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DEVELOPMENT AND PERFORMANCE OF THE 6 ERM-35/315 SEPARATOR WITH A HIGH INTENSITY MAGNETIC FIELD

R.S. ULUBABOV
The State Institute for the Design of the Processing Equipment, Lugansk, USSR

and

V.I. KARMAZIN
The Mining Institute, Dnepropetrovsk, USSR

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Abstract Design and operational experience with a new rotor high-intensity magnetic separator are discussed.Improved metallurgical efficiency and a greater resistance against the matrix clogging were found to be the main advantages of the new design. Comparison with the Jones separator is outlined.

INTRODUCTION

Electromagnetic high-intensity separators were developed some twenty years ago. The introduction of Jones rotor separators with a ferromagnetic matrix formed by grooved plates, and their application on production scale advanced significantly the beneficiation technology. Exceptional importance in the processing history belongs to the Jones separator DP-317 which enabled various feebly magnetic ores to be beneficiated in high-intensity magnetic fields.

At the end of the seventies, however, it became evident that the Jones separator DP-317 could not ensure efficient separation of ores with complicated mineral composition and fine dissemination (e.g. deposits of Krivoy Rog and Kursk Magnetic Anomaly in the USSR and La Perla in Mexico). There was a need to look for principally new engineering solutions that could be applied in highly efficient separators and which would contribute to a wider extension of the beneficiation technology to feebly magnetic minerals.

DEVELOPMENT OF A NEW SEPARATOR DESIGN

While gaining experience from the operation of separators with grooved plates it became evident that they do not meet some, often contradictory, demands encountered in the treatment of ores that require fine milling, and of the ores containing mixtures of minerals having a wide range of magnetic susceptibilities.

One of these demands is that in order to achieve the efficient recovery of fine particles the width of the gap between the plates that form the matrix should be as small as possible. At the same time, however, the width should be as large as possible to prevent the clogging of the gaps and to maintain high operational reliability.

The gaps in the present separators do not ensure sufficient recovery of weakly magnetic fine particles. At the same time, a decrease of the width of the gap causes a rapid clogging and deterioration of the operation of a separator. This is the reason why the selection of the width of the gap is usually done on the basis of a compromise between the demand to ensure the reliability of the operation of gaps and acceptable recovery.

The practice has shown that, as a result of such a compromise, high reliability of operation is not achieved and, simultaneously, the recovery of fine particles is considerably reduced.

Another contradictory demand arises in the case of beneficiation of minerals with widely different magnetic susceptibilities. To treat such ores successfully, the magnetic field has to be high enough to ensure the recovery of particles with the lowest value of magnetic susceptibility. At the same time, the magnetic field must be low enough so that the particles with higher magnetic susceptibility do not interfere in the separation process. When the magnetic induction is too high, such particles are attracted to the plates in upper sections of the gaps as soon as the pulp enters the matrix. Matrix blockage and restriction of normal flow of the pulp then follows. As a result, throughput of the separator is reduced and the grade of the magnetic product decreases.

The scheme of a parallel feed on upper and lower rotors, as employed in Jones separators, proved to be correct, particularly when treating coarse ores. The matrix height, as used in one rotor was found to be sufficient. In order to separate finely ground ores, however, such a height is not adequate; scavenging separators must be installed. This requires additional floor space and auxiliary equipment which in turn results in growing capital and operational costs. The same condition exists for magnetic field of the Jones separators. It is usually sufficient for the treatment of coarse ores and insufficient for efficient recovery of fine minerals.

As a result, it is necessary to install additional scavenging separators with negative consequences, as shown above, or to remove fine particles from the ore, which results in a decrease of the yield of the concentrate.

Separators of new generation do not have the above-mentioned disadvantages. It became possible, as a result of the development and the application of fundamentally new technical approach to the design of the separator.

