Объединение независимых экспертов в области минеральных ресурсов, металлургии и химической промышленности

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Review of modern coal preparation technologies in the world

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Annotation

The purpose of research is a study of new coal preparation technologies.

The object of research is coal preparation technologies, and the equipment for coal preparation.

Geography of research: Russia and the world.

This work is a ***desk study***. As information sources, we used data of the sectoral and regional press, the annual and quarterly reports of issuers of securities, materials of the internet-sites of enterprises engaged in the extraction and enrichment of coal and the manufacture of equipment, of design and engineering companies, materials of scientific articles and conferences.

Telephone interviews with market participants were conducted when working on a report.

The report consists of 6 Sections, contains 176 pages, 39 Figures and 19 Tables.

The **first chapter** describes the existing coal preparation technologies, both well-known traditional ones and new techniques, not so widespread.

This chapter provides information on the key technologies of coal enrichment, gives a detailed description of technologies that are currently used in the world on an industrial scale.

The **second chapter** describes the features of the existing coal preparation practices in the largest coal producing enterprises worldwide. Examples are given of the use of the latest achievements in the coal preparation industry.

The **third chapter** is devoted to the main companies manufacturing equipment for the coal preparation in Russia and worldwide. Brief summaries of companies are given, their contacts, and concentrating plants using their equipment in Russia.

The **fourth chapter** gives a detailed description of the major concentrators in Russia, describing technologies and equipment used at these plants.

The **fifth chapter** describes the basic principles of decision-making on the need and feasibility of construction of new coal preparation plants.

The **sixth chapter** contains information about the Russian expert organizations conducting the qualitative analysis of the coal washability in order to select the optimal technology for its further enrichment.

1. Summary of the existing coal preparation technologies. Current status and prospects

1.1. Gravitational methods of coal beneficiation

1.1.1. Dense media separation

A separation/enrichment in dense media is a process of the gravity concentration in liquids or suspended mixtures having a density intermediate between the densities of the separated solid particles, implemented in gravitational or centrifugal fields.

If an enriched material is loaded into a medium having a density intermediate between the densities of the components to be separated, then particles with a density less than the density of a medium will float, and particles with a density greater than the density of the medium will drown.

The separation in dense media is carried out in a liquid medium or in air suspensions. Dense liquid media used are homogeneous organic liquids and solutions, aqueous salt solutions and suspensions.

A suspension is a slurry in a liquid of finely divided (less than 0.1 mm) mineral particles, which are weighting materials for the medium. In industry, the most common are aqueous mineral suspensions using magnetite as the weighting material.

The coal enrichment/preparation in dense media gives the following final products: a concentrate, middlings and wastes.

The main advantage of the dense medium separation is its high technical efficiency, since the obtained enrichment indicators are close to the theoretically possible.

Currently, there are 70 kinds of designs of industrial dense media devices (separators). Separators are divided into two main types: static and dynamic. Static separators perform a separation of particles larger than 3 mm under a normal gravity, and dynamic separators - of smaller (less than 0.5 mm) particles at an elevated gravity. Static devices contain significantly more media than the dynamic ones, therefore, the residence time of particles is larger in the first type of separators compared with the second type.

In most cases of coal beneficiation, the dense media separation is much more effective than the jigging, but it is a more expensive process and therefore it is used to enrich large coal with a high content of materials of a

similar density or to produce low-ash metallurgical coals.

1.1.1.1. Static separators

There are conical, drum, bath, and combined static separators.

Drum separators with a movable cover are widely used. Such devices are manufactured by the company **WEMCO®** (WEMCO® Dense Media Drum Separator. *A note: the company WEMCO is part of the FLSmidth Group*). Performance of separators can reach 900 ton/h. The great advantage of these devices lies in the fact that all mechanical moving parts are located outside the drum, there are no scoops, chains or other moving parts inside. This significantly reduces a wear caused by abrasive particles of a material, simplifies maintenance and reduces operating costs. Drums are available in different sizes - from the laboratory to a diameter of 5.4 m and a length of 8.1 m for the two- and three-products separation.

A promising device for the enrichment of large coals is the separator of the US company Daniels (the **DANIELS** brand), which belongs to the bath type. (*A note: bath separators have a relatively shallow fixed bath with a moving system of the solids removal*). A separator Daniels is used for coal preparation with a particle size of from 6 to 250 mm. It features a simple design, a low specific power consumption and a low quantity of metal. The inner lining is made of ceramic that ensures the reliability and longevity of operation without major repairs.

