To Study Some Characteristics of Porosity of Organomineral Sorbents Obtained by Electroplasmic Processing from Coal Flotation Waste

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Abstract. The article considers the basis for creating organic mineral sorbents with a highly developed porous structure from coal mineral raw materials aimed at developing methods for deep processing of waste coal enrichment - coal cake of the Tugnui coal processing plant by means of electroplasmic activation of its substance, with the development of technology for obtaining carbon sorbents, with the study of their porosity characteristics, the average diameter of macropores for judging the degree of thermal destruction and activation occurring on the surfaces of dispersed cake particles during electroplasmic processing during the implementation of a comprehensive study of coal-mineral raw materials designed to further develop the scientific basis for creating organic-mineral sorbents for wastewater treatment. The article provides microscopic analysis of the composition of the substance of coal-mineral raw materials, data on the composition of minerals included in the substance, determines the composition of the functional groups of cake before and after thermal exposure using IR-spectroscopy, as well as using optical microscopy, studies the porosity of the organomineral sorbent and calculates the average size of macropores.

1. Introduction

When studying the porosity, specific surface area and other characteristics of sorbents, special attention is paid to the fact that adsorption is the basis of numerous industrial operations and scientific research. The most important of them are purification, isolation and separation of various substances, increasing the production of sorbents with a wide range of actions, with the involvement of organic-mineral substances in the production of absorbers. There is no doubt that a significant role among other types of sorbents belongs to carbon materials. Thus, organomineral sorbents based on thermally activated coal-mineral raw materials (coal sludge, cake, coal-mineral pulp) have recently begun to acquire special significance. Important factors in the use of these substances are their selectivity, achieved by the formation of active sorption centers, as well as the possibility of recycling multi-ton dumps [1-7]. It is known that during the extraction of fossil coals, part of them in the process of coal enrichment inevitably goes to waste (coal sludge-cake, pulp). However, the main limiting factor for processing organomineral coal residue into sorbents is its high humidity, sometimes reaching up to
40%. The use of the electroplastic thermal activation method makes it possible to significantly intensify the processes of obtaining a sorbent from a coal-mineral substance associated with its thermodestructive dehydration caused by steam-gas reactions occurring on the surfaces of particles at an exposure temperature of up to 3000 K, which helps to reduce production costs and significantly improves environmental indicators associated with the involvement of secondary raw materials in production, as well as the absence of emissions during its processing.

2. Experiment and installation
To study the process of thermal activation of coal cake, a universal plasma modular installation of a combined type was used, which makes it possible to obtain an organomineral sorbent as a result of electroplastic processing of the cake [8].

The study used a cake without separation into fractions, which was passed through a plasma-chemical reactor with a rotating magnetic field arc (Figure 1). With uniform rotation of the anode spot of the arc between the annular anode and the rod cathode, a continuous plasma medium with an average temperature of 2500-3000 K was formed in the reactor. Due to this, the particles fed from above into the reactor were completely thermochemical treated with plasma. The residence time of the particles in the thermal zone depended on the size of the fraction, and was also regulated by the installation of a diaphragm in the lower part of the reactor, and on average is from 0.1 to 1 sec. The temperature and rotation speed of the plasma were regulated by changing the current of the arc and solenoid power sources. When passing through the plasma zone, all cake particles were treated with plasma, which caused them to dehydrate and form porosity. Solid particles were collected in the lower part of the plasma reactor—a collection of activated sorbent [9].

![Figure 1](image1.jpg)

Figure 1. General view of the installation (a) with the capture of age-old dust and its rotation (b) in a magnetic field.

As already noted, the high moisture content of coal cake makes it impossible to use traditional processes for the production of organomineral sorbents from it. Therefore, the use of electric arc plasma that allows for the thermal activation of cakes is justified not only by the fact that the cost of producing the sorbent is reduced and the environmental indicators associated with the use of waste - coal cake are significantly improved, but also by the very possibility of conducting such processes.