An increase in the width of the gap between the plates

To eliminate one of the main contradictory demands on rotor separators, it was proposed to pass the pulp through the gaps in the form of a film, along the plate surfaces only. Central sections of the gaps would thus be free of the pulp. With such an approach, the favourable conditions to recover fine magnetic particles are determined by the thickness of the pulp film on the surface of the plate, and not by the distance between the plates. This distance does not affect a lateral displacement of the ore particles; it is chosen in such a way that the clogging be eliminated. The width of the gap can thus be large enough.

Figure 1 demonstrates the influence of the width of the gap on some metallurgical parameters. Curves 1 are based on the results obtained with the Jones separator and were provided by Jones Ferro Magnetics and KHD Humboldt Wedag AG. Curves 2 were constructed according to the data obtained by the design engineers of the separators with the film mode of the pulp flow along the plates. Taking into consideration that these studies were carried out using ores that differ considerably in iron content, the right-hand section of Figure 1 shows the changes of relative values of the iron recovery (the recovery results with 1.8 mm gap are taken as 100 per cent).

This diagram illustrates principally different character of the effect of the width of the gap on the beneficiation parameters as obtained in a conventional (Jones) separator and a separator using the film mode. The film mode permits to increase considerably the width of the gap which results in relatively a small decrease in the iron recovery. It can be seen from curves 2 that the 4 mm gap can be used in separators working in the film mode. This is the main advantage of this type of the film flow since each additional millimeter of the width of the gap increases many times the reliability of the operation of the separator.

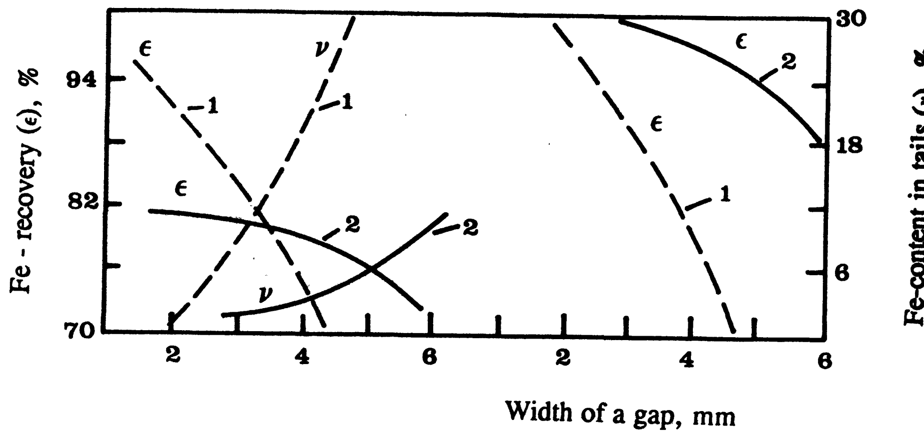

FIGURE 1 The influence of the width of the gap between the plates on the parameters of beneficiation

New ferromagnetic matrix

This matrix is designed in such a way that the gaps are formed by the plates with inclined grooves; the plates forming the gap have oppositely inclined riffles. Table I summarizes the results of the tests with a vertical matrix (Jones separator) and with newly developed inclined riffles, in which case the pulp flows along the plates in the form of a film.

It transpires from these results that the new matrix enables us to increase by approximately 25 per cent the throughput of the separator, as a result of corresponding increase of the specific feed rate per meter of the gap length (in the rotor plane), the recovery of iron being the same.

TABLE I Results of the tests using vertical and inclined matrices

Orientation of grooves	Gap width (mm)	Field in gap(T)	Unit load (kg/m)	Fe-recovery (%)
Vertical (Jones)	4	1.25	0.95	86.1
Inclined	4	1.25	1.2	86.1

Additional rotor with reduced magnetic field

Additional rotor with reduced magnetic field, as compared to main rotors, was installed and the scheme with subsequent pulp flow along the rotors in one separator was applied in order to solve the problem of selective separation of minerals with different magnetic susceptibilities. Rotors with magnetic field intensity ranging from 0.3 T to 1.2 T allowed us to remove, from the ore to be treated, firstly the particles with higher magnetic susceptibility in a low magnetic field, followed by the removal of particles with lower magnetic susceptibility in a high magnetic field.

