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Development of a grinding device for producing coal powder-raw materials of coal-water fuel

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This article proposes a method for grinding coal based on the use of the energy of a pulsed shock wave resulting from a spark electric discharge in a liquid. The main purpose of the scientific work is the development of an electric pulse device for producing coal powder, the main component of coal-water fuel. The diameter of the initial coal fraction averaged 3 mm, and the size of the resulting product was 250 μm. To achieve this goal, the dependence of the length of a metal rod electrode (positive electrode) on the length and diameter of its insulation is investigated. Various variants of the shape of the base (bottom) of the device acting as a negative electrode are considered, and an effective variant based on the results of coal grinding is proposed. An experimental electric pulse installation is described, the degree of coal grinding is determined depending on the geometric parameters. The optimal characteristics of the obtained coal powder have been established.

1. Introduction

Currently, due to the rapid development of the fuel and energy complex, the volume of solid fuel consumed is increasing annually. When coal is burned at heat-generating stations, solid fuel waste is released, which negatively affects the state of the environment and the entire ecosystem of the planet as a whole [1–3].

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Methods of reducing the concentration of ash in the atmosphere with flue gases include not only the use of ash collectors, but also other methods of reducing harmful impurities through the use of new fuels that are environmentally friendly in terms of physical and chemical composition. This type of fuel can include coal-water fuel [4–7]. The use of these fuels will increase the efficiency of coal combustion, reduce the risk of explosion of fine coal dust and reduce emissions of nitrogen oxides and sulfur into the atmosphere [8, 9].

In thermal power installations, the efficiency of using coal-water fuel significantly depends on its technological and granulometric composition. For coal-fired thermal power plants, the optimal parameter of solid particles of coal-water fuel is 250 μm [10–12].

The main tasks in the production process is the grinding of coal to obtain the coal-water fuel. In the production, ball and vibrating mills of dry or wet grinding are used for grinding coal. These are characterized by multi-stage processing and greater metal consumption [13, 14].

In connection with the above, this paper proposes a method for grinding coal based on the use of the energy of a pulsed shock wave resulting from a spark electric discharge in a liquid, which allows solving a number of problems associated with the grinding of solid materials [15–17]. This method is implemented in the laboratory of "Electric Pulse Technology" of the Karaganda University named after E.A. Buketov.

A distinctive feature when using an electric discharge in a liquid is that the conversion of electrical energy into mechanical energy occurs with the direct transformation of electrical energy into pressure energy of shock waves with a high efficiency of the installation with reliable long-term operation [16, 17].

2. Experimental installation

The experimental installation consists of a power supply unit, an energy storage capacitor (C), an adjustable spark gap (PP), and grinding devices (Fig. 1). The power supply unit is designed to monitor and control the operation of an electric pulse unit, which allows one to set various modes of the grinding process.

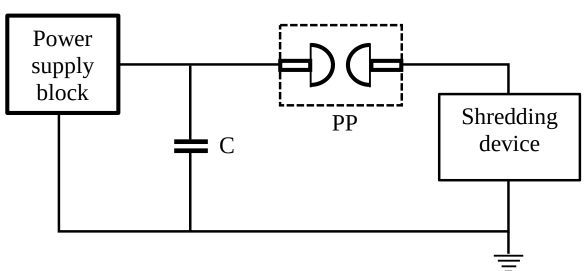
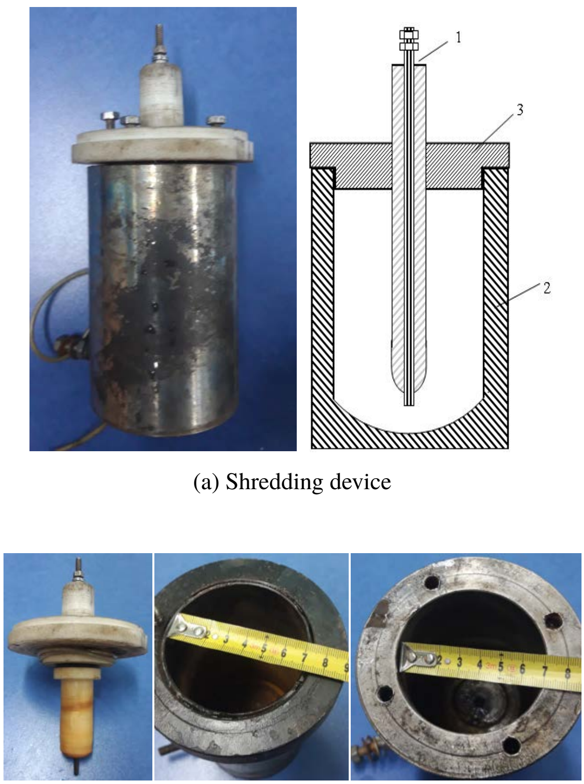