3. Methods and approaches
Due to the fact that coal cake is an organomineral structure with a high content of the mineral part, it became necessary to conduct a microscopic analysis in order to identify the distribution of the organic and mineral parts of the substance that forms its main properties. The study of the mineralogical part of the cake was carried out by the anschlift method. At the same time, the method of infrared microscopy was used, which has a greater selectivity to the absorption of IR radiation by an organomineral substance. Photography was performed using a narrow-band technical infrared filter with a radiation wavelength \( \lambda = 890 \) nm.
Microscopic examination revealed a complex and diverse mineralogical composition of the cake, which makes it difficult to study a number of characteristics. Thus, mineral impurities included: clay shale Al2O3 * SiO2 * 2H2O (mudstone), sand shale SiO2 (siltstone), pyrite FeS2, sulfates CaSO4, carbonates MgCO3, FeCO3, etc. At the same time, the minerals included in the cake are inherently bound, transferred (as a result of metamorphism) to coal from plant organisms, as well as alluvial - caught during the accumulation of plant residues, since only free (trapped in coal during mining) mineral impurities are removed as a result of flotation. Micrographs of particles of the dispersion phase without separation into fractions are shown in figure 2.

![Micrographs of cake particles](image)

**Figure 2.** Micrographs of cake particles (without separation into fractions) a-duren; b - splice vitren + mudstone; c - concretion siltstone + vitren; d - splice vitren + siltstone + pyrite; e - splice duren + siltstone + mudstone + calcite; f - splice vitren + duren + mudstone; g - splice vitren + claystone + pyrite; h - splice vitren + mudstone + siderite.

Analyzing the obtained microimages, it can be concluded that IR radiation, having a greater selectivity of absorption, makes it possible to distinguish not only coal particles (represented mainly by vitren and Duren) and mineral formations, but also coal-mineral aggregates containing the organomineral part. Therefore, based on the conducted microanalysis, it can be argued that the cake substance not subjected to fractional separation is a natural carbon-silicate composition of shale-mudstone-siltstone nature with a high density and developed contact of interpenetrating phases. That is why the physical and chemical characteristics of the cake are determined by the ratio and structure of the coal (shale) carbon and the aluminosilicate component, the strength and development of the interfacial boundary [10-12].

The fact that carbon and carbon-mineral particles have strong absorption in the ultraviolet and visible regions makes it difficult to study their spectral characteristics in these ranges. Therefore, IR-spectroscopy provides an opportunity to reliably study the nature of surface compounds of optically opaque organomineral substances [13, 14].

Infrared spectroscopic analysis was performed using a Nicolet-380 Fourier-infrared spectrometer with a Smart ITR prefix equipped with a diamond window in the wavelength range 4500-400 cm-1. The IR spectra of the coal cake before and after electroplasma treatment are shown in Figure 3. Thus, the bandwidth in the region of 2923.8 cm-1 corresponds to valence vibrations -C-H-bonds in the
aromatic ring and its associated -OH groups. The transmission frequency at 1596 cm\(^{-1}\) refers to the vibrations of the C-O bonds of carboxyl groups and lactones, as well as the condensed aromatic core. The band at 1436 cm\(^{-1}\) can be interpreted as deformation vibrations of the -COOH groups. The minimum transmission (maximum absorption) at 1007 cm\(^{-1}\) is due to fluctuations in -C-O, -C-O-C - and -C-C - bonds, as well as aromatic structures. The frequency at 789 cm\(^{-1}\) can be attributed to deformation vibrations O-C=O, and 685 cm\(^{-1}\) - to out-of-plane vibrations of C-h aromatic bonds. Side frequencies lying in a wide frequency range of 3500-4500 cm\(^{-1}\) correspond to the frequencies of OH-group valence vibrations, and the frequency of 3260 cm\(^{-1}\) shifted to the low-frequency range corresponds to the valence vibrations of NH3+ - groups. Si-O bonds in the silicon skeleton are associated with valence and strain vibrations with bands of 912 and 752 cm\(^{-1}\) [14].

![IR spectra](image)

**Figure 3.** IR spectra of coal cake before (a) and after (b) electroplasma treatment. Experiment parameters: Nicolet-380 IR-Fourier spectrometer, smart ITR set-top box, window: diamond, scan: 32, resolution: 4, wavelength range 400-4500 cm\(^{-1}\).

Thus, the results of spectroscopic studies demonstrate the polyfunctionality of the surface of the organic mineral sorbent from the cake, almost unchanged by electroplasma treatment, which further makes it possible to use the presented functional groups in the sorption of wastewater with a wide range of pollutants. Therefore, the specificity of the composition of coal cake and, as a consequence, its properties make it an attractive and promising material in the processes of sorption treatment of wastewater from organic substances and heavy metal ions.