Thus, the clogging of the gaps is eliminated and the high efficiency of the separator is maintained. Figure 2 illustrates the efficiency of the additional rotor with the field intensity of 0.3 T, with grooved plates 200 mm high, as a function of the feedrate.

When processing martite and hematite ores from Krivoy Rog with the iron content of 35 per cent, using the separator with the feedrate of 100 t/h, the additional rotor gives the yield of more than 16 per cent of medium-magnetic product.

The scheme with a subsequent pulp flow is particularly effective when the height of the plates, as used in one rotor, is not sufficient for more acceptable recovery of the magnetics. For instance, in order to upgrade a difficult-to- treat limonite from Lisakovsky deposit (-0.15 mm, 40.9% Fe), as shown in Table II, the total height of the gap, that exceeds several times the gap height of one rotor is required (as can be seen from Table II). The parameters obtained with the 200 mm height apply to the low-intensity rotor.

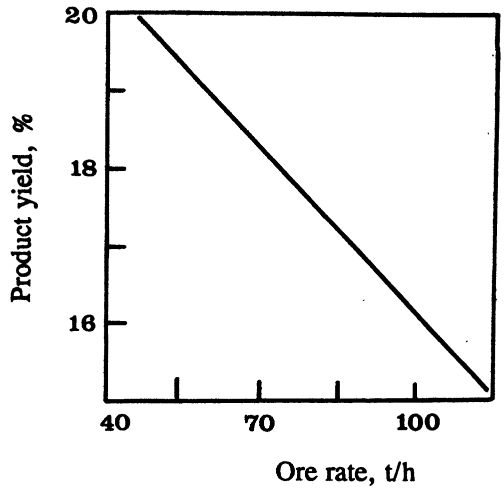

FIGURE 2 The effect of the additional rotor

TABLE II Beneficiation results at different heights of the plates

	Beneficiation indices		
Plate height (mm)	Concentrate yield (%)	Fe-content in conc. (%)	Fe-recovery (%)
200	2.6	48.2	3.0
400	12.5	49.2	14.5
600	26.8	50.3	32.1
800	31.0	30.0	37.6

An increase in the magnetic field

Figure 3 demonstrates the effect of magnetic intensity on the beneficiation indices of finely disseminated ore with 34.9% Fe. In order to treat such an ore, magnetic field of 1.2 to 1.3 T is needed. Calculations showed that in order to obtain such a field, the height of the cores of the magnetic system should exceed approximately three times the height of the rotor plates, as compared to 10 per cent excess used in the D-317 Jones separator.

Small cross-section of the core of the Jones separator reduced the mass of the D-317 separator; at the same time, however, it did not allow to increase the field intensity above 0.9 to 1.0 T at 2.5 mm gaps. When designing a new separator the height of the core was increased by a factor of 2.5 as compared to the DP-317 separator. This modification allowed us to increase the field to 1.3 T with a 4 mm gap. The corresponding increase in the mass of the separator is compensated for by a higher efficiency, the main requirement for a processing equipment.