Fig. 1. Block diagram of the experimental installation

The most important element of high-voltage commutation is an adjustable spark gap. This piece of equipment ensures stable operation of the installation in various operating modes, both in voltage and frequency. The need for its use is dictated by the fact that the breakdown voltage of the working medium (technical water) is much lower than the voltage required for the operation of the equipment. When the air gap is broken, a high-density discharge current is applied to the working gap. At the same time, it becomes possible to supply the necessary voltages to the working interval. The operating voltage can be adjusted with the necessary accuracy by increasing or decreasing the air gap in the adjustable spark gap. For this purpose, the electric pulse installation contains a special spark gap with an adjustable interelectrode distance, which is determined by the selected operating mode.

The grinding device contains a cylindrical chamber (Fig. 2), which is equipped with a linear electrode system. The positive electrode is positioned vertically, and the bottom of the metal chamber serves as a negative electrode. When a powerful



(a) Shredding device

(b) positive electrode and metal chambers with an inner surface of a flat and hemispherical shape

Fig. 2. Shredding device: 1 – positive electrode, 2 – cylindrical metal housing (chamber), 3 – non-conductive insulating material

pulse passes through a liquid medium with a wet mass, an electrical breakdown occurs, accompanied by a hydraulic shock of great destructive force.

The discharge channel of the aqueous medium, where a high-voltage electric discharge occurs, is a transformer of the energy released in the discharge channel, which leads to a sharp increase in pressure due to its low compression.

Under the action of electrical impulses, hydrodynamic fluid flows and acoustic waves arise in the treated medium, and cavitation occurs as a result of a local decrease in pressure in the liquid. In this case, the cavitation bubble, moving under high pressure, closes and emits a shock wave. After the bubbles collapse, micro-shocks of cumulative flows appear. As soon as the mixture has received acceleration from the high-speed discharge channel, it moves away from it in all directions. At the beginning of the operation, the discharge channel increases at maximum speed, as the flow proceeds, the cavity of the discharge channel continues to expand due to the inertia of the medium, reaches its maximum size, and then begins to shrink. As the cavity expands, the temperature and pressure in it decrease, and during compression they increase, i.e., there is a damped pulsation of the cavity.

Electric pulse devices, unlike mechanical crushers, have no moving parts, are made of ordinary structural steel, and their body practically does not wear out. During operation, these devices do not emit dust, occupy relatively small production areas and allow grinding, mixing and flotation of materials. The process of electric pulse crushing is easy to automatize, since the maintenance of electric pulse crushers does not require a large number of highly skilled workers. Under the influence of electrical impulses on a solid, the process water is used as a pressure conductor, since it is the most accessible, economical and environmentally friendly environment [18].

One of the most important elements in an electric pulse device for grinding solid materials are working electrodes. The operating mode of the device depends on the design of the electrodes. The main obstacle in the long-term continuous operation of electric pulse devices is the resistance of the working electrodes and the insulation of the electrodes in the case of a pulsed discharge between the electrodes.

The main reason for the destruction of the working electrodes are thermochemical and mechanical effects exerted on the insulation of the streamers that occur in the liquid at the insulation – liquid interface. Firstly, they cause only a weak thermal effect (polymerization of the upper layer of insulation along the insulating path). During further discharge, more streamers pass through these paths, which leads to a change in the properties of the upper insulation layer in these areas. In this way, conduction paths are created, along which random discharges constantly pass, increasing charring that deepens into the insulating housing. When the burn penetrates deep enough into the end surface of the insulation, mechanical factors caused by cavitation shocks that occur when the cavities close begin to affect the insulation of the electrode and lead to the penetration of water jets and particles of the treated material into the insulating housing.

