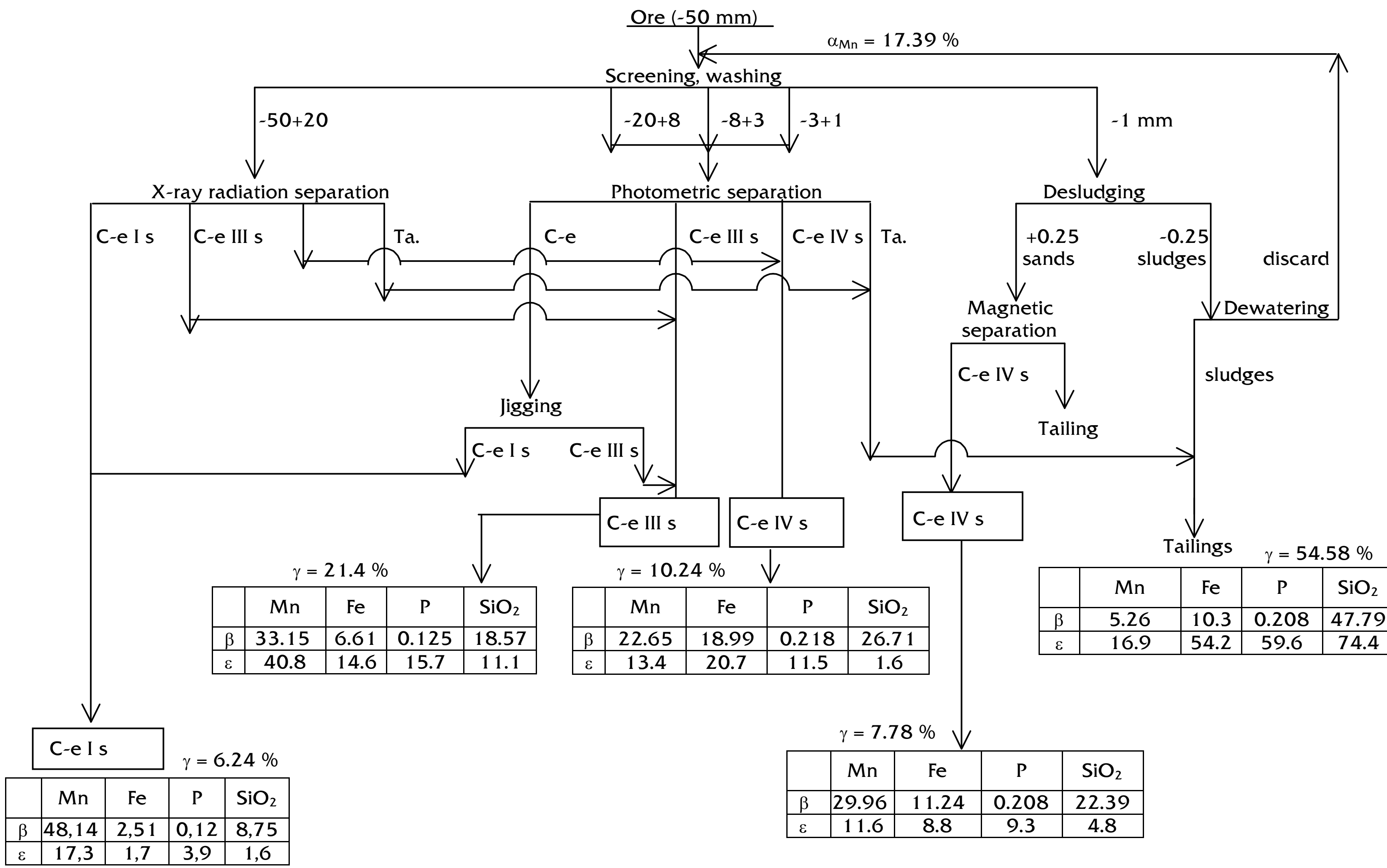
This technology operates effectively at "ARLOSA" Int. Stk. Co. with diamond beneficiation (X-ray luminescence) and it has been realized in a number of Russian objects. In recent years (Tatarinov et al., 1995) a new concept has been worked out for developing methods of lump by lump separation based on the use of highly effective technology that provides separation of lumps of rock from ore for beneficiation with an efficiency of 0.75-0.90 and a combination of processes of screening, washing, and separation in one module.

