Research of a possibility of receiving sorbents for a sewage disposal from a wastage of coal preparation factory

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Abstract The paper presents the results of the studies of the structure and porosity of the coal cake processed by electric arc plasma. The main limiting factor in processing of coal cakes sorbents is their high water content. As a result of coal washing, the main share of water introduced into the cake falls on hard-hydrate and colloidal components. This makes impossible application of traditional processes of manufacturing from a cake of coal sorbents. Using the electric arc intensifies the processes of thermal activation of coal cakes associated with thermal shock, destruction and vapor-gas reactions occurring at the surfaces of the particles at an exposure temperature of up to 3000 °C, which increases the title product outlet (sorbent) and thereby reduces manufacturing costs and improves environmental performance. The investigation of the thermal activation zone is carried out in the plasma reactor chamber by thermal imaging method followed by mapping-and 3D-modeling of temperature fields. The most important physical and chemical properties of the sorbents from coal cake activated by plasma was studied. The obtained results showed the possibility of coal cake thermal activation by electric arc plasma to change its material composition, the appearance of porosity and associated sorption capacity applied for wastewater treatment.

1. Introduction

Now the coal sorbent is used in many processes of engineering chemistry. Besides, a sewage disposal is based mainly on adsorption by the absorbent carbon. Hardwood or high-grade coals briquettes-sorbents after carbonization are commonly used for production of sorbents [1].

In extraction of fossil coals, some of them in wet-process coal cleaning inevitably go to waste in the form of so-called highly watered coal cake. The major limiting factor of coal cake processing in sorbents is their high moisture content, and the main share of moisture entered in cake as a result of coal preparation is hardly removable that makes impossible application of such traditional processes of thermal activation as pyrolysis, devolatilization of coal, thermo-briquetting, etc. in production of coal sorbents. One of the perspective directions in this area is using of electric arc plasma allowing intensification of the processes of thermal activation of coal cake considerably related to thermal shock, the destruction and steam-gaseous reactions occur on the particle surfaces at exposure temperature up to 3000 °C. This increases the yield title product (sorbent) and thereby reduces manufacturing costs and improves the environmental performance associated with the use of waste product-coal cake [2].

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The paper presents the results of the studies of thermal activation of the coal cake, processed by electric arc plasma treatment with change in its material composition, the appearance of porosity and associated sorption capacity applied for industrial wastewater treatment.

2. Measurements technique
Because of high moisture content it is impossible to use a coal cake in traditional production process of coal sorbent. Therefore, application of electric arc plasma for thermal activation of the coal cake reduces the cost of production of a sorbent and significantly improves environmental performance.

To study the process of the coal cake thermal activation, the combined plasma modular unit was created to produce coal sorbent by the electric plasma processing [3].

In the experiment, a reagent (coal cake) comes from above through the lid of the reactor into the interelectrode interval where the direct current arch is rotated by the external electromagnetic coil. Continuous plasma environment is formed with a uniform rotation of the anode arc spots between the annular cathode in the reactor with an average temperature of 2500–3000 K. Due to this, particles of the cake given from above to the reactor undergo thermochemical processing by plasma. The thermal activation zone in the camera of the electric plasma reactor was studied by the imaging infrared method for subsequent mapping with model operation of temperature profiles (figure 1) using the high-temperature infrared camera mcs-640 by Luma Spec. Particle residence time in the plasma zone depends on size fractions, and the arc rotation speed which is between 0.1 to 1 second (figure 2). The temperature and the rotational speed of the plasma are generally regulated by changing the power source and the coil current.

![Figure 1. Temperature profiles of the reactor in the range of 1500–3000 °C (a, b) with the map of characteristic lines (c) and creation of a temperature profile (d)](image-url)
Figure 2. The time of the coal cake in the reactor. Area of electric plasma zone (a) with capture of cake dust and its rotation (b) in a magnetic field

In electric plasma activation, in conditions of high temperature generated by rotating electric arc plasma, a thermal shock occurs that results in the release of the colloidal moisture present in the composition of the substance cake and thermal degradation accompanied by the release of volatile substances (flammable gases). Fiery steam and gas products interact with the newly incoming cake particles and the process becomes avalanche. This freed up excess moisture and combustible volatile substances, which loosen the cake particles, making them porous. A part of the mineral in the form of clay minerals softens and sticks together in the agglomerates under the influence of rotating electric arc plasma. It falls together with the heat-treated cake (sorbent) to the camera of the sorbent tank for further removal by sieving. There is an additional sorbent demineralization. This principle of creation of plasma installations will allow reaching the level of industrial production of carbon sorbents [4, 5].

The thermal energy is generated in the rotating arch zone under the influence of gas flow (plasma). This is obtained by thermal influence on the coal dust, with its distribution throughout the volume. Therefore, the power generation area was determined by condition of its uniform distribution. In the calculations of the reactor chamber diameter was taken as reference dimension, and all the basic laws of electric zone expressed through it. This makes it possible to extend the experiment results obtained in low-power reactors, reactors are geometrically similar to high power, and therefore, large diameter cells [6].

The current of the Ip reactor is expressed through the current density carried to a camera sectional area:

$$I_p = \Delta i_p \pi D_k^2 / 4$$

(1)

Current density is $\Delta i_p = 4 I_p / \pi D_k^2 = 1.132$ A/cm$^2$.

Tension of the Up reactor is represented through a gradient of tension of an interelectrode interval:

$$U_p = E_p D_k / 2,$$

(2)

where $D_k/2$ is an interelectrode gap to which the arc voltage is supplied to determine a voltage gradient (in the reactor with a rod cathode).

Respectively tension gradient $E_p = 2 U_p / D_k = 26.7$ V/cm.

