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Design of the Electrode System of the Working Channel of the Electric Pulse Installation for Producing Water-Coal Fuel Raw Materials

The article discusses the application of the electric pulse method of coal grinding for obtaining raw materials for water-coal fuel. It is noted that the combustion efficiency of water-coal fuel is largely determined by its granulometric composition, which is traditionally formed using mechanical mills. Despite their widespread use, such systems are characterized by high energy consumption, intensive wear of working parts, and significant operational costs. Therefore, the use of electric pulse discharges as an alternative method of coal disintegration is of particular interest. The study analyses the physical principles of electric pulse grinding, which is based on the impact of short-term high-voltage discharges that cause local micro-explosions, shock waves, and destruction of the material's structure. Special attention is given to the electrode system of the electric pulse installation operating in a heterogeneous "water-coal" environment, including the selection of materials, electrode geometry, and discharge parameters. The design and operating principle of the experimental electric pulse installation are described. The aim of the study is to justify and develop an effective electrode system for the working channel of the electric pulse installation for obtaining water-coal fuel raw materials with minimal energy consumption and increased equipment reliability. It has been established that using the inner surface of the working channel as the negative electrode increases the yield of the finished product with a powder diameter ranging from $D < 0.04$ mm to $D < 0.2$ mm. Additionally, there is a decrease in the size of the coal powder with a diameter of 0.4 mm $< D < 0.7$ mm. The obtained results allowed us to choose the optimal variant of the electrode system in the working channel during the grinding of raw materials using the electric pulse method.

Keywords: electric pulse discharge, high-voltage discharge, raw materials, water-coal fuel, working electrode, carbon powder, disintegration, discharge voltage, yield of the finished product, raw material of water-coal fuel

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Introduction

The use of fuel in thermal power plants significantly impacts their performance, as the correct process and particle size distribution of the fuel facilitates more complete and efficient combustion [1–3]. Water-coal fuel production involves grinding the feedstock coal to the required particle size distribution. Various types of mills, such as ball mills, rod mills, and vibration mills, are used for this purpose. They operate in both dry and wet modes, providing flexibility in the technological process. However, they have certain disadvantages associated with the complexity of the design, high maintenance costs, and wear of the working parts. Wear is particularly sensitive under intense mechanical stress, requiring replacement of parts and increasing costs. In connection with the above, active research is being conducted aimed at developing new methods and technologies for coal grinding [4, 5].

From a scientific point of view, there is a number of experimental studies on the use of electric pulse discharges for grinding raw materials and subsequent production of powdered materials. This technique is based on the application of high-voltage short-term discharges, which create powerful electromagnetic pulses that can induce extreme conditions in the material, such as rapid heating, expansion, and intense mechanical stress. During this process, local microexplosions are created within microscopic pores and structural defects in the material, leading to the destruction of aggregates and the separation of particles [6, 7].

Some types of electric pulse crushing devices have certain similarities (in terms of appearance and electrode system), such as an electrode system consisting of a positive and a negative electrode. However, the physical characteristic of electric pulse crushing is the high pulse voltage applied at intervals of 10^{-7} s or

less, which significantly changes the approach to justifying the design and parameters of a high-voltage electrode. Comparative indicators of energy consumption at the initial stage of electrical load allow us to propose electrodes with increased working area and the range of action of electrodes for modes typical of electric pulse grinding [8].

The electrode system of an electric pulse device for coal grinding is the main component of the system that interacts with the electric discharge to form fragments of material in a medium consisting of a mixture of raw materials and processed water. These systems are designed to transmit high-voltage pulses through the coal pieces to break them into small particles. They are typically made of metal alloys that are resistant to electrocorrosion and high temperatures, ensuring reliable operation and a long service life of the device.

The choice of electrode material and geometry is crucial for ensuring stable operation and preventing wear and damage. It is also important to properly position the electrodes relative to the material being processed and adjust the discharge parameters (voltage, frequency, and duration) to achieve optimal results with minimal energy consumption. The purpose of this research is to present an effective electrode system for the working channel of an electric pulse installation for extracting water-coal fuel raw materials.

Materials and Methods

The electric pulse installation consists of the following main components: a control unit for monitoring the unit's operating modes; a generator for converting the input alternating voltage into a constant voltage at the output; a capacitor for storing energy; a protection system for disabling the unit when the capacitor's voltage exceeds the set safe discharge voltage; an ignition gap (forming gap) consisting of two conductive hemispherical electrodes separated by an air gap, designed to generate an electric spark between the conductors; and a working chamber (working channel) for grinding coal [9].