Technical documentation has been developed for universal separators (RSM) and production has been provided in the Volga engineering plant. The new technology pays for itself in six months.

Thus, radiometric sorting in transport vessels or on a conveyor makes it possible to reduce to a minimum impoverishment of the ore flow and to separate it into the required technological types and sorts, as well as to involve ores with low content of useful components in processing. Radiometric separation, that is a technically improved version of ore preparation, makes it possible to remove lump rock in the form of rubble and other associated production, or to use it as a stowing material in mining production.

The high efficiency of radiometric separation is confirmed by the results of manganese ore beneficiation of the Porozhinsk deposit (NVP "Tsentr") (Figure 2).

During beneficiation of a mineral raw material about 70% of the energy is used in crushing and grinding the ore. The consumption of electrical energy during grinding ranges between 20 to 60kW.h/t depending on the type of ore. In a number of cases an increase in the fineness of the flow does not lead to an increase in the level of mineral exposure, whereas there is an increase in the number of finest particles (<10μm).



C-e I s, γ = 6.24 %

	Mn	Fe	P	SiO_2
β	48,14	2,51	0,12	8,75
ε	17,3	1,7	3,9	1,6

C-e III s, γ = 21.4 %

	Mn	Fe	P	SiO_2
β	33.15	6.61	0.125	18.57
ε	40.8	14.6	15.7	11.1

C-e IV s, γ = 10.24 %

	Mn	Fe	P	SiO_2
β	22.65	18.99	0.218	26.71
ε	13.4	20.7	11.5	1.6

C-e IV s, γ = 7.78 %

	Mn	Fe	P	SiO_2
β	29.96	11.24	0.208	22.39
ε	11.6	8.8	9.3	4.8

Tailings, γ = 54.58 %

	Mn	Fe	P	SiO_2
β	5.26	10.3	0.208	47.79
ε	16.9	54.2	59.6	74.4

Figure 2. Basic scheme of primary processing of rebellious ores

Analysis of the main losses during primary processing shows that 35-40% is connected with aggregates and 30-35% is connected with fine particles less than 40μm. In order to reduce these losses during processing of finely-disseminated ores without forming aggregates and simultaneously without excessive overgrinding, the non-selective traditional processes of crushing and grinding in jaw and cone crushers, and ball mills should be replaced by selective disintegration.

The physical meaning of the change-over to selective disintegration involves organizing the process so that crushing occurs not over the random directions of compressive forces, but predominantly over the boundaries of mineral grains as a result of developing shear and tensile loads at their boundaries. These methods are realized in dynamic self-grinding mills, conical inertial crushers, gas stream and spring mills (Abouzeid and Fuerstenau, 2000; Sander and Schonert, 2000), for ultrafine grinding ("Mekhanobr" Int. Stk. Co.).

Mechanical methods that provide breaking over interphase boundaries as a result of forming microcracks during electrochemical processing of pulp or creation of penetration channels under the action of accelerated electron energy or powerful electromagnetic pulses are much more selective.

Due to the fact that the majority of sulfide minerals and oxides exhibit semiconducting properties and they are electrochemically active, we have proposed a hypothesis about the possibility of increasing the concentration of defects and weakening bond at the accretion boundary of mineral grains with application of electrochemical effects to grindable ore (Yeliseyev et al., 1982).