Taking into account expressions for Ip and Up, the formula for reactor power is removed:

$$P_p = U_p * I_p = \pi / 4 * 1/2 E_p \Delta i_p D_k^3 \approx 0.39 E_p \Delta i_p D_k^3.$$

(3)

Reactor power is $P_p \approx 0.39 E_p \Delta i_p D_k^3 = 0.39 * 26.7$ V/cm $* 1.132$ A/cm$^2$ * (15)$^3$ cm$^3 = 40$ kW

As a result of transformations, it is concluded that allocated in the amount of thermal power generation area, which is equal to input electrical power, is proportional to the cube of the diameter of
the chamber, it is also proportional to $\Delta i_p$ and voltage gradient density $E_p$, otherwise bulk power $P_p$, released in the area.

$\Delta i_p = I_d/D_k^2$ determine the size $\Delta i_p$ by models [7] from conditions of technological indexes at high efficiency of installation. Then with the given diameter of the reactor, its size is provided with the choice of current.

3. Experimental results and discussion
At a tentative stage of studying of getter properties of the cake processed by plasma, the change in its element structure before thermal activation was investigated. The research data are presented in tables 1 and 2. The porosity of obtained sorbents was also determined, and analyzes were performed on the lightening capacity and sorption activity in wastewater treatment.

**Table 1. Element structure of a coal cake before plasma processing**

|   | C   | O   | Mg  | Al  | Si  | S   | K   | Ca  | Ti  | Fe  | Zr  | Result |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|
|   | 42.98 | 39.69 | 0.16 | 4.76 | 7.77 | 0.33 | 0.41 | 0.62 | 0.25 | 1.66 | 1.37 | 100.00 |

**Table 2. Element structure of a coal cake after plasma processing**

|   | C   | O   | Mg  | Al  | Si  | S   | K   | Ca  | Ti  | Fe  | Zr  | Result |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|
|   | 48.73 | 34.61 | 0.16 | 4.60 | 7.33 | 0.30 | 0.41 | 0.58 | 0.25 | 1.66 | 1.37 | 100.00 |

Then, the study of a cellular structure of a cake after electric plasma activation was conducted. For this purpose, the thermally activated exemplars were impregnated with luminescent dye to make the contrast with the aim of a clear distinction between particles and boundaries deep pores [8]. Light areas in the image correspond to the pores filled with a luminescent substance, and the dark ones indicate cake particles (fig. 3.). The study of the pore surface of the activated plasma cake was conducted by means of computer 3D-model operations [9].

![Figure 3](image)

**Figure 3.** Example of the coal cake 3D Model before electric plasma processing (a, b, increase in X200). Thermally processed coal (c), model of representation of the volume structure of the scan (d)

Further study of the possibility of technical application of the sorbents processed by plasma for a sewage disposal was carried out. In the course of the analyses, it was noticed that if coal cake processed in electric arc plasma pour into water, there is no washing away. The low leachability of fraction to 1 mm, being the main in fractional composition, is caused by rather high sedimentation speed of particles that is explained by a hydrophilic nature of their surface owing to an inexact dehydration of particles of a cake after thermal activation.

The samples of industrial waste water used for the experiments dealt with the urban CHP, the sampling point is the drain sump. To test the sorption activity was carried out to study the ability of lightening (absorbance) photocolorimetry samples both before and after passing through the sorbent
cakes (fig. 4), and chemical analysis of water by capillary electrophoresis unit "Kapel 105M" by PNDF 14.1.2.3 and PNDF 14.1-95. methods of state environmental control [10].

![Electronic absorption spectra of exemplars of sewage before getter tests.](image)

**Figure 4.** Electronic absorption spectra of exemplars of sewage before getter tests.

The results of studying the clarifying ability showed (fig. 4.) 2-fold decrease in an optical density (A) of the exemplars which passed through activated coal cake, in comparison with initial exemplars of sewage that indicates effectiveness of application of those sorbents.

The following stage of the research included the study of chemical composition of sewage. The samples were tested before and after passing through the column with activated cake. The results of the studies of sewage before cleaning are presented in tab. 3.

**Table 3.** Results of researches of sewage before and after cleaning

| Chemical substance | Without sorbent, mg/l | After passing through a sorbent, mg/l | Cleaning, % |
|--------------------|-----------------------|--------------------------------------|-------------|
| Sodium             | 5.87                  | 1.45                                 | 75.30       |
| Magnesium          | 10.6                  | 7.54                                 | 28.87       |
| Strontium          | 4.21                  | 2.19                                 | 48.00       |
| Barium             | 4.89                  | 0.307                                | 93.72       |
| Calcium            | 78.5                  | 17.1                                 | 78.21       |
| Iron               | 0.08                  | 0.04                                 | 50.00       |
| Chloride           | 4.37                  | 3.04                                 | 30.43       |
| Sulphate           | 93.9                  | 12.1                                 | 87.11       |
| Fluoride           | 0.820                 | 0.392                                | 52.20       |
| Ammonia            | 0.34                  | 0.105                                | 69.11       |

The carried-out tests showed the fitness of the coal cake processed by plasma as a sorbent for purification of the production sewage.

4. Conclusion

Thus, the coal cake, as the final stage of coal washing, is fundamentally suitable to extract the carbon sorbent by method of thermal processing in the electric plasma reactor. The tests are considered relevant since the presented methods improve an ecological situation in the region of coal mining by using technogenic wastage, coal cakes, and creation of carbon sorbents on their basis for purification of the production sewage.

It is also necessary to note that the coal sorbent can be considered as one of production components of coal plasma processing such as synthesis gas and carbon nanoparticle [2, 3, 4, 5, 10].
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