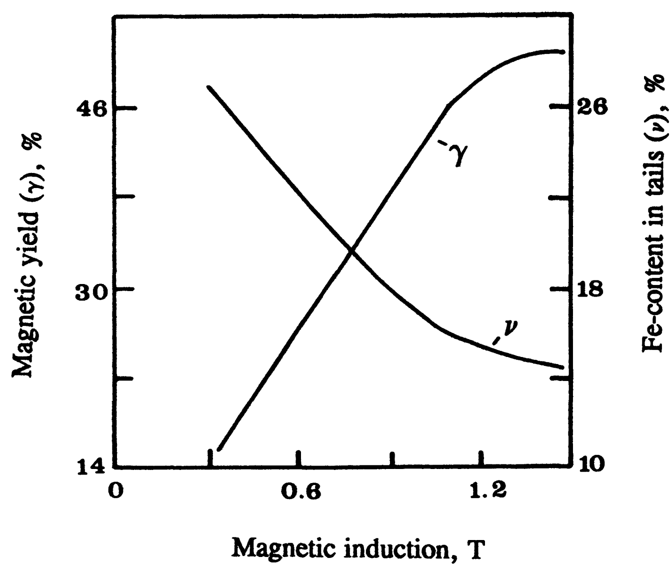

FIGURE 3 The effect of magnetic induction in a gap on metallurgical performance of the separator

THE ROTOR SEPARATOR AS A RESULT OF NEW TECHNICAL SOLUTIONS

The proposed construction of the Krivoy Rog (USSR) mining and preparation plant for oxidized ores (KGOKOR) required a selection of the most efficient magnetic separator to upgrade the difficult-to-treat finely disseminated magnetite, martite and hematite ores. The selection was based on comparative tests carried out with Jones DP-317 separator (Germany) and VMS-100/2 separator (Czechoslovakia).

Another separator used in the comparatory trials was the separator of new generation 6 ERM-35/315 developed jointly by the Institute for Design of Coal Equipment in Lugansk, Krivoy Rog Institute for Research and Design of Processing Machines for Ferrous Metals, Dnepropetrovsk Institute of Geotechnical Mechanics of the UkSSR Academy of Sciences and Dnepropetrovsk Mining Institute.

Description of the design of the separator

Figure 4 shows a principal scheme of the 6 ERM-35/135 separator. The separator has two electromagnetic systems 1; each of them consists of a magnetic circuit 2, of two blocks of coils 3 and of an additional upper pole 4. The rotor block 5 is positioned between the magnetic systems. Drive 7 and two feeders 8 are arranged on frame 6.

The separator is equipped with sprays and product-collecting launders. Block 5 consists of three rotors. Grooved ferromagnetic plates are installed along the circumference of each rotor. The lower and middle rotors are positioned against the cores of the magnetic circuit, the upper rotor is above the magnetic circuit.

This arrangement ensures the variation of the magnetic field from 0.25 T to 0.3 T in the upper rotor to 1.3 T in the lower one. The pulp flows through the feeders into the upper rotor and it then passes through the gaps between the plates. Subsequently, it enters the middle rotor and then the lower one. Minerals with the highest magnetic susceptibility are recovered in the upper rotor, those with the lowest susceptibilities in the lower rotor.