During polarization of sulfide ores under wet grinding conditions at the contact boundary of minerals, electrochemical reactions occur with formation of new products, i.e. elemental sulfur, metal hydroxide, and a number of others, which lead to weakening of particles along the mineral accretion boundaries and a reduction in the probability of defect "healing" (Yeliseyev et al., 1982). In addition, in the case of cathodic polarization of pulp or supply during grinding of catholyte (cathodically treated water), as a result of impregnation of the pulp (water) with finely-dispersed hydrogen bubbles and creation of a strong-reducing medium ($Eh \geq 1000mV$) oxidation is sharply retarded, and this creates favorable conditions for a reduction in the consumption of grinding bodies.

Optical and X-ray phase studies of mineral particles were used in order to reveal the mechanism of intensifying the process of grinding of iron ores after electrochemical pulp treatment. On the basis of comparing the main crystal lattice parameters for magnetite, hematite, quartz, and ore complexes before and after treatment, it was established that cathodic polarization of suspensions promotes an increase in the defective nature of the structure of ore minerals, reduces local stresses over grain boundaries, and leads to formation of a considerable number of cracks which predetermines subsequent effects during ore grinding.

Experimental studies on the effect of a direct electric current on grinding of sulfide and magnetite ores were carried out both in ball mills and under conditions of preliminary pulp treatment.

Computer image analysis established that the level of sulfide exposure increases by 25% (relative) for copper-zinc ore (the grade of copper concentrate increases from 16.88 to 20.46% Cu), and by 15% for magnetite ores. The quality of iron concentrate increases by 1.5%, and the grinding process productivity increases by 12 and 18% respectively. The consumption of electrical energy for electrochemical polarization is 0.2-0.4kWh/t (Chanturiya, 1993).

In the case of cathodic polarization of pulp or supply of catholyte during grinding (technology developed at IPCON, Russian Academy of Sciences, in the 1980s) with beneficiation of Dzhezkazgan copper-zinc ores and magnetite ores from the Mikhailovsk DP the possibility was established of reducing the consumption of balls by 20-25%, which is from 1.5 to 5kg/t of ore. Realization of this technology (industrial electrochemical conditioners for water EKV-50 are manufactured by the "Kommunalnik" plant) at the Russian ore-dressing plants will make it possible to save every year up to 5.10^5t of metal. Similar results were obtained by Pazhianur et al. (1997) and were presented at the XX International Mineral Processing Congress.

More significant results are achieved with irradiation of ores by accelerated electron energy with a dose of 0.4-0.7Mrad before grinding (studies by Institutes of the Siberian Branch of the Russian Academy of Sciences, IPCON, Russian Academy of Sciences).

A study of the mechanism of the action of accelerated electron energy on mineral-semiconductors (sulfides, oxides), dielectrics (quartz, calcite) and analysis of a physical model of the process (Chanturiya and Vigdergauz, 1993) made it possible to establish that of all effects that arise in a solid with these energies, the main one is governed by the different charging mechanism for mineral-semiconductors and dielectrics.

Charge drainage predominates over charging process for conductors. In high-ohm dielectrics charging occurs by another scheme. The rate of charge accumulation within them is governed by equilibrium between the inflow of charge and conductivity induced under the action of irradiation. Here the accumulating charge may create electric fields with voltage ranges between 1.10^3 to 1.10^4V/cm reaching the breakdown value. There is discharge of excessive charge along breakdown channels, then a stage of charge accumulation follows anew to the next breakdown. This charge is pulsating in nature and a system of microcracks may arise developing after each discharge pulse and leading to strength loss of mineral associates. Thus, during irradiation of mineral aggregates at the accretion boundary in mineral-semiconductors and dielectrics discharges arise that both lead to an increase in the efficiency and the selectivity of grinding processes.

The ILU and ELV electron accelerators produced in Russia make it possible to irradiate ore with a beam of electrons directly on conveyor belts. Due to the rapid (parts of a second) charging of dielectric inclusions energy consumed for treatment with an electron beam is insignificant and the productivity of the operation is limited as a rule only by the productivity of the conveyors.