The separators Daniels are available in various sizes with nominal capacities ranging from 90 to 590 ton/h for the coming coal and from 235 to 1500 m^3/h - for the coming pulp.

These units are installed on the new concentrators Krasnogorskaya (the Russian Federation, Kemerovo region), Listvyanskaya-2 (the Russian Federation, Novosibirsk region), Krasnoarmeyskaya-Zapadnaya (Ukraine, Donetsk region). The supplier of equipment - the exclusive distributor - is the company CETCO.

Bath separators are also produced by **Peters Equipment Company** (USA).

A popular type of separators for enrichment of coals on the large Russian plant is the rotary type. Separators of the rotary type are machines unloading the sunken product using the rotary elevator, which can be positioned at an angle, longitudinaly and transversely, when the flow of a slurry and an enriched material moves perpendicular to the plane of rotation of the rotary elevator.

In Russia and Ukraine, two-product separators with a vertical rotary elevator SKVP are produced. Manufacturers are ZAO Spetstekhnomash (the Russian Federation, Krasnoyarsk) and Lugansk Machine-Building Plant (Ukraine).

The SKVP separators are designed for enrichment of coal, anthracite and shale particle of sizes of 13-300 mm. They are available in several sizes (Table 1). The most demanded separator SKVP-32 is produced in two versions: a 500 ton/h and 380 ton/h. The separators of 500 ton/h have a receiver equipped with a tray, performing the reciprocating motion in the bath with a slurry and stirring a sunken product, which improves the efficiency and eliminates the desintegration of the slurry throughout the height of a bath.

Table 1. Technical characteristics of dense media separators SKVP

Characteristics	SKV 20	SKVP 32-500	SKVP 32-380
Bath width, mm	2000	3200	3200
Performance for the initial product, ton/h: – when size 13-300 mm; - when size 25-300 mm	 215 270	 400 500	 300 380
Power of electric motors, kW: - of drive units of rotary elevator; - of drive units of revolving arms; - of drive units of a tray	 5.5 2.2 -	 11 (2x5.5) 2.2 4	 11 (2x5.5) 2.2 -
Overall dimensions, mm: - length - width - height	 4,500 4,700 4,100	 7,000 6,400 5,800	 5,900 6,400 5,800
Weight, kg	15,800	32,000	28,500

Source: review of scientific and technical literature

Of interest is the liquid rotary separator DREWBOY (the manufacturer is the Czech company Alta, its site is alta.cz). The wheel diameter is 3,800-550 mm (Figure 1).

Figure 1. Dense media rotary separator DREWBOY (manufactured by Alta)

Source: data of the company

1.1.1.2. Dynamic separators

A dynamic dense media separation was first investigated in 1945 in a conventional hydrocyclone. Large forces acting during a centrifugal separation, successfully separate quite fine particles and create large shearing forces inside the machine, allowing the use of a thin, very stable, but not overly viscous medium. In addition to the cyclone, a variety of devices have been developed such as a modified cyclone.

The lower limit of a size of particles, which can effectively be separated in the system of a dynamic dense medium, rarely depends on the separation unit, and mainly - on the medium of the regeneration system. The minimum size of the effectively separated particles is 0.5 mm.

Essentially, any suitable *cyclone of the DSM type* with the taper angle 20^o may be used for a dynamic dense media separation. The DSM system was the first and remains one of the most widely used in the coal preparation practice. The principle of operation is similar to a conventional cyclone. A feed, suspended in a very thin medium, is introduced to the cyclone, which is ideally installed nearly horizontally, thereby enabling the feed supply to the apparatus at a relatively low inlet pressure, usually from a constant head tank. The optimum diameter of the latter must be 9 times greater than the diameter of the cyclone at the coal processing.

Heavy particles are moved along the walls of the cyclone and discharged through an outlet nozzle (sand), light particles pass through the drain connection (a drain), and a thin medium forms the density gradient inside the cyclone.

Dense media hydrocyclones are used for the enrichment of coal, anthracite and shale of particle sizes of 0.5-6, 6-25 and 0.5-25 mm, as well as to enrich the middlings of size 0.5-25 mm. In some cases the size limit can be increased to 30 (40) mm.

In addition, *cylindric hydrocyclones* (with an enlarged cylindrical portion of the body) are manufactured.

Performance of the hydrocyclone increases with the increase of the inlet section and decreases with decreasing the cross-section of discharge openings. Selecting a size of the sand nozzle, one can change over a wide range the separation density. Performance of the hydrocyclone also depends on the diameter, the length, and the angle of taper.