The study of the degree of thermal degradation and activation occurring on the surfaces of dispersed cake particles during electroplasmonic treatment required the establishment of quantitative dependences of the porosity and average diameter of the macropores of the organomineral sorbent. Porosity analysis and calculation of the average size of macropores were performed using optical microscopy.

Porosity is expressed as a percentage of the total volume of the sorbent. This usually does not take into account such important factors as the uniform distribution of pores in the cross-section plane (in volume) of the substance, the shape and size of the pores [15]. Meanwhile, these data can serve as an additional characteristic of the quality of the cake that has undergone thermal activation. But if the idea of the uniform distribution of pores along the plane of the sample under study and their shape can be obtained relatively simply by ordinary viewing (or photographing) a polished section under a microscope, then reliable determination of the average pore diameter as a value characteristic of a given carbonaceous material or product is a more difficult task [16].

Porous materials (coal-mineral sorbents) are characterized by physical qualities peculiar only to porous media : significant diffusion permeability, low hydrodynamic resistance, filtering capacity, high adsorption properties and developed internal surface, low sound and heat conductivity, etc.
The procedure for determining the true pore size is based on accurate knowledge of the magnification of the microscope. The latter, as is known, depends separately on the magnification of the lens and eyepiece and is determined by the product of these magnifications. For example, the combination of a twenty-fold (X20) magnification of the lens and a ten-fold (X10) — eyepiece gives a total 200-fold magnification of the microscope (20 x 10 = 200). However, this calculation of the magnification of the microscope is approximate and can only be used for general indication of the accepted magnification. To determine the magnification in determining, in particular, the size of the pores, it is necessary to measure them directly under a microscope. For this purpose, an object is used—a micrometer, which is used to determine the price of dividing the ocular scale. The polished section was mounted on the microscope slide table, and the entire section was viewed in two directions using mounting screws. Such viewing made it possible to make a certain judgment about the nature of porosity (the configuration and size of the pores, the uniformity of their distribution, etc.), as well as about the structure of the sample as a whole. This made it possible to select the most characteristic section of the section in order to measure the pores in two directions (along and across) [16, 17]. At the same time, the section of the section that directly fell into the field of view of the eye was still insufficient to determine the average pore size of the sample. It is necessary to measure all the pores — large, medium and small, falling into the area of the section, limited to the maximum possible movement of the slide slide with the help of mounting screws.

The number of pores per unit section surface varies for each sample, so when measuring the pores over the entire section area (within the movement of the slide), the number of measured pores may vary, for example, in the range of 250-14000 [18].

When studying the features of the effect of electroplasma on the processing process and the structure of organomineral sorbents, microslips were made and the porous structure was analyzed using a metallographic microscope. When performing calculations, the price of dividing the eyepiece-micrometer scale was 0.01 mm. When examining the cake section that has undergone plasma treatment, a very large number of small pores are clearly observed (Figure 4).

![Figure 4. Pore surface of cake particles after plasma treatment, magnification X200(a), the particle section at magnification X400 (b).](image)

Therefore, all large and medium-sized pores were measured on a certain area of the section, and then two or three characteristic sections of the section were allocated on the same area, where the total number of small pores (indicating their size) is calculated for a certain number of medium-sized pores available on the same section of the section [16, 18, 19]. This made it possible to calculate the number of small pores based on the number of all measured medium pores.

Tables 1 and 2 show records when measuring pores on the section of an organomineral sorbent sample that has undergone plasma treatment. Based on these data, the average (reduced) pore diameter is calculated, assuming a round pore shape [18-20]:

\[ d = \frac{\sqrt{A}}{\pi}, \text{ units of the ocular scale} \quad (1) \]
where: \( S \) - is the pore area in divisions of the ocular scale; \( \pi \) - 3.14.

Medium and large pores were measured on the most characteristic section of the 100 mm\(^2\) section (table 1).

Since the section has a large number of small pores, the latter were counted on the two most characteristic sections of the section (table 2).