Hydraulic shocks acting on the wedge-shaped opening of the burn cause a mechanical rupture, steaming of its insulation and the formation of new, even more deeply buried burns inside the insulation. As a result, this leads to a gradual "cutting" of the insulation along the entire length of the electrode rod [16]. After the insulation is destroyed, the condition for obtaining ultra-long discharges is immediately violated, losses increase sharply, as a result of which the operation of the electrohydraulic device becomes uneconomical. In this case, the discharges may stop altogether due to a sharp increase in losses, accompanied by an increase in the active surface of the working (positive) electrode.

In order to deal with this problem, the research has been carried out on the design of the optimal version of the working electrode of an electric pulse device for obtaining the necessary raw materials for coal-water fuel.

The function of the negative electrode (2) in the grinding device was performed by the inner surface of the bottom of a metal cylindrical body (diameter d = 70 mm, height h = 150 mm) and a caprolon-insulated rod with a diameter of 5 mm – a positive electrode (1) made of carbon steel grade 30HGSA. The positive electrode was mounted at the top of the device on a bar made of insulating material (3).

3. Analysis of experimental results

In the experimental research, the raw brown coal of the B-3 grade of the Kuznetsky section, located in the Karaganda region of the Republic of Kazakhstan, was taken as the object of the study. The qualitative characteristics of coal were: ash content – 12.71–18%, lower heat of combustion – 4600–4930 kcal/kg, moisture – 16.56%.

In the experimental part, pulse capacitors with a nominal voltage of up to 100 kV, with a difference in capacitance of 0.4 μF (C) (in the amount of 3 pcs) were used. During the experiment, the capacitance of the capacitor bank was: 0.4, 0.8 and 1.2 μF.

The pulse voltages (U, kV: 15, 20, 25, 30, 35) were measured and monitored using a C100 mirror kilovoltmeter, in which the limit of the permissible value of the basic error in the working part of the scale was ±2.0%.

The mass of the feedstock and the resulting product was determined using laboratory scales (maximum load – 1200 g; readability 0.1 g). The mass of the initial product for each experiment was 200 g, and the crushed coal powder obtained by the electric pulse method was sieved through a sieve with a hole diameter of 250 microns (a sieve calibrated in accordance with Test sieves of metal wire cloth. Specifications 51568-99).

The measurement errors were: for the pulse voltage – 3.5%, for the capacitance of the capacitor bank – 2.5%, for the weight of the initial product and the product obtained by the electric pulse method, about 1%.

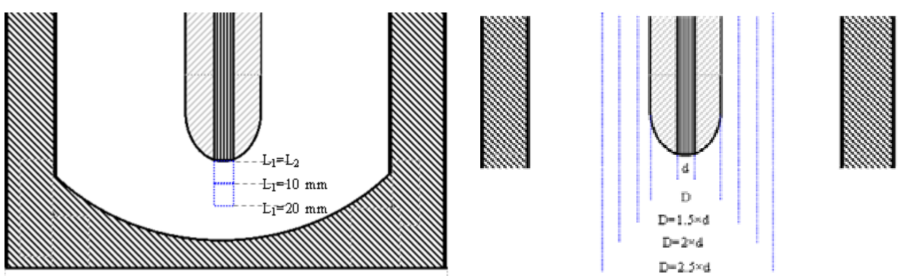
In the course of experimental studies, the dependence of the tip of the working electrode on external insulation was studied (Table 1):

- the dependence of the length of the tip of the electrode (L_1) on the length of the insulating (L_2) material – determined under the condition that the length of the working electrode is equal to the length of the insulation and when the electrode protrudes from the insulation (Fig. 3a);
- the dependence of the diameter of the electrode (d) on the diameter (D) of its insulation (Fig. 3b).

Table 1. Dependence of the diameter of the electrode (d) on the diameter (D) of its insulation

Dependence of the length of the electrode end on the length of the insulating material					
N	300	500	800	1000	1500
$L_1 = L_2$	+	–	–	–	–
$L_1 = 10$ mm	+	+	+	–	–
$L_2 = 20$ mm	+	+	+	+	+
Dependence of the diameter of the electrode (d) on the diameter (D) of its insulation					
N	300	500	800	1000	1500
$U = 15$ kV					
$D = 1.5 \times d$	+	+	–	–	–
$U = 25$ kV					
$D = 2 \times d$	+	+	+	+	+
$U = 35$ kV					
$D = 2.5 \times d$	+	+	+	+	+

Note: "+" – insulation material is not damaged, "–" – insulation material is damaged.