Coal grinding by the electric pulse method is carried out as follows. Pieces of coal mixed with water are placed in the working channel. After the generator is powered by the control unit, the high voltage at the generator output is supplied in parallel to the capacitor. The voltage accumulated on the capacitor increases to a value at which the air space between the hemispherical electrodes in the forming gap spontaneously breaks down. Then, all the energy stored in the capacitor is instantly transferred to the positive electrode of the working channel. Coal grinding occurs under the influence of electric pulse discharges formed between the positive and negative electrodes in a heterogeneous medium, as well as when shock waves are generated in the water by these discharges [10–14].

In order to provide an effective version of the electrode system in the working channel, a metal rod with a diameter of 6 mm corresponding to GOST ISO 3506 was used as a positive electrode. The upper part of the positive electrode was powered by a switching power supply unit, which included a control unit, a pulse generator, a pulse capacitor, and an air-cooled converter gap. The lower part of the electrode was placed in a medium consisting of a mixture of coal and water.

In experimental studies, the preparation of pre-processing material was performed as follows:

- mechanical disassembly of a large piece of coal (Fig. 1);
- extraction of the necessary fractions from pieces of coal;
- determination of the mass of the coal fraction of the required granulometric composition.



Figure 1. Large piece of coal

Mechanical disassembly of a large piece of coal was carried out in a simple way. For this purpose, tools that are widely used in everyday life were used. To dismantle the material, a large piece of coal was placed in a special large-scale container and struck with a mechanical tool from the open part of the container. After

each blow, pieces of coal in the range $d = 13\text{--}28$ mm were separated (Fig. 2, Table 1). To separate the necessary fractions from the pieces of coal, a digital caliper was used, which has the simplest structure, one of the most common measuring instruments and is distinguished by its versatility, high accuracy.



Figure 2. Pieces of coal between 13–28 mm

Determination of the mass of the coal fraction in granulometric composition was performed using electronic scales (maximum load — 1000 g; discreteness 0,001 g). d — in the table is the average diameter of the coal fraction, mm; m is the average mass of the sorted coal fractions, g.

Table 1

Granulometric composition of the original product and mass of sorted pieces

Coal fragments №	d , mm	m , g	Coal fragments №	d , mm	m , g
1	13–28	7.326	26	13–28	6.265
2		7.727	27		7.827
3		6.215	28		6.443
4		6.412	29		6.892
5		6.947	30		7.364
6		8.768	31		7.767
7		6.037	32		6.095
8		7.044	33		6.564
9		7.330	34		8.028
10		7.181	35		6.934
11		6.166	36		6.362
12		6.355	37		8.146
13		7.163	38		7.861
14		7.889	39		7.384
15		8.762	40		7.576
16		8.282	41		8.343
17		7.273	42		8.124
18		8.937	43		7.565
19		7.099	44		8.129
20		6.129	45		6.662
21		6.902	46		6.433
22		6.831	47		6.927
23		7.917	48		8.851
24		6.761	49		7.744
25		6.386	50		6.583

In the work, the sorting of coal fractions in the range of 13–28 mm allows you to determine the yield of the finished product after grinding the studied raw materials in electric pulse technology, select electrical and geometric parameters of the material processing technology, design the structure of the disassembly and grinding device. The mass of the coal fractions was assumed to be approximately the same before processing.