**Table 1.** Size, number, area and large average pore character.

| Characteristics of the section | Pore size (in the division eyepiece scale) | Number of pores of this size, pieces. | Pore area of this size (in the division eyepiece scale) | Pore size (in the division eyepiece scale) | Number of pores of this size, pieces. | Pore area of this size (in the division eyepiece scale) | Number of pores of this size, pieces. | Pore size (in the division eyepiece scale) |
|-------------------------------|-------------------------------------------|--------------------------------------|-------------------------------------------------------|-------------------------------------------|--------------------------------------|-------------------------------------------------------|--------------------------------------|-------------------------------------------|
| Organomer sorbent.           | 29x7                                      | 1                                    | 203                                                   | 25x15                                     | 1                                    | 375                                                   | 30x10                                | 1                                          | 300                                      |
| The structure                | 15x28                                     | 1                                    | 420                                                   | 7x9                                       | 1                                    | 63                                                     | 8x10                                 | 1                                          | 80                                       |
| of the section               | 30x14                                     | 1                                    | 420                                                   | 17x12                                     | 1                                    | 204                                                   | 17x4                                 | 1                                          | 68                                       |
| 7x10                         | 1                                         | 70                                    | 40x12                                                 | 1                                         | 480                                                   | 3x7                                                     | 1                                    | 56                                       |
| 13x17                        | 221                                        | 8x21                                  | 1                                                     | 168                                       | 24x6                                    | 1                                                     | 144                                    |                                           |
| 5x17                         | 85                                         | 13x19                                 | 1                                                     | 247                                       | 25x8                                    | 1                                                     | 200                                    |                                           |
| heterogenous,                | 48x16                                     | 1                                    | 748                                                   | 18x10                                     | 1                                                     | 180                                                   | 39x7                                 | 1                                          | 273                                      |
| eous, 6x17                   | 1                                         | 102                                    | 32x7                                                  | 1                                         | 224                                                   | 8x9                                                     | 1                                    | 72                                       |
| there are                    | 35x8                                      | 1                                    | 280                                                   | 8x18                                      | 1                                                     | 120                                                   | 13x73                                | 1                                          | 169                                      |
| large pores, but of the latter | 12x13                                     | 1                                    | 156                                                   | 47x11                                     | 1                                                     | 517                                                   | 38x10                                | 1                                          | 380                                      |
| are distribute 7x13          | 1                                         | 91                                    | 13x16                                                 | 1                                         | 208                                                   | 12x15                                                   | 1                                    | 180                                      |
| 14x15                        | 1                                         | 210                                    | 11x14                                                 | 1                                         | 154                                                   | 27x7                                                   | 1                                    | 189                                      |
| 10x7                         | 1                                         | 70                                    | 12x11                                                 | 1                                         | 132                                                   | 13x8                                                   | 1                                    | 104                                      |
| dominate by pores of the latter | 13x14                                     | 1                                    | 221                                                   | 15x40                                     | 1                                                     | 600                                                   | 26x14                                | 1                                          | 364                                      |
| with sizes 8x26              | 1                                         | 208                                    | 7x8                                                   | 1                                         | 56                                                     | 11x13                                                   | 1                                    | 143                                      |
| 3*2 and 2*2                 | 12x13                                     | 1                                    | 156                                                   | 32x14                                     | 1                                                     | 448                                                   | 12x20                                | 1                                          | 240                                      |
| 11x31                        | 1                                         | 341                                    | 20x7                                                  | 1                                         | 140                                                   | 15x19                                                   | 1                                    | 285                                      |
| 28x18                        | 1                                         | 504                                    | 21x8                                                  | 1                                         | 168                                                   | 36x14                                                   | 1                                    | 584                                      |
| 28x13                        | 1                                         | 364                                    | 42x16                                                 | 1                                         | 672                                                   | 12x8                                                   | 1                                    | 96                                       |
| 18x10                        | 1                                         | 180                                    | 28x10                                                 | 1                                         | 280                                                   | 6x5                                                     | 1                                    | 30                                       |
| 33x25                        | 1                                         | 825                                    | 26x10                                                 | 1                                         | 260                                                   | 12x24                                                   | 1                                    | 288                                      |
| 49x14                        | 1                                         | 686                                    | 56x10                                                 | 1                                         | 560                                                   | 14x9                                                   | 1                                    | 126                                      |
| 25x8                         | 1                                         | 200                                    | 32x8                                                  | 1                                         | 256                                                   | 4x4                                                     | 1                                    | 16                                       |
| 100x25                       | 1                                         | 2500                                   | 16x13                                                 | 1                                         | 208                                                   | 5x6                                                     | 1                                    | 30                                       |
| 35x14                        | 1                                         | 182                                    | 15x16                                                 | 1                                         | 240                                                   | 3x5                                                     | 1                                    | 15                                       |
| 48x8                         | 1                                         | 864                                    | 8x12                                                  | 1                                         | 96                                                     | -                                                      | 1                                    | -                                        |
| 20x8                         | 1                                         | 160                                    | 12x9                                                  | 1                                         | 108                                                   | -                                                      | 1                                    | -                                        |