(a) (b)

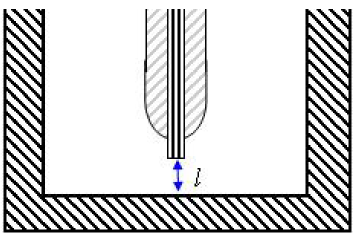
Fig. 3. Working electrodes

The experimental work was performed with a change in the number of pulse discharges from $N = 300$ to $N = 1500$ and the discharge voltage from $U = 15$ kV to $U = 35$ kV. From the data obtained, it can be seen that the electrode and its insulation are stable when the tip of the metal electrode is located on a protrusion of 20 mm from the insulation and the ratio of insulation diameter to the electrode diameter is $D = 2.5 \times d$.

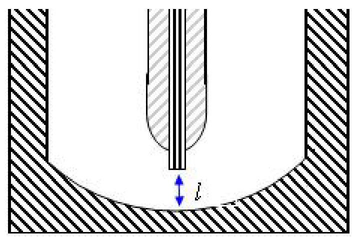
In addition, in order to increase the intensity of the degree of grinding of the material (K, %), the surface of the inner bottom of the metal cylinder, the negative electrode, was made in the form of flat or hemispherical shape (Fig. 4, Table 2).

Table 2. The degree of coal grinding depends on the distance between the electrodes and on the number of pulse discharges in the electric pulse device

Number of pulse discharges	Negative electrode with a flat surface				Negative electrode with hemispherical shape			
	Distance between positive and negative electrodes (l)							
	5 mm	10 mm	15 mm	20 mm	5 mm	10 mm	15 mm	20 mm
	K, %				K, %			
N = 300	9	10.5	13	15	12	14.3	17	19.6
N = 500	13	14.2	15.5	18	15	18.2	21	26.4
N = 800	16	19	22.4	25	19.2	24	29	38
N =1000	22	29	35	42	30	39	52	75



(a)



(b)

Fig. 4. Type of negative electrode with a flat surface (a) and a hemispherical shape (b)

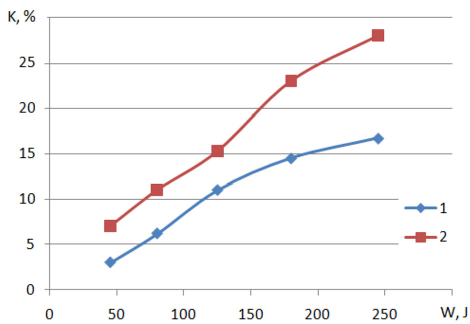
After obtaining the geometric data of the working electrodes, we carried out experimental work on grinding coal using an underwater spark discharge. At the same time, coal with a fraction diameter of 3 mm was crushed to 250 µm with the distance between positive and negative electrodes changing within a interval. The loaded mass into the shredding device was 200 g, and the formation time of pulse discharges was about 0.3–0.4 s.

Coal grinding was carried out at a discharge voltage $U = 30$ kV, capacitor capacitance $C = 0.4$ µF and an increase in the number of pulse discharges from 300 to 1000. The distance between the positive and negative electrodes (l) was changed from 5 mm to 20 mm. According to the results obtained, it was found that with the hemispherical shape of the negative electrode the intensity of coal grinding increases compared to that of the flat shape. It was found that the degree of coal grinding ($K = (m/m_0) \cdot 100\%$, m is the average mass of sifted coal powder from a sieve with a lattice diameter of 250 microns after grinding by electric pulse method, m_0 is the mass of source raw materials) also depends on the distance between the working electrodes. At the same time, optimal results were obtained at

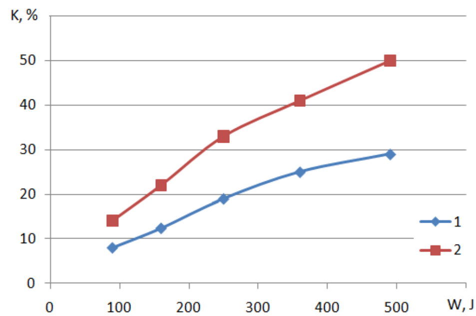
l = 20 mm. A further increase in the distance between the electrodes did not have any positive effect, i.e., the parameter of the crushed material did not change.