The use of centrifugal forces, many times greater than gravity, allows increasing the separation density by about 20%.

Advantages of hydrocyclones:

- Simplicity of the device;
- Greater productivity;
- High precision of separation E_{pm}=50-60.

The presence of rotational flows in hydrocyclones helps destroy the structure formation in the suspensions, which makes it possible to enrich smaller and thinner grades of coal (up to 0.15 mm).

A *three-product hydrocyclone separator* comprises two hydrocyclones in series arrangement designed to separate the material into 3 final products (a concentrate,

middlings and wastes) using a single density slurry entering the first hydrocyclone. This distinguishes it from two hydrocyclones in series arrangement, using as a feed the slurry flows from the individual systems of different densities.

The principle of separation in a three-product hydrocyclone is based on the ability of the magnetite suspension to separate in layers in a centrifugal field, whereby the density of the slurry passing from the first to the second unit becomes higher than the density of slurry in the circulation system.

There are also different types of cyclones (separators) with a full cylindrical reservoir.

New coal preparation plants in Russia now install mainly devices Deister and KREBSTM. Hydrocyclones Deister are produced by Deister Conzentrator (USA).

Dense media hydrocyclones Deister are used for the enrichment of coal of the particle size from 0.5 to 60 mm in the magnetite slurry. According to the manufacturer: "innovative design and high quality construction materials of hydrocyclone provide superior performance, long life and minimal maintenance costs." Devices are used for preparation of coals of the difficult and very difficult degrees of washability. These hydrocyclones are available in various sizes with capacities ranging from 50 to 400 ton/h on the original coal and 160 m^3/h to 1,320 m^3/h on the original pulp. They are installed in the new concentrating plants Krasnogorskaya, Listvyanskaya-2, Raspadskaya, Koksovaya, and Krasnoarmeyskaya-Zapadnaya (Ukraine).

Performance of dense medium hydrocyclones KREBSTM (FLSmidth Krebs, Inc.) is in the range of 58-985 ton/h. The thickness of the ceramic lining is 1-1.5 inch. For the preparation of suspensions magnetite of the particle size of 325 mesh is used. These hydrocyclones are installed on the concentrating plant Chernigivskaya koksovaya.

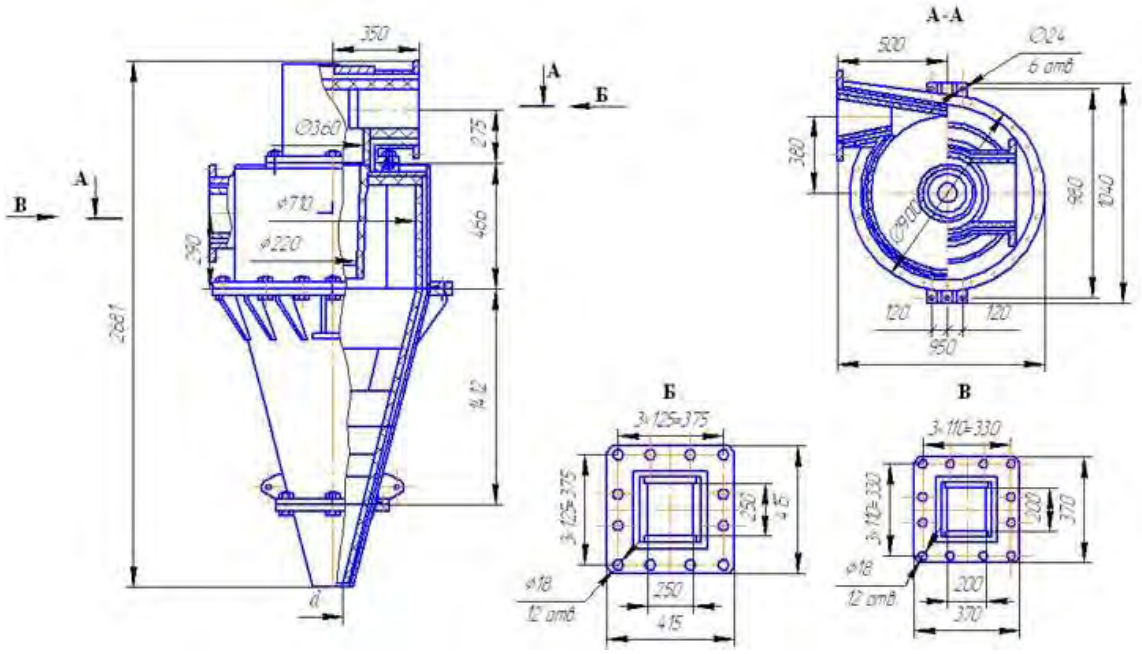
The Russian market also has a production of the company Weir Minerals - dense media hydrocyclones Cavex CVX with the ceramic lining and the prefabricated housing. The diameter of the devices is up to 1,000 mm.