In accordance with the data in table 2, the pore area was calculated in two sections:

**Section I** - 37 medium pores with a total area of \( S1 = 688 \) have small pores:
- Size 3x3, \( S = 126 \) number of pores of this size
- Size 3x2, \( S = 132 \) number of pores of this size
- Size 3x1, \( S = 36 \) number of pores of this size
- Size 2x2, \( S = 120 \) number of pores of this size

**Section II** - 15 medium-sized pores with a total area of \( S2 = 715 \) have small pores:
- Size 2x1, \( S = 44 \) number of pores of this size

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Size 1x1, \( S = 70 \) number of pores of this size 70

Next was the average area of medium sized Sm pores of sections I and II and the average number of small pores of sections I and II that fall within this area of the Sm was determined = \((715 + 688)/2 = 702\)

The number of small pores (n) that fall on average on this area:
- Size 1x1, 70/2 = 35 pores;
- Size 2x1, 22/2 = 11 pores;
- Size 2x2, 30/2 = 15 pore;
- Size 3x1, 12/2 = 6 pores;
- Size 3x2, 22/2 = 11 pores;
- Size 3x3, 14/2 = 7 pores.

Table 2: Size, number, area and large average pore.

| Average pore size (in the division. Eyepiece. Scale) | Average pores of a given size, pieces. | pore area (in the division eyepiece. scale) | Fine pore size (in the division. Eyepiece. Scale) | The number of fine pores of this size, pieces | pore area (in the division eyepiece. scale) |
|------------------------------------------------------|----------------------------------------|-------------------------------------------|-------------------------------------------------|-------------------------------------------|------------------------------------------|
| 6x9                                                  | 1                                      | 54                                        | 3x3                                             | 14                                        | 126                                      |
| 3x5                                                  | 4                                      | 60                                        | 3x2                                             | 22                                        | 132                                      |
| 5x5                                                  | 1                                      | 25                                        | 3x1                                             | 12                                        | 36                                       |
| 8x15                                                 | 1                                      | 120                                       | 2x2                                             | 30                                        | 120                                      |
| 8x8                                                  | 1                                      | 64                                        |                                                 |                                            |                                          |
| 4x2                                                  | 7                                      | 56                                        |                                                 |                                            |                                          |
| 6x5                                                  | 1                                      | 30                                        |                                                 |                                            |                                          |
| 4x4                                                  | 4                                      | 64                                        |                                                 |                                            |                                          |
| 5x7                                                  | 1                                      | 35                                        |                                                 |                                            |                                          |
| 4x10                                                 | 1                                      | 40                                        |                                                 |                                            |                                          |
| 4x3                                                  | 9                                      | 108                                       |                                                 |                                            |                                          |
| 4x1                                                  | 3                                      | 12                                        |                                                 |                                            |                                          |
| 5x2                                                  | 2                                      | 20                                        |                                                 |                                            |                                          |
| plot II                                              |                                        |                                            |                                                 |                                            |                                          |
| 6x3                                                  | 1                                      | 18                                        | 2x1                                             | 22                                        | 44                                       |
| 7x2                                                  | 1                                      | 14                                        | 1x1                                             | 70                                        | 70                                       |
| 8x3                                                  | 1                                      | 24                                        |                                                 |                                            |                                          |
| 7x6                                                  | 2                                      | 84                                        |                                                 |                                            |                                          |
| 7x7                                                  | 1                                      | 49                                        |                                                 |                                            |                                          |
| 10x9                                                 | 1                                      | 90                                        |                                                 |                                            |                                          |
| 9x9                                                  | 1                                      | 81                                        |                                                 |                                            |                                          |
| 9x12                                                 | 1                                      | 108                                       |                                                 |                                            |                                          |
| 8x6                                                  | 1                                      | 48                                        |                                                 |                                            |                                          |
| 8x5                                                  | 1                                      | 40                                        |                                                 |                                            |                                          |
| 4x7                                                  | 1                                      | 28                                        |                                                 |                                            |                                          |
| 2x8                                                  | 1                                      | 16                                        |                                                 |                                            |                                          |
| 10x7                                                 | 1                                      | 70                                        |                                                 |                                            |                                          |
| 9x5                                                  | 1                                      | 45                                        |                                                 |                                            |                                          |