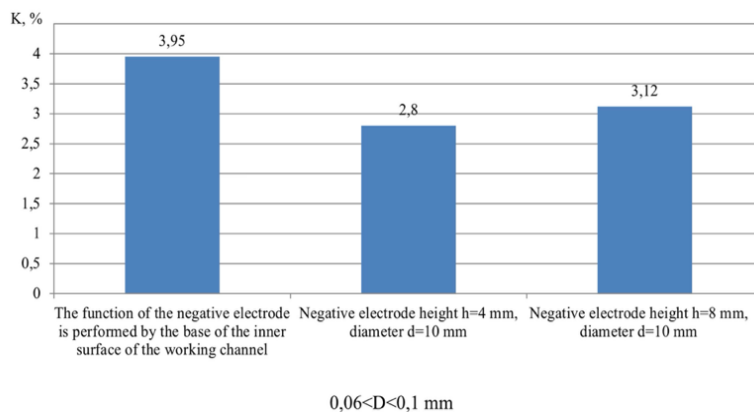
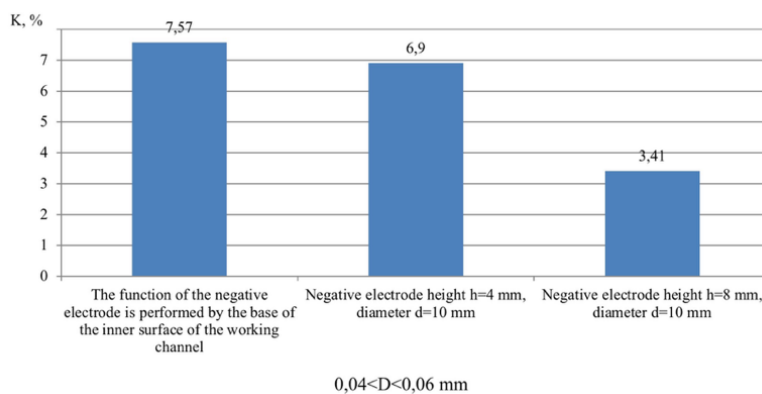
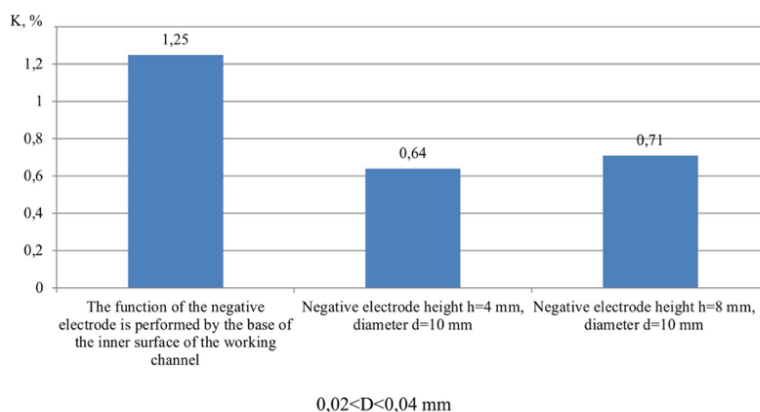
Results and Discussion

For the design of the working channel electrode system, various options for electrodes were considered. The negative electrode was offered in variants such as:

- sole of the inner surface of the working channel made of steel;
- negative electrode height $h = 4$ mm, diameter $d = 10$ mm;
- negative electrode height $h = 8$ mm, diameter $d = 10$ mm.

The tests were performed at the following parameters: pulsed capacitor capacity $C = 0.4 \mu\text{F}$; pulsed discharges formed in the air converter interval voltage $U = 25$ kV, number of pulsed discharges $N = 1000$ discharges (Fig. 3).

After coal crushing works by the electric pulse method, the crushed raw materials were separated from the water and dried. The granulometric composition of coal powder was determined by Standard sieves according to GOST 12536-2014 "Methods for laboratory determination of Granulometric and micro-unit composition". The yield of the finished product was calculated as follows: $K = (m/M) \cdot 100 \%$, where M is the mass of the primary raw material, m is the mass of the powder material obtained by the electric pulse method). The mass of the initial raw materials was constant for each experiment ($M = 100$ g).