An example of the effective use of an electron beam in grinding is its action on the technological properties of iron quartzites, polymetallic and gold-containing ores. For all types of ores there is both an increase in grinding productivity by a factor of 1.2 to 1.8 and an increase in the beneficiation technological indices. Calculations performed in IPCON, Russian Academy of Sciences, showed that introduction of the new technology into six ore-dressing plants of the Kursk Magnetic Anomaly (KMA) will make it possible to save more than 800 million kWh per year.

An even more effective method of selective disintegration of complex minerals is the action of powerful electromagnetic pulses on ore raw material and its beneficiation products substantiated scientifically and suggested by IRE, Russian Academy of Sciences, and IPCON, Russian Academy of Sciences. Use of powerful short pulses with an energy considerably exceeding the electric strength of a substance in a static field, makes it possible to expose rebellious gold-containing ores by substantial changing their physical and mechanical characteristics after the action. With certain parameters for the high-voltage electromagnetic field the main channel for passage of a current becomes the less inertia breakdown channel for solid dielectrics (semiconductors) that are within the composition of a rebellious ore containing precious metals.

The method of action on gold-containing raw materials and polymetallic ores by powerful electromagnetic pulses has considerable advantages over all of the methods listed above for disintegrating mineral raw materials since it makes possible most rationally to use the electric energy (selective breaking occurs without heating the ore) and to achieve the greatest completeness of intergranular breaking of mineral components with the least electrical energy consumption. Studies performed (IPCON, IRE, Russian Academy of Sciences, TSNIGRI, Russian Ministry of Nature) on rebellious gold-containing ores indicated the possibility of reducing energy consumption by a factor of three to five, increasing the completeness of intergranular breaking of mineral complexes, and as a consequence, an increase (extraction of gold and silver into productive solutions by 25-30% (absolute) and achievement of high technological indices for extracting gold up to 90%) without using roasting operations or autoclave treatment of concentrates (Table 5).

Table 5
Extraction indices for gold and silver under cyaniding of rebellious gold-containing concentrate from Nezshdaninsk deposit

Method of action	Extraction %		Extraction increase %		Total extraction increase of gold and silver %
	Gold	Silver	Gold	Silver	
Gravity concentrate					
Screening – 50μm	79.42	44.00			
Screening – 400μm	51.25	32.59			
Irradiation of accelerated electron energy	82.43	51.68	3.01	7.68	10.69
Screening – 50μm					
Irradiation of powerful electromagnetic pulses	82.30	68.85	2.88	24.85	27.73
Screening – 400μm					

4. ORE TREATMENT

The problem of separating minerals with similar technological properties is traditionally resolved by increasing HIR selectivity of beneficiation processes. This work is carried out along the path of reagent synthesis of directed action for flotation, development of highly effective flotation machines for separating coarse and finest particles (IPCON, Russian Academy of Sciences, "Mekhanobr Int. Stk. Co.", GNTs "Gintsvetmet", Institute of Mining, Siberian Branch of the Russian Academy of Sciences, Moscow State Mining University (MSMU), Irkutsk State Technical University (ISTU), MISiS, Russian Federation Ministry of Education, etc.); use of high-gradient fields and magnetic systems with increased induction, high-voltage electric fields in an inert gas medium; application for separation with respect to density of combined action using centrifugal, magnetohydrostatic, magnetohydrodynamic, and electrophysical effects ("Mekhanobr Int. Stk. Co.", MSMU, Russian Federation Ministry of Education, etc.). However, for cases when the contrast is practically zero, for example during beneficiation of oxidized ores of nonferrous metals, these measures do not give results. An increase in the contrast is achieved by selective changing the technological properties of minerals based on energy effects, which makes it possible to develop ecologically safe technology in future.