The British company Parnaby Cyclones specializes in the production of hydrocyclones and equipment for washing, classifying, and dewatering. It produces also dense media hydrocyclones. In Russia, these machines are installed on the concentrator Schedruhinskaya.

In Ukraine, dense media hydrocyclones are manufactured by OOO Vostokuglemash. There are available in 2 modifications - GT-630 and 710 (Figure 2).

The cyclone lining is made of polycrystalline monolithic silicon carbide. The size of particles of the separated material is 0.5-40 mm, the density separation - between 1,300 and 2,300 kg/m^3, the fluid temperature - from 1°C to 40°C. Performance on the initial feed is 85-100 ton/h.

Figure 2. Scheme of the dense media hydrocyclone GT-710



Source: data of the company

The disadvantages of the use of dense media hydrocyclones are relatively high operating costs (mainly for electricity and magnetite) and the need for regeneration of the magnetite suspension, which complicates the process flow diagram.

1.1.2. Hydraulic jigging

The **jigging** is an enrichment method based on separation by density of a mixture of mineral grains on a sieve under the influence of a water flow, pulsating with an alternating speed with respect to the sieve.

The size of coal, enriched by jigging, usually is in the range of 100 mm, sometimes it drops to 0.3 mm and increases to 250 mm. Depending on the size of the grains of enriched coal, the following types of the jigging are distinguished:

- Large coal (the size is more than 10 (13) mm, less than 25 mm);
- Fine coal (the particle size is less than 10 (13) mm, or less than 25 mm);
- Broadly classified coal - a joint enrichment in the jigging machine of large and small coal classes, usually 0.5-80 mm, or 0.5-100 mm with pre-classification of raw coal on the upper and lower sizes;
- Ungraded coal - an enrichment in one jigging machine of raw coal without prior classification.

The jigging method is used for enriching coal, anthracite and shales of different washability. Due to the simplicity, flexibility and low cost, the jigging is widely used in the coal preparation industry.

The final products of jigging are usually a concentrate (or mixed masses) and tailings. With a high content of concretions in the starting coals or under stringent quality requirements to concentrate, one can allocate as an individual product a mixture of grains of an intermediate density - middlings.

According to the working principle of the drive, providing a pulsation of water in the enrichment section, jigging machines are divided into *piston, diaphragm, air-pulsation (piston-free)* and *with a movable sieve.*

From all variety of designs of jigging machines for the enrichment of coal, the widest use have air pulsation machines with a side or an undersize location of air-chambers and machines with a movable sieve.

In the last decade, Russian concentrators installed hydraulic jigging machines BATAC® (production of MBE, formerly KHD Humboldt Wedag AG, Germany), machines manufactured by Allmineral, Germany and units produced by Lugansk Machine-Building Plant, Lugansk Electromechanical Plant (Ukraine) and ZAO Spetstekhnomash (the Russian Federation, Krasnoyarsk).

The jigging machine BATAC® is used for enrichment of ores of large, medium and small classes, of a size from 0.5 to 150 mm. The machine performance can vary from 50 to 800 ton/h with a power consumption of 75-300 kW. One machine can create from 1 to 3 density separations, i.e. these units many be manufactured for the processing of two, three or even four products.

The Technical Center of the company MBE Cologne shows the pilot jig BATAC®, providing for the needs of the customer the test of samples to determine the optimal parameters of jigging for the best results with a different composition of a feed.

Jigging machines with a movable sieve ROMJIG® of the MBE production are not used in Russia. ROMJIG® is designed to enrich the coal of large factions and is used for the separation of rock and raw coal of the lumpiness from 30 to 350 mm. The

machine capacity may be from 100 to 400 ton/h at a maximum power input of 110 kW.

The ROMJIG® machines operate on the concentrator Tunliu (China). Three ROMJIG® machines allowed to increase the capacity of the plant compared to the design by more than 400 ton/h. The jigs ROMJIG®, unlike the jigs BATAC®, have ascending and descending streams of water coming through the movable frame supported on the outside by a jig tray and controlled by hydraulic cylinders.