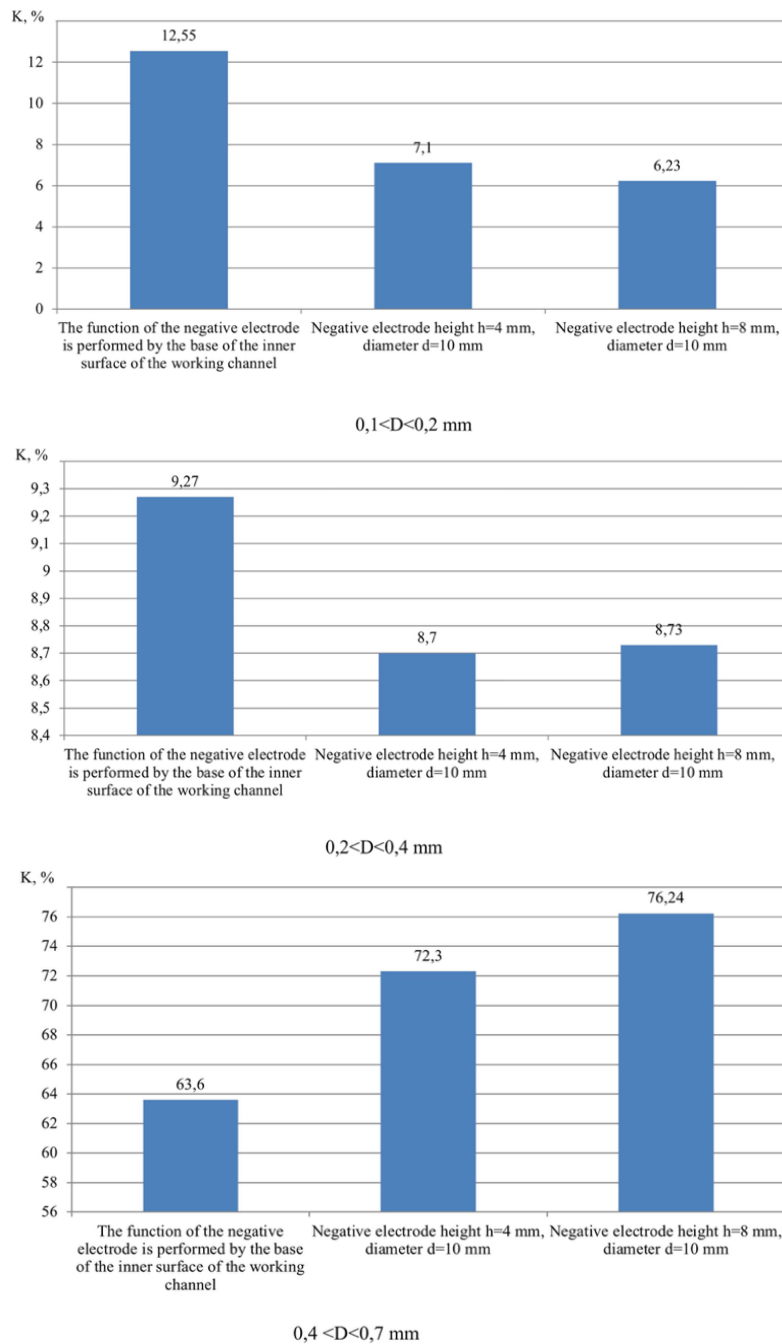


Figure 3. The output of the finished product, which depends on the type of negative electrode in the working channel for crushing coal by the method

From the results of the research, it follows that the yield of the smallest product ($0,02 < D < 0,04$ mm) when the base of the inner surface of the working channel performed the negative electrode function was 1.25 %, for the largest product ($0,4 < D < 0,7$ mm) — 63.6 %. When the negative electrode function was performed by a metal rod with a height of $h = 4$ mm $d = 10$ mm, the smallest coal yield was 0.64 %, the largest — 72.3 %. When increasing the height of the negative electrode $h = 8$ mm, these indicators changed at intervals as follows: 0.71 % for coal powder $0,02 < D < 0,04$ mm, 76.24 % for coal powder $0,4 < D < 0,7$ mm.

Experimental studies show that the configuration of the electrodes is important for the formation of favorable discharges in an environment consisting of a mixture of water and coal. In particular, when creating such a discharge, the active area of the positive electrode is minimized, and the active area of the negative electrode is increased. Such a circuit makes it possible to develop long and extensive electrical circuits—the

so-called ultra-long discharges between the electrodes. The basic idea is that by reducing the active part of the positive electrode (that is, the part where direct contact with the liquid occurs) and simultaneously increasing the area of the negative electrode, conditions are created to maintain a stable long discharge. This change allows the discharge to “germinate” over long distances inside the liquid, and also promotes the formation of thin luminous channels called streamers. These processes make it possible to form discharges with a long length and a significant channel area capable of intensively releasing energy into the surrounding space [11, 15–17].

Conclusion

Coal was crushed under the influence of electric pulse discharges, and the granulometric composition of the resulting powdered product was analyzed. The yield of the finished product was determined and the coal grinding was studied depending on the type of electrode in the working channel for coal grinding using the electric pulse method. According to experimental data, it was found that using the bottom of the inner surface of the working channel as a negative electrode increases the yield of the finished product with a powder diameter from $D < 0.04$ mm to $D < 0.2$ mm. At the same time, a decrease in the amount of coal powder with a diameter of 0.4 mm $< D < 0.7$ mm was observed. The results obtained made it possible to choose the optimal version of the electrode system in the working channel for grinding raw materials using the electric pulse method. Analysis of experimental data has shown that the intensity of grinding of raw materials can be increased using the proposed electrode system. The results of the study can be used in the design of new types of devices that improve the energy efficiency of the technology of electric pulse processing of natural raw materials.

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Көмір-су отыны шикізатын алудың электр импульсті қондырғысы жұмыс арнасының электродтық жүйесін жобалау

Мақалада көмір-су отынының шикізатын алу үшін көмірді ұнтақтаудың электр импульсті әдісін қолдану қарастырылды. Көмір-су отынының жану тиімділігі көбінесе оның гранулометриялық құрамымен анықталады, оның қалыптасуы дәстүрлі түрде механикалық диірмендерді қолдану арқылы жүзеге асырылады. Кең таралғанына қарамастан, мұндай қондырғылар жоғары энергия сыйымдылығымен, жұмыс бөліктерінің қарқынды тозуымен және айтарлықтай пайдалану шығындарымен сипатталады. Осыған байланысты көмірді дезинтеграциялаудың балама әдісі ретінде электр импульсті разрядтарды қолдану ерекше қызығушылық тудыруда. Жұмыста жергілікті микрожарылыстарды, соққы толқындарын және материал құрылымының бұзылуын тудыратын қысқа мерзімді жоғары вольтты разрядтардың әсеріне негізделген электр импульсті ұсақтаудың физикалық негіздері талданды. «Көмір-су» гетерогенді ортасында орналасатын электр импульсті қондырғының электродтық жүйесіне, сондай-ақ материалдарды таңдауға, электродтардың геометриясына және разряд параметрлеріне ерекше назар аударылды. Тәжірибелік электр импульсті қондырғының құрылымы және оның жұмыс принципі сипатталды. Зерттеудің мақсаты минималды энергетикалық шығындармен және жабдықтың сенімділігін арттыра отырып, көмір-су отынының шикізатын алу үшін электр импульсті қондырғының жұмыс арнасының электрод жүйесінің тиімді нұсқасын негіздеу және әзірлеу. Жұмыс арнасының ішкі бетін теріс электрод ретінде пайдаланған кезде ұнтақ диаметрі $D < 0,04$ мм-ден $D < 0,2$ мм-ге дейінгі дайын өнімнің шығымы артатыны анықталды. Сондай-ақ, диаметрі $0,4 \text{ мм} < D < 0,7$ мм көмір ұнтағының мөлшерінің азаюы байқалды. Алынған нәтижелер шикізатты электроимпульсті әдіспен ұнтақтау кезінде жұмыс арнасындағы электродтар жүйесінің оңтайлы нұсқасын таңдауға мүмкіндік берді.

Кілт сөздер: электр импульсті разряд, жоғары вольтты разряд, шикізат, көмір-су отыны, жұмыс электроды, көмір ұнтағы, дезинтеграция, разряд кернеуі, дайын өнім шығымы, көмір-су отынының шикізаты

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Проектирование электродной системы рабочего канала электроимпульсной установки для получения сырья угольно-водяного топлива

В статье рассматривается применение электроимпульсного метода измельчения угля для получения сырья угольно-водяного топлива. Отмечено, что эффективность сгорания угольно-водяного топлива во многом определяется его гранулометрическим составом, формирование которого традиционно осуществляется с использованием механических мельниц. Несмотря на широкое распространение, такие установки характеризуются высокой энергоёмкостью, интенсивным износом рабочих органов и значительными эксплуатационными затратами. В связи с этим особый интерес представляет использование электроимпульсных разрядов как альтернативного способа дезинтеграции угля. В работе проанализированы физические основы электроимпульсного измельчения, основанные на воздействии

кратковременных высоковольтных разрядов, вызывающих локальные микровзрывы, ударные волны и разрушение структуры материала. Особое внимание уделено электродной системе электроимпульсной установки, функционирующей в гетерогенной среде «уголь–вода», а также выбору материалов, геометрии электродов и параметров разряда. Описана конструкция экспериментальной электроимпульсной установки и принцип её работы. Целью исследования является обоснование и разработка эффективного варианта электродной системы рабочего канала электроимпульсной установки для получения сырья угольно-водяного топлива с минимальными энергетическими затратами и повышенной надёжностью оборудования. Установлено, что при использовании внутренней поверхности рабочего канала в качестве отрицательного электрода увеличивается выход готового продукта диаметром порошка от $D < 0,04$ мм до $D < 0,2$ мм. Также отмечено уменьшение размеров угольного порошка диаметром $0,4$ мм $< D < 0,7$ мм. Полученные результаты позволили выбрать оптимальный вариант системы электродов в рабочем канале при измельчении сырья электроимпульсным методом.

Ключевые слова: электроимпульсный разряд, высоковольтный разряд, сырье, угольно-водяное топливо, рабочий электрод, угольный порошок, дезинтеграция, напряжение разряда, выход готового продукта, сырье угольно-водяного топлива

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