In recent years extensive studies have been carried out on the use of such energy effects as radiation, ultrasonic, electrochemical, mechano-chemical, and plasma in order to change directionally the surface properties of minerals. Although these trends were considered exotic in the past, in view of the onset of output of industrial electrochemical conditioners for pulp, plasmotrons, linear accelerators, and ultrasonic generators, it is possible to considerthe actual introduction of new ecologically safe technologies into primary processing of rebellious ores and coal of a complex substance composition (IPCON, Russian Academy of Sciences, Institute of Mining, Siberian Branch of the Russian Academy of Sciences, GNTs "Gintsvetmet", MSMU, IrSTU, Russian Federation Ministry of Education).

Electrochemical preparation of ore raw material whose minerals exhibit semiconducting properties involves treatment of mineral suspensions by a direct electric current with a prescribed potential with which at the surface of minerals there are electrochemical reactions with formation of new phases at the contact boundary with the electrode. For each mineral there exists its own potential with which some compounds form at its surface, and provide an increase in the contrast of mineral properties resulting in effective separation (IPCON, Russian Academy of Sciences, Institute of Mining, Siberian Branch of the Russian Academy of Sciences, MSMU, IrSTU, Russian Federation Ministry of Education).

The electrochemical conditioning method has moved into industrial testing with flotation of copper-nickel, copper-zinc, polymetallic, and gold-containing ores, and magnetic separation of oxidized iron-containing ores and has also been introduced into a number of ore-dressing enterprises with a significant economic effect (Chanturiya and Vigdergauz, 1993). Flotation process productivity has been increased by a factor of 1.3, and the extraction of copper, lead, zinc, nickel, and gold has been increased by 1.5-5%.

Prior mechano-chemical activation of industrial products and concentrates in planetary mills as a result of creating additional defects and forming new phases within the volume of mineral particles intensifies the processes of subsequent leaching of these products and concentrates (OIGGM, Siberian Branch of the Russian Academy of Sciences).

Thus, measured amounts of physical and physico-chemical actions on the surface of minerals change their properties in the required direction and make it possible to convert rebellious ores into the category of normally dressed ores.

All of these directions are important for increasing the efficiency of beneficiation processes, but they have approached the limit of their potential. Beneficiation is the separation of minerals without changing their phase and chemical compositions. Beneficiation becomes impotent in treating ores with a submicro-granular structure. At the same time, the main contradiction of the contemporary state of the raw material base and traditional technology for primary processing is the requirement for exploiting ores, coal, and technogenic deposits containing mineral aggregates for which it is impossible to lay bare their mineral phases, and consequently are impossible to dress.

5. PYRO- AND HYDROMETALLURGY

The most cardinal solution for this contradiction is processing of these types of ores under conditions of mining and metallurgical plants when within the beneficiation cycle only the readily enriched part of valuable materials is extracted into concentrates and the unexposed mineral aggregates (in the form of intermediate product) are directed into a metallurgical cycle (Habashi, 1997). The level of mineral raw material concentration with primary processing after which it is expedient to transfer it to metallurgical finishing is determined for each specific deposit individually, taking into account features of the mineral composition and ore structure. The optimum concentrate quality with which further beneficiation is not effective, and in a number of cases it does not make sense, should be clarified by calculation from mining the ore to obtaining the metal (final product).

For deposits with submicro-granular accretion of ore minerals it is inexpedient to carry out selection, and it is more convenient to submit collective concentrates and industrial products for metallurgical finishing. The development of pyro- and hydrometallurgical processes designed for processing lean raw material makes it possible to obtain by this combined beneficiation-metallurgical technology metals or chemical compounds with high through extraction of components and maximum complexity of the raw material used.

This technology has been introduced successfully in Norilsk mining-integrated iron-and-steel works with autoclave oxidation decomposition of pyrrhotite concentrates. The connection of autoclave processes for leaching with flotation and chloride-sublimation based on their optimum combination in processing copper-zinc ores makes it possible to increase copper extraction by 4-12%, zinc by 10-25%, and precious metals by 10-20%. Processing of rebellious polymetallic ores of the Ozemy deposit by a combined scheme, including collective flotation of lead and zinc minerals, autoclave leaching of zinc and chloride leaching of lead from cakes, makes it possible to increase zinc extraction to 80-90%, and lead to 70-80% ("Mekhanobr" Int. Stk. Co., GNTs "Gintsvetmet").