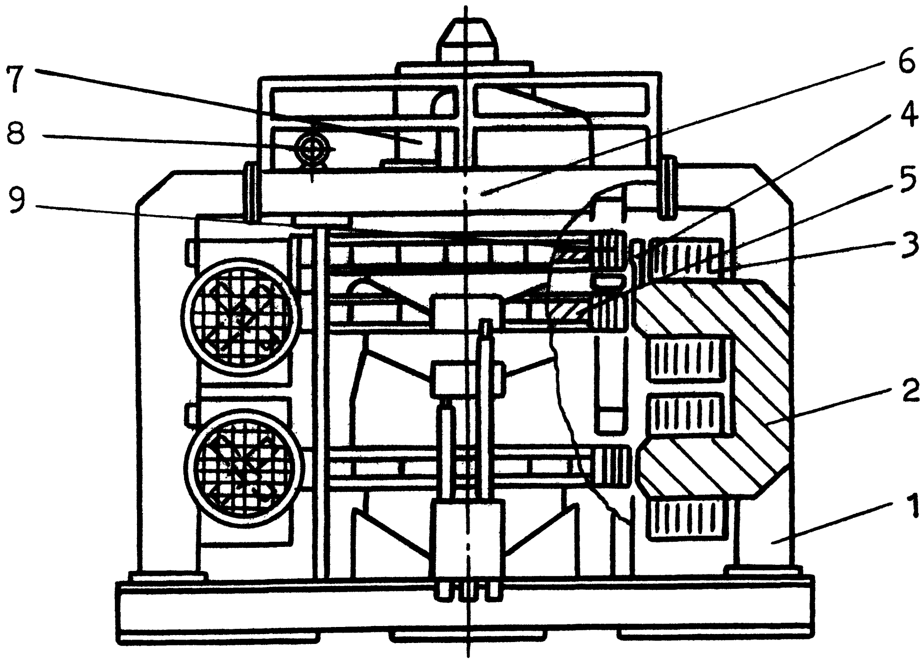

FIGURE 4 Schematic diagram of the 6 ERM-35/135 magnetic separator

Main features of the new design of the separator

The 6 ERM-35/135 separator is the first machine of its kind that concentrates finely ground weakly magnetic particles and generates low-grade tailings using 4 mm gaps between the grooved plates. This width ensures a reliable operation of the separator and considerably facilitates the protection of the gaps against the blockage by oversize particles. The application of wide gaps in the separator is made possible by employing a film mode of the pulp flow. Specially designed feeders and matrices with inclined grooves are used to form the film flow.

For the first time in the world practice several stages with a wide range of magnetic field are used in a single unit. The 6 ERM-35/135 separator and number of its parts were designed on the basis of inventions used for the first time in a magnetic separator.

COMPARATIVE ASSESSMENT OF THE EFFICIENCY OF THE NEW DESIGN

The assessment of new technical solutions implemented in the separator, and their comparison with well-established Jones separator can be made correctly only using a concrete application and comparing the values of beneficiation parameters thus obtained. For instance, in Brazil the feed rate to the DP-317 Jones separator is 120 t/h. The same separator applied to the processing of ores of the Mikhailovsky deposit (USSR) has shown the capacity of 80 t/h only, for two successive separators, or 40 t/h per one separator.

In order to treat the La Perla ore (Mexico), additional DP- 335 Jones separator had to be installed ahead of DP-317. In this case, the recovery of iron by the DP-317 separator is 44.4 per cent only. It is an extremely low value for the head grade of 37.5 per cent.

Assessment of the efficiency of the additional rotor

With the aim to remove martite and magnetite concretions, the auxiliary DP-335 separator having mass of 114 tonnes and capacity of 200 to 250 t/h was installed ahead of DP-317. Throughput per rotor is 100 to 125 t/h and the rotor mass is 57 tonnes, as compared to 10 tonnes for 6 ERM-35/135 rotor having the same throughput.

An account must also be taken of such a factor as energy consumption by DP-335 separator and by a pump station between DP-317 and DP-335. In accordance with approximate estimate, the DP-335 separator requires not less than 50 kW/h per rotor, whereas the additional rotor of the 6 ERM-35/135 separator does not require any increase in energy consumption. It should also be noted that the installation of auxiliary rotor in 6 ERM-35/135 does not require additional floor space, while the installation of DP-335 needs the same floor space as DP-317.

Assessment of the efficiency of a wide gap

The application of a 4 mm gap between the plates in the 6 ERM-35/135 separator improves considerably technological and economic indices of the treatment, as can be seen from an example as shown for Krivoy Rog ore. When testing the DP- 317 model, two separators were used: one with 2.5 mm gaps, the other (retreatment of the non-magnetics from the first separator) with 0.8 mm. The separators operated successively, the concentrate yield amounted to 40.7 per cent.

The testing of the 6 ERM-35/135 separator fed with the same ore resulted in the concentrate yield of 42.6 per cent, i.e. 1.9 per cent higher. The 6 ERM-35/135 separator with a 100 t/h throughput ensures additional production of the concentrate of not less than 15 000 tonnes per annum, that is more than US$300 000 in today's world market price. The real effect will be considerably greater because the operation of the DP- 317 separator with 0.8 mm gap is practically impossible. Should the gaps in DP-317 be wider, the yield of the concentrate would be reduced.