Then the total number of small pores was determined over the entire studied area of the section, where 94 pores with a total area of 26056 (ocular scale divisions) were measured. Since these are mainly large and medium-sized pores, the average number of small pores was calculated by drawing up the appropriate proportions:

1) 702 - 35 pores 1x1)
\[ \text{26056} \times 1 \rightarrow 1 = \left( \frac{26056 \times 35}{702} \right) = 1299 \text{ pores;} \]

so \( S = 1 \times 1 \) pores 1299

2) \( 702 - 11 \) pores (2x1)

\[ \text{26056} \times 2 \rightarrow 2 = \left( \frac{26056 \times 11}{702} \right) = 408 \text{ pores;} \]

so \( S \) pores 2x1 = 408 * 2 = 816

3) \( 702 - 15 \) pores (2x2)

\[ \text{26056} \times 3 \rightarrow 3 = \left( \frac{26056 \times 15}{702} \right) = 556 \text{ pores;} \]

so \( S = 2 \times 2 \) pores 2224

4) \( 702 - 6 \) pores (3x1)

\[ \text{26056} \times 4 \rightarrow 4 = \left( \frac{26056 \times 6}{702} \right) = 222 \text{ pores;} \]

so Pores \( S = 3 \times 1 \) 666

5) \( 702 - 11 \) pores (3x2)

\[ \text{26056} \times 5 \rightarrow 5 = \left( \frac{26056 \times 11}{702} \right) = 408 \text{ pores;} \]

so \( S = 3 \times 2 \) pores 2448

6) \( 702 - 7 \) pores (3x3)

\[ \text{26056} \times 6 \rightarrow 6 = \left( \frac{26056 \times 7}{702} \right) = 259 \text{ pores;} \]

so \( S = 3 \times 3 \) pores 2331

Thus, the total number of small pores in the studied area will be: 1299+408+556+222+408+259=3152 pores; and their area: 1299+816+2224+666+2448+2331=9784 ocular scale units.

Therefore, the number of all small, medium and large pores in the studied section of the section will be: 3152+94=3246 pores, with a total area of: 9784+26056=35840 units of the ocular scale. Knowing the total number of measured pores and their total area, the average (reduced) pore diameter was calculated:

\[ d = \frac{A_{\text{sm}}}{\pi} \text{ units of the ocular scale} \]  \hspace{1cm} (2)

where \( S_m = 35840 \) substituting it in the ratio (2) we find \( d = 213 \) units of the ocular scale and, knowing the number of all small, medium and large pores in the studied section of the section (3246 pores), we find dm:

\[ d_{\text{m}} = \frac{d \times k}{m}, \text{ mm} \]  \hspace{1cm} (3)

where \( d_m \) - is the middle (reduced) pore diameter; \( k \) - is the price of dividing the eyepiece-micrometer scale, mm; \( m \) - is the total number of all pores in the studied section of the section. Therefore, \( d_m = (213 * 0.01) / 3246 = 0.000656 \text{ mm} = 0.656 \text{ microns}. \)

4. Conclusion

Thus, the use of electroplasma makes it possible to intensify the processes of cake heat treatment, expand the range of target synthesis products, and improve environmental performance. In addition, the plasma system is reliable and easy to operate [21]. During heat treatment, there is a sharp increase in pore formation, which dominates in the micropore region, this is due to the processes of volatile release, dehydration, opening of closed pores, etc.[9, 12, 18, 20-22]. It should be noted that this method can be used to determine the average pore diameter in sections of organomineral sorbents, as well as other porous and dispersed materials, since most of the listed materials, along with large and medium pores, have a significant number of small pores.

The relevance of the tests is also due to the fact that the methods used to produce products (carbon sorbent) improve the environmental situation in the coal mining region due to both the use of man-made waste-coal cakes, and the creation of carbon sorbents for wastewater treatment on their basis.
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Acknowledgments
The work is executed at financial support of Russian Foundation for basic research (RFBR, project №18-48-030009 r_a).