6. ENVIRONMENTAL ASPECTS

New methods for ore preparing and mineral raw materials processing make it possible to reduce the amount of waste to a minimum although storing of tailings with rare exception is unavoidable (Harada, 1995).

Currently more than 12 billion tons of wastes have accumulated containing valuable components which in a number of cases exceed their content in natural deposits. The gold content in beneficiation tailings for placer deposits and polymetailic ores from previous years (20 to 30 years distant) is from 2 to 6g/t. As far as secondary processing of tailings of sulfide ore beneficiation from tailings dumps (for extraction of nonferrous metals) is concerned, in the majority of cases schemes for beneficiating them are complex including gravitation, flotation, hydrometallurgy, and according to the technical-economic-indices and the quality of concentrates they are not competitive with products obtained from natural raw material. It is economically profitable to extract valuable components form "current" beneficiation tailings.

As shown by foreign practice and domestic experience of processing ores with low content of useful components at the enterprises of medium engineering, it is most effective and economically profitable to process overburden rocks and waste from the beneficiation of gold-containing ores and nonferrous metal ores by heap leaching (VNIIKhT Minatom, TsNIGRI, Russian Federation Ministry of Nature). In recent years in the USA half of the increase in gold mining has been obtained as a result of heap leaching. There is also positive experience in Russia of heap leaching gold from tailings of beneficiation. According to the developments of TsNIGRI, Russian Federation Ministry of Nature, this technology is realized in the "Yuzhuralzoloto" plant with processing of beneficiation tailings containing 1.5g/t of gold providing an extraction of 50-60%.

Nature-protective politics dictate the attitude towards constructing tailings dumps as to the creation of technogenic deposits. In accordance with using features of natural enrichment, which manifest themselves during washing of placers, it is possible to organize washing of tailings dump so that the residues of ore minerals are concentrated in the peripheral parts of tailings dump. They may be extracted from here, for example by methods of geotechnology without disturbing the stability of embankment.

A technogenic deposit, i.e. a tailings dump, should be formed by taking into account conditions for minimum hydrogeological interaction with the surrounding geological structures, but with the termination of exploitation time measures are necessary for recultivation and restoring the area occupied for land use.

The problem of preserving the environment is also resolved as a result of changing to a system of closed water circulation. A change-over from a self-regulating medium of system of return water supply to the system with conditioning makes it possible to avoid the discharge of waste water and thereby to provide stability of the technological process due to creating or maintaining the optimum ion content.

Currently, purification and conditioning of return water at beneficiation plants is accomplished by means of chemical reagents, sorption, electrodialysis, and combined methods with use in the first purification stage of natural sorbents (highly-porous coal, zeolites). However, these technologies are expensive and mainly it is only possible to accomplish purification of industrial water from toxic substances. It does not provide control of their ion content with the aim of giving the liquid phase of pulp optimum physico-chemical properties for effective performing some technological process for mineral separation.

In the 1980s at IPCON, Russian Academy of Sciences, scientific bases, industrial technologies, and equipment for electrochemical water treatment were developed (Chanturiya et al., 1996). All of this made it possible without using chemical reagents as a result of proceeding decomposition reactions for water at a cathode and anode to change the color, oxidation-reduction properties, ion and gas content of water, thus creating conditions for directed controlling the ion content of the liquid phase for pulp and improving the contrast of mineral properties. Results of industrial tests for this water treatment technology on polymetallic, scheelite, apatite, phosphoritic, bauxite, and rare-metal ores confirmed its high efficiency, the possibility of reducing the consumption of reagents-absorbents, medium regulators by 50%, and increasing the extraction of valuable components by 5-10% under conditions of closed water circulation. Electrical energy consumption is 0.5-2kWh/m^3 of water.