Evaluation of the efficiency of individual parts of the separator

Under the conditions of Krivoy Rog ores, one 6 ERM-35/135 separator with mass of 195 tonnes replaces not fewer than two DP-317 units with total mass of 196 tonnes. Moreover, the 6 ERM-35/135 machine has three rotors, two bearing assemblies, four blocks of coils, one drive and four fans for ventilation. Two DP-317 separators have four rotors, four bearing assemblies, eight blocks of coils, two drives and eight fans.

It can be seen from this comparison that the operation of the 6 ERM-35/135 machine is significantly simpler and will require fewer spare parts. It should be noted that the rotor separators in general have components characterized by low cost, e.g. magnetic circuits in form of steel blocks which are heavy and simple by construction. The cost of magnetic circuits does not differ much from the price of metal from which these blocks are manufactured. The unit mass of the magnetic circuit of the 6 ERM-35/135 separator is 50 per cent compared to approximately 40 per cent for DP-317. Consequently, there are objective reasons to lower the cost and thus to reduce the price of the separator based on technical solution of the design of the 6 ERM-35/135 separator.

Assessment of the technological efficiency and of the economics using raw ore, materials and energy

It is expedient to compare different separators according to their specifications from the point of view of beneficiation technology. As for such parameters as mass and energy, the separators can be evaluated most exactly not by absolute values but by specific ones, referred to one tonne of concentrate.

Table III summarizes the results achieved when testing the 6 ERM-35/135 and DP-317 separators on the same ore. The beneficiation was carried out in two passes. In accordance with the flowsheet, it is required to install, for each pass, one 6 ERM-35/135 separator and two DP-317 separators, the second unit retreating the non-magnetics form the first stage. The auxiliary equipment, such as sumps, pump stations and screens must be installed to transport the non-magnetics between the DP-317 separators. Additional building space and access facilities are needed for this equipment. Their operation necessitates further energy consumption and operational costs.

As can be seen from Table III, the 6 ERM-35/135 separator achieves not only higher recovery of iron and higher yield of the concentrate, but also a higher grade of the concentrate owing to the fact that large gaps can be easily rinsed and the concentrate is, to a minimum degree, contaminated with the tailings.

TABLE III Results achieved in testing martite and hematite ores of the Krivoy Rog deposit

Specifications	6 ERM-35/135	DP-317
Throughput in the 1st pass (t/h)	100	80
Fe-content, % in		
feed to the 1st pass	36.0	36.7
concentrate from the 2nd pass	61.1	59.8
Fe-recovery in the concentrate, %	73.0	66.3
Concentrate yield, %	42.6	40.7
Fe-recovery (by operation), %		
in the 1st pass (-0.074 mm)	82.3	80.4
in the 2nd pass (-0.045 mm)	90.0	78.4
Consumption for the concentrate production		
- ore, t/t	2.35	2.46
- water, m^3/t	6.57	17.74
- energy, kW/t	8.93	20.59
The efficiency of using:		
- the separator mass, t.h/t	8.92	11.20
- floor space, $m^2.h/t$	1.50	2.74

The advantage of the 6 ERM-35/135 separator appears particularly evident when fine particles are treated. For instance, the 6 ERM-35/135 separator achieved, in 2nd pass, the recovery of -0.045 mm particles that was by 11.9 per cent higher than that achieved by DP-317.

The width of the gaps in 6 ERM-35/135 was 4 mm compared to 2.5 mm and 0.8 mm in DP-317. These results confirm the advantage of the film mode of the pulp flow. Depending on the size of particles to be recovered, one can form a film of required thickness and, as a result, to warrant the recovery of fine particles. For this reason, there is no need to use hydrocyclones to remove particles smaller than 0.02 to 0.03 mm from the feed to 6 ERM-35/135, as is the usual practice with DP-317.