Subsequently, we investigated the dependence of the degree of coal grinding on the energy of pulsed discharges (Figs. 5 and 6). The discharge energy varied at different values of capacitor capacitance and discharge voltage ($W = CU^2/2$):

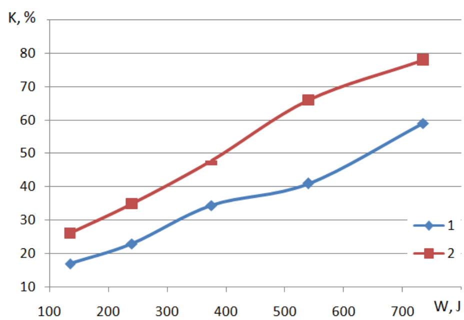
condenser capacity (C, μF) – 0.4, 0.8, 1.2;
discharge voltage (U, kV) – 15, 20, 25, 30, 35;
discharge energy (W, J) – of 45 to 735.



(a) C = 0.4 μF, N = 800



(b) C = 0.8 μF, N = 800



(c) C = 1.2 μF, N = 800

Fig. 5. Dependence of the degree of coal grinding on the energy of pulsed discharges: 1 – negative electrode with a flat surface; 2 – the shape of the negative electrode is hemispherical

Figs. 5 and 6 show that as the discharge energy increases, the degree of coal grinding increases. It has been found that the crushing of the material occurs more intensively (at W = 640 J, K = 89.3%) when the negative electrode of the device has a hemispherical shape.

As experimental work shows, the choice of the shape of negative electrodes of this type was based on the formation of an acceptable discharge (ultra-long discharges) between the electrodes located in the liquid. The method for obtaining ultra-long discharges in conductive liquids consists in limiting the active (i.e., in contact with the liquid) area of the positive electrode while increasing the active area

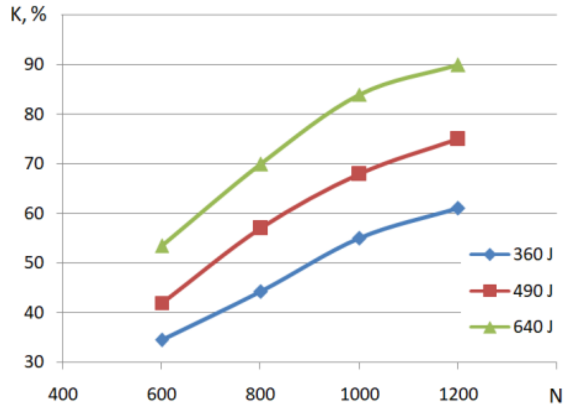


Fig. 6. Dependence of the degree of coal grinding on the number of pulse discharges (the shape of the negative electrode is hemispherical) $C = 0.8$ μF, $U = 30$ kV

of the negative electrode. The method makes it possible to obtain the germination of streamers in conductive liquids (a streamer is a luminous weakly ionized thin channel that occurs in the pre-breakdown stage of a spark discharge in water) for considerable distances. In such a way, one obtains discharges with a long length and a channel surface capable of intensively releasing its energy into the surrounding space [16].

4. Conclusion

In the course of experimental studies, an effective variant of working electrodes was proposed and the degree of coal grinding was determined depending on the parameters of the electric pulse technology. As a result of the research, a product necessary for coal-water fuel was obtained.

The analysis of the results obtained and the conditions of the work carried out contributed to the development of technical recommendations for increasing the intensity of coal grinding. The following optimal parameters for obtaining coal powder with a fraction diameter of 250 μm were determined: $N = 1000$, $C = 0.8$ μF, $U = 30$ kV, $W = 640$ J.

In the future, it is planned to use this method for producing coal powder with a size of less than 100 μm and to study the effect of electric pulse discharges on ash content in the composition of raw materials.

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