Also, Russian coal preparation plants buy jigs alljig® of production Allmineral Aufbereitungs-technik GmbH & Co. KG (Germany).

Russian concentrators are well familiar with jigging machines of production of Lugansk machine-building plant and institute Gipromashugleobogaschenie (Ukraine), and the Rostov plant "Vostok" of series MO.

Examples of operation of jigging machines on modern Russian coal preparation plants:

1. The concentrator Severnaya uses a three-product jigging machine of production of Allmineral (Germany). The machine works on the class size 0-75 mm of an unclassified material. There are two end products: a concentrate and wastes (middlings join the waste).

During design works the experts of the enterprise considered jigging machines of two well-known manufacturers in Germany - Allmineral and Batac. As a result of comparison of their performance, the jig of Allmineral was chosen.

During the operation of the concentrator, OAO Sibniiugleobogaschenie performed research on the development of a standard for coal losses from the tailings. Basic losses of coal of the class 2-75 mm accounted for 0.6%, indicating a high efficiency of operation of the jigging machine

2. The concentrator Antonovskaya uses the two-product jigging machine of Allmineral (Germany). The machine works on the class size 3(2)-75 mm. The scheme involves the cleaning depth of coking coal to zero with the dewatering all classes of enrichment products only by mechanical means, without the use of a thermal drying.

3. The concentrator Listvyazhnaya uses one jig of Batac, Belovskaya - 4 such units, Ziminka - 1 unit, the Bachptsky quarry - 1 unit;

4. The second stage of the mine named after Kirov (OAO SUEK-Kuzbass) installed the jig of Batac of capacity of **800 ton/h** (2013). This machine is considered the largest in the world. The old installation uses the jig MO-318 (the capacity 450 ton/h);

5. The concentrator Komsomolets (OAO SUEK-Kuzbass) operates the upgraded jig MO-318 (Ukraine).

1.1.3. Air jigging

As noted above, new generation plants mainly use the wet enrichment methods. Despite their efficiency, they have several disadvantages. The use of wet methods of enrichment requires:

- Construction of heat-insulated buildings to work in the winter season;
- Additional equipment for enrichment and dewatering of sludge;
- Significant areas to complete the water-slurry circuit.

An alternative to the wet method is a dry method of the coal preparation and of the enrichment of the diluted rock mass, which does not require expenses for the heating installation of the building, for the dewatering equipment and the water treatment, and thus significantly reduces the cost of processing the rock mass. In the dry (pneumatic) method of enrichment, air moving at a certain speed is used as a separating medium. The pneumatic enrichment is carried out by the air flow, often in combination with a mechanical shaking. As a result, there is a loosening and stratification of the material according to the density and the grain size. Separation of products is performed by moving the forming layers in different directions, or by removing the lower layers through the discharge pockets.

The advantages of the pneumatic enrichment method are:

- Simplicity of the schemes and of enrichment plants in general;
- Low capital cost and cost of the process;
- Lower energy consumption;
- No need for water;
- Production of dry concentration products.

Disadvantages of the air enrichment method:

- The dependence of the separation results on the external moisture of coal and its washability;
- Relatively high inaccuracy of separation as compared with wet processes.

As a result, the air enrichment method has a limited use, mainly for the enrichment of brown and easy coals, as well as in areas with a water scarcity and in northern areas.

Air separators and ***pneumatic jigging machines*** are produced. The feature of pneumatic jigs is a sequential separation and unloading of separate layers of a bed from above and below. The air separator performs a gradual separation of the layers on the entire surface of the working area, and unloading products from the peripheral deck areas.

In the 70-80's of the last century in the Soviet Union there were about 80 units of the dry processing represented by commercially available separators SP-12, SP-6, OSP-100, SPB-100(40) M, as well as about 30 pneumatic jiggs POM-2A, which enriched brown coals and oil shales.

At that time, 13 concentrators and 10 enrichment units were in operation, which annually processed more than 30 million tons of coal, or about 8% of all enriched coals of the Soviet Union.

The separators enriched coal of the size 6x75(50) mm, and jigs enriched small classes 0x13(25) mm.

In recent years, the Russian press reported about the pneumatic separator "Sepair" (Novosibirsk, ZAO Gormashexport /OOO Promobogaschenie) and separators FGX (China). Lugansk Machine-Building Plant manufactures a pneumatic vibration separator SVP-5.5x1.