The acid product of water electrolysis (anolyte) with high oxidizing-reducing properties (Eh>800mV) and pH 5-3 makes it possible with use of it in conditioning coarse concentrates to accomplish effectively cleaning of the surface of minerals from hydrophilic carbonate-silicate and iron-containing hydrophilic films, creating conditions for improving the quality of concentrates and extracting valuable components from them (Chanturiya et al., 1997; Chanturiya and Ye., 1992). Prior treatment of diamonds by water electrolysis product (anolyte) makes it possible to clean effectively the surface of diamonds (by 80-90%) from carbonate-silicate compounds, to increase the water-repellency of crystals that are not easy to extract, and their output into finished products by a factor of two.

The creation and production of industrial electrochemical conditioners for water (EKV-50) and also realization of electrochemical technology for water treatment in froth and adhesive separations for the beneficiation of diamond-containing kimberlites at "ALROSA" Int. Stk. Co. made it possible to provide an increase in diamond extraction by 15% and to obtain an annual saving of 1.8 billion rubles (more than 60 million $ USA).

7. CONCLUSIONS

Thus, in Russia there are currently available effective, energy-saving, high technologies for ore preparation and primary processing of ores of complex substance composition corresponding to the world level, and a number of technologies exceeding them, and this has been presented several times in international congresses for beneficiation of mineral resources.

Realization of new technologies at the Russian ore-dressing plants will make it possible to increase the extraction of metals by 10-15%, to obtain highly qualitative finished products, competitive in the world market, to reduce the energy intensity and increase labor productivity by a factor of two to three, to process ores with low content of valuable components and technogenic raw material, to compensate for the deficit of a number of metals (manganese, rare metals), and to improve drastically the ecological situation in mining-industrial regions.

Further development of methods for primary treatment of mineral raw material should be based on fundamental studies of the processes of separation of mineral components (Figure 3).

The main course for developing scientific knowledge in the field of primary processing of mineral and technogenic raw material is a study of the interconnection of structural, substance, and phase compositions, of natural and technogenic raw material with the physical, physico-chemical, and technological properties of minerals, the combination of methods for physico-chemical modeling of the separation of minerals with experimental investigations of the main beneficiation processes, and creation of intergranular breaking theory for mineral complexes and the mechanism of intensive exposure of rebellious ores and technogenic formations.

BENEFICIATION OF MINERAL RESOURCES

Technological mineralogy	Disintegration and preparation of mineral raw materials for beneficiation	*Physical and chemical processes of separation, concentration and processing of minerals*	*Physical and chemical processes for extracting valuable components from natural and technogenic water*

The main course of developing fundamental knowledge is a study of the interconnection of structural, substance, and phase composition of natural and technogenic raw materials with physical, physico-chemical, and technological properties of minerals, combinations of physico-chemical modeling of mineral separation processes with experimental researches of the main beneficiation processes, and creation of theory for intergranular breaking of mineral complexes and the mechanism of intensive exposure of rebellious ores

PRIORITY COURSES

To create a programming-equipment complex and to perform express mineral-technological evaluation of natural and technogenic deposits base on image analysis to give a scientifically substantiated prediction technology for complex processing of ores and coals	*To develop a general theory for intergranular breaking of rocks, energy methods for intensifying strength loss of mineral complexes, and to create new technologies for radiometric beneficiation of rebellious ores*	*To create new ecologically safe processes for complex processing and opening of rebellious ores and beneficiation products based on combined contemporary methods of beneficiation, pyro- and hydrometallurgy, using supplementary energy effects*	*To develop the theory and technology of forming technogenic deposits, new methods for conditioning and purification of technological water, providing additional extraction of valuable components under conditions of a closed ecologically safe system*

Figure 3. Priority courses of studies in the field of economic mineral beneficiation

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