In spite of higher mass and energy consumption, the 6 ERM- 35/315 separator is more economical than DP-317 as regards specific consumption of raw mineral, materials and energy per tonne of the concentrate. When determining the energy consumption, the demand for the delivery of the pulp from one DP-317 unit to another, and of the water is taken into account. The 6 ERM-35/315 separator is much more economical in using the mass of the separator and the floor space, per tonne of the concentrate per hour.

The operational experience

The operation of the 6 ERM-35/135 separators and a long-term experience with their servicing have shown that the arrival of a new-generation separator has been long overdue. In Soviet Union, several attempts were made to beneficiate feebly magnetic ores in the DP-317 Jones separators with a gap of 0.8 mm to 2.5 mm, and in 2/2 ERFM-160 separators of Soviet production, with a gap of 1.8 to 2.5 mm.

These attempts cannot be considered successful as the 0,8 mm wide gaps clogged with ore very rapidly. The gaps of 1.8 to 2.5 mm were slightly more reliable, but the clogging by the ore was so frequent that the separators had to be stopped two to three times a month and the gaps had to be manually cleaned. Such a cleaning is tedious and laborious and causes considerable economic damage. The blockage of the gaps leads not only to undesirable shut-downs to clean the matrix but also causes deterioration of the metallurgical performance.

The main reason for the blockage of the gaps was also identified. Practically all feebly magnetic ores contain particles of higher magnetic susceptibility. These particles are fairly well washed off with water in the upper part of the gaps. As the water is moving along the gaps, its pressure drops and some particles are retained in the lower part of the gaps as a result of the presence of stray magnetic field. Consequently, gradual clogging of the gaps develops upwards.

This effect is absent in separators with wide gaps and with additional low-intensity rotor. Separators with 4 mm gaps do not require the shut-downs for cleaning, except for cases when, as a result of operational errors, the particles whose size is equal or greater than the width of the gaps enter the separator. Even in this case, however, the reliability of the separator increased considerably, as it is easier to achieve the reliability of the operation by removing the 4 mm particles rather than the 2 mm ones.

Modifications of the separator

Various modifications of the separator with capacity ranging from 2 to 100t/h were designed and manufactured. These modifications can be used to treat efficiently not only the iron ores, but also chromite, apatite, manganese, rare earth feebly magnetic ores as well as quartz-feldspar and other similar materials. All separators are characterized by wide gaps between the grooved plates and by a film mode of the pulp flow.

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R.S. Ulubabov is a mining engineer, with main interest in electromechanics. Since 1961, he has been employed by the State Institute for the Design of the Processing Equipment, in Lugansk. He is the chief designer of magnetic separators for mineral beneficiation. R.S. Ulubabov designed, developed, built and tested a variety of magnetic separators: low-intensity machines for heavy media recovery and for regeneration of cooling oil, for dry separation of fine magnetite ores, high-intensity and high-gradient magnetic separators for quartz purification and for the recovery of weakly magnetic minerals.

V.I. Karmazin received the CSc (PhD) degree in engineering in 1938 and the D.Sc. degree in 1958. In 1938 he was appointed an associated professor in the Dnepropetrovsk Metallurgical Institute and in 1958 he became a professor in the

Moscow Mining Institute of the Academy of Sciences of the USSR. From 1945 to 1957 he was employed by the Krivoy Rog Mining Research Institute as the head of the ore-dressing division. In 1957 he was appointed a deputy scientific director of the Institute Mechanobrchermet. In 1962 he was appointed the head of the Department of Mineral Processing of the Dnepropetrovsk Mining Institute. Since 1973 he has been a professor and a chief scientist at the above department and is involved in the development of environment-friendly techniques of coal treatment and minerals processing, with main emphasis on magnetic and electrical separation. Professor Karmazin is an author or co-author of 12 textbooks and of numerous papers, conference reports and patents. Since 1967 he is an editor-in-chief of "Obogascheniye poleznih iskopeamih" published by the Ukrainian Ministry of Higher Education.

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