Note 1: The separator "Sepair" implements the principle of separation of products in density in an upward flow of air produced by the nozzle, which is located above the perforated cloth. The high efficiency of the process is ensured by the fact that at the time of separation there is the two-stage separation for a given boundary of the density for each individual grain of a processed material. Tests of "Sepair" were held using coals mined in the quarry Bungur, the mine Kusheyakovskaya and the mine Erchim Thani. When tested in the experiment, the coal fraction of a size up to 13 mm was used. According to the manufacturers, this installation "ensures the effectiveness of the separation of the raw material with a step in density of 0.01 ton/m^3, from 96% and above." In 2008, in the quarry Bunguro an industrial machine started working, produced under the license of OOO Promobogaschenie, designed for processing of 120 tons of coal per hour. During the presentation as a result of the enrichment of coal of the class 25-50 with the original ash content of 26% the obtained product was coal with an ash content of 9%, coal with an ash content of 11.1%, and middling 35% of ash and tailings with an ash content of 78%.

However, further operations showed the inefficiency of this unit. In 2011, the separator was dismantled.

Note 2: The separator SVP-5.5x1 of production of Lugansk Machine-Building Plant for enrichment in air of coal, ores and other materials of a bulk density up to 2.8 ton/m^3 with a surface moisture up to 8%, and of a size up to 75 mm.

It is used for the enrichment of bituminous coal and anthracite in regions with limited water resources, as well as processing of dumps. It allows to reduce the ash content of the starting material to 20%.

Note 3: Separators FGX are manufactured by the group ShenZhou. The Headquarter of the Group is in Tanshan of the province Hebei. The Russian Federation has about 10 units of FGX.

Analysts say that the air technologies have not a widespread in Russia due to the relatively low efficiency of work related to the complexity of finding the optimum operation of the separators, their suitability only for coals of light washability, with a humidity of no more than 6%. In addition, the vortex separators can be used for the narrow coal classes in a feed, and there is a great influence of the shape of pieces on the separation efficiency.

Promising among the "dry" jigging machines is allair®, invented and patented in 2000 by Allmineral (Germany). This company is known on the Russian market as a manufacturer of alljig® jigs for a wet separation. In Russia, these machines are installed in the Kemerovo region in concentrators Antonovskaya and Severnaya. The world has more than 60 machines of a dry jigging allair®. Industrial applications of dry jigging machines Allmineral in the CIS are not yet present, but the pilot units were

used in October and November 2012 to carry out trials on fossil fuels in Kuzbass, on the basis of Kuzbasservis (Myski), and Kazakhstan.

The separation of a material in the jig allair® Allmineral occurs with a pulsing and a constant air supply, and the air distribution is made uniform over the entire area of the deck having an adjustable frequency and amplitude of shaking. The power supply is carried out uniformly by a rotary loader, which provides a stable operation of the machine. The level of the bed rock on the deck is controlled and there is an automatic monitoring of the rock discharge with a control of its density. A determination of the density separation takes place on unloading at the end of the jig, where there is an ash meter, which automatically regulates the work of an unloading mechanism (a star-flap). When a heterogeneous material is received, a star-flap speeds up the unloading of high-density particles. This minimizes the loss of clean coal. All separation operations occur automatically. Upon completion of the process, the dust particles are trapped by a bag filter and, depending on the ash content, are sent to the concentrate or to wastes. The jigging machine allair® Allmineral is designed to enrich coal of sizes up to 50 mm. Maximum throughput depends on the size of the particles of the starting material. Performance of the one-deck installation with a large coal of 6-50 mm is 50 ton/h, and with a fine coal (0-6 mm) - 40 ton/h. Performance of the two-deck machine is 100 and 80 ton/h, respectively..

It is recommended to perform preliminary tests on small units, which fully reflect the efficiency of the industrial process. RPB Kuzbasservis has such a small-sized pilot plant for semi-industrial tests at the facility. There is a two-deck pneumatic jig allair® Allmineral of the capacity of 100 ton/h (the circuit diagram of apparatus is designed by SCETCO).

In conclusion, we can say that a dry dressing is the main perspective direction of processing of a diluted coal supply and its cost is significantly lower compared with wet methods of enrichment. We note again the main advantages of the dry process of enrichment of power coals: the lack of the water consumption, the ability to work in the winter time of the year, the decrease of the volume of transportation of high-ash rock mass, the reduction in capital and operating costs compared to a wet separation process.