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Simulation and experiment of plasma ignition of low-grade coal

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ABSTRACT

A plasma-coal burner is studied utilizing a model of plasma thermochemical preparation of coal for combustion, implemented in the PlasmaKinTherm program. For boiler start-up and coal combustion stabilization, plasma-coal burners do not require fuel oil or gas. The PlasmaKinTherm program combines thermodynamics and kinetics to describe the thermochemical preparation of fuel in the plasma-coal burner volume. The purpose of the simulation was to determine the conditions for plasma ignition of low-grade coal. A numerical study was carried out of the influence of the plasmatron power on the ignition of the air mixture (coal + air). High-ash Ekibastuz coal was used in the calculations. The distributions of temperature and velocity of gas and coal particles and concentrations of products of plasma thermochemical preparation of coal for combustion along the length of the burner were calculated. As a result of the analysis of the processes of plasma ignition of coal, their main patterns were revealed, including the shift of the maximum temperatures and velocities of the products of thermochemical preparation of coal for combustion upstream (towards the plasma torch), as well as the fact that the maximum values of temperatures and velocities of the products do not depend on power plasmatron. At the plasmatron power determined by kinetic modeling, experiments were conducted to test and validate the ignition and combustion conditions for a highly reactive two-component fuel torch. The assumptions made during the development of the mathematical model were confirmed by comparing the calculations with experimental data.

Keywords: coal, plasma ignition, plasma-coal burner, highly reactive two-component fuel, modeling.

1. Introduction

German thermal power plants are being restarted and new natural gas processing facilities are being built despite massive investments in green technologies and renewable energy. A growing number of investments are being made in coal power. The European Union's (EU's) transformation efforts have reached an important milestone with this trend. Despite the best efforts of the fashion environmental agenda, not everything is going as planned. Sustainable and green technologies have resulted in the expenditure of nearly 1 trillion euros. As a consequence, Berlin is switching openly to coal and gas now that its budget has hit rock bottom [1].

Only about a third of global electricity is generated by coal, which is the most carbon-intensive fossil fuel. While most countries are in the process of phasing out coal, it will remain important for metallurgy and power generation. There will be an increase in coal-fired power generation, as well as an increase in CO_2 emissions from power plants by over 2% per year. By 2030, coal power plants must be reduced by an annual average of 10% if net zero is to be achieved. According to the latest data, coal-fired power plants continue to produce electricity at record levels for the second year in a row - around 10400 TWh.

According to the International Energy Agency, the amount of coal used to generate electricity in the Asia-Pacific region increased by about 3% in 2022 compared to 2021 due to extreme weather conditions and high natural gas prices. The number of coal power plants in China has continued to grow, and the nation's coal capacity in 2022 is expected to exceed its current level by 11GW. The energy sector is adopting this strategy because of energy security constraints, current economic benefits, and the tendency to combine modern energy sources with additional variable renewable energy sources. Due to extreme heat, India has increased coal-fired power production. The coal-fired power generation market is expected to grow by more than 8.5% by 2022.

During Russia's ongoing special military operation in Ukraine, the European Union and the United

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Kingdom have again begun to use coal as an additional energy source to improve their energy security. The ongoing global energy crisis have forced the EU to take steps to improve energy security while facing a shrinking gas market and limited fuel supplies. In the UK and some EU countries, plans are being discussed regarding a return to full capacity of coal generation or delaying the date of the closure of coal-fired thermal power plants. Coal-fired power capacity is expected to grow by about 10 GW in the winters of 2022 and 2023 in Germany. It is estimated that EU and UK coal capacity will increase by 15% (19 GW) to 146 GW as a result of the approved plan [2].

Energy efficiency improvements have always been driven by the cost-effectiveness of power generation and growing concerns about CO_2 emissions. Electricity is generated by directly converting the chemical energy of coal into thermal energy and then directly converting this into electrical energy. Thermal efficiency has been improved by minimizing heat losses at low temperatures, reducing the irreversibility of the process of converting coal's chemical energy into thermal energy, and maximizing thermal energy production [3].

It is crucial for power generation to develop more efficient, low-emission coal technologies in order to reduce carbon emissions. In spite of rapid advances in renewable energy and energy storage, fossil fuels will remain a significant component of global energy consumption. A report by the International Energy Agency (IEA) estimates that coal will become the leading source of electricity production by 2040, surpassing all renewables except hydropower. World Energy Outlook, published by the International Energy Agency in late 2016, forecasts the construction of 730 gigawatts (GW) of coal-fired power plants by 2040, mostly in developing nations.

Worldwide, coal-fired power plants have an average efficiency of 33 percent, according to the World Coal Association, which actively supports HELE (High-Efficiency, Low-Emissions). For modern stations, this figure rises to 45%, while for «ready» stations, it is about 40%. By improving coal power plant efficiency by just 1%, CO_2 emissions can be reduced by 2-3% [4].

Coal-fired power plants continue to be a reliable and stable source of energy. The use of new innovative technologies at these stations is becoming increasingly important as a result of modern environmental problems. In addition to reducing harmful emissions, they also reduce the impact on the environment, which is hugely beneficial for human health and the environment. These new technologies are environmentally and economically efficient, which allows us to prevent environmental problems while also promoting the health and wellbeing of people and animals. In order to create an environmentally friendly and sustainable energy system, investing in this area and developing these technologies are essential. Developing plasma technologies in the energy sector can help overcome the energy crisis. In response to the increasing population growth and its standard of living, plasma technology has become increasingly popular and relevant for destroying solid and liquid wastes containing carbon, including toxic healthcare wastes [5-8]. Thermal power plants can be repowered using plasma-assisted combustion to increase combustion efficiency, decrease emissions, and, most importantly, limit unburned fuel [9].

The main goal of coal energy development is to develop new technologies to improve the efficiency of solid fuel use, both environmentally and economically. It is one of the innovative technologies in this field to utilize plasma ignition, stabilize combustion, and burn different types of coal with plasma-coal burners (PCBs). Traditionally, fuel oil and gas have been used in flaring and fire-up boilers to stabilize the pulverized coal combustion. The new system eliminates the use of fuel oil and gas altogether. In plasma ignition and combustion stabilization (PICS), an air mixture containing coal dust and air is heated to the temperature necessary for coal volatiles to be released and coke residue to partially gasify. As a result, in the PCB coal is converted into a high reactive two-component fuel (HRTF) containing combustible gas and coke residue. With effective mixing with air, HRTF ignites and burns sustainably in boiler furnaces without further highly reactive fuel. Fig. 1 illustrates the PCB diagram.

PCB design involves using mathematical and physical models of thermochemical processes involving oxidizers and fuels, as well as heat and mass transfer. Using PICS technology in PCBs has been studied numerically and experimentally to improve environmental and energy efficiency. A comparison is made between numerical simulations and experimental data using thermodynamic and kinetic models [10-12].

2. Kinetic modeling

The purpose of the simulation is to determine the conditions for plasma ignition of low-grade coal. The criterion for stable ignition and combustion of the fuel mixture at the outlet of the PCB is a high content of combustible gases (CO and H_2), above

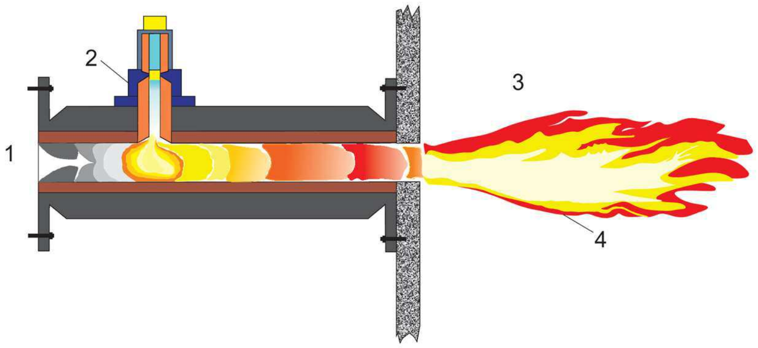

Fig. 1. PCB diagram: 1 – air mixture; 2 – plasmatron; 3 – boiler furnace; 4 – HRTF torch.

15%, and gas heating to a self-ignition temperature (>800 °C) [13]. In PlasmaKinTherm, which was developed using TERRA and Plasma-Coal softwares, a thermodynamic approach is combined with the calculation of thermochemical transformations of primary coal degradation products in the gas phase to determine oxidation of coke residue carbon and volatile release kinetics. A plasma source is used to simulate the flow of coal and air particles in a two-phase reaction channel. Particles and gas are evenly mixed as they enter the PCB (Fig. 1). Plasma flame heats the gas, which heats the particles. As the particles heat up, the kinetic mechanism begins to release volatile substances into the gas phase. Coal particles and ash (mineral mass) are assumed to be isothermal and inert components, respectively, in the model based on one-dimensionality and quasi-stationarity. The particles are also assumed not to interact with one another. When pulverized coal fuel interacts or mixes with plasma, it is heated by a flow of high-temperature gas. In the model, organic and mineral masses make up coal's composition. Coal's organic mass is made up of carbon and volatile substances (CH_4, C_6H_6, CO, H_2, H_2O, CO_2). The kinetics of coal particle heating determines the process of volatile release. When volatile substances are released into the gas phase, a high-temperature gas flow reacts with them. An equilibrium model of local thermodynamics is implemented in TERRA for calculating such reactions in the gas phase. The thermodynamic method was used to calculate high-temperature thermochemical transformations in gas phase of primary coal degradation products based on the oxidation of the coke residue and the kinetics of volatile release.

In the numerical simulation of the PICS process, Ekibastuz coal was used in a straight-flow cylindrical PCB (Table 1). With its 40% ash content, 24% volatile yield, and 5.8% moisture content, Ekibastuz hard coal has a specific heat of combustion of 4000 kcal/kg. According to Table 1, coal has the following chemical composition. Based on the data in Table 2, a model composition for Ekibastuz coal was determined, wt.%: ash content – 40, C – 46.18, H_2 – 2.63, H_2O – 1.84, CO – 3.95, CO_2 – 1.4, CH_4 – 0.55, C_6H_6 – 3.45.

Coal dust consumption was 1000 kg per hour, while air consumption was 1429 kg/h, which implies a dust concentration of 0.7 kg/kg in the air mixture. The concentration of dust in the air mixture required to obtain a HRTF torch in work [13] was found to be sufficient for Ekibastuz coal. An initial temperature of 27 °C is applied to the air mixture and the inner wall of the PCB, which is 3 m in length and 0.15 m in diameter. Calculations were performed for PCB plasmatron power of 40, 60, and 80 kW to determine

Table 1. Composition and technical characteristics of Ekibastuz coal, in mass percentages.

Technical characteristics					
Moisture content per working weight	Volatile matter per combustible weight	Fixed carbon	Ash content per dry weight	Total	Higher calorific value per dry weight, kJ/kg
5.8	24.0	30.2	40.0	100.0	16740.0

Chemical composition											
H	C	S	N	O	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
3.05	48.86	0.73	0.8	6.56	23.09	13.8	2.15	0.34	0.31	0.16	0.15

Table 2. Ekibastuz coal fractional composition

Fraction	Particle diameter, microns	Fraction share, mass. %
1	10	10
2	30	20
3	60	40
4	100	20
5	120	10

PICS of coal. In Table 2, coal dust fractional composition is determined by sieve analysis. 60 microns was the average diameter of coal particles.

Figure 2–6 illustrate the results of the kinetic calculations. In Fig. 2, the gas phase compositions for 40, 60, and 80 kW plasmatron powers are compared along the length of the PCB. The process of ignition occurs for all plasmatron powers (Fig. 2(a), 2(b), and 2(c)). For all plasmatron powers, the curves of the products of plasma thermochemical preparation of coal (PTPC) for combustion are almost the same, but the contents are different. A crucial indicator is the concentration of flammable components ($CO+H_2$). Small-scale extremes of the concentration curves of flammable gas ($CO+H_2$) were observed at the beginning of the channel (0.1–0.4 m): 1.4, 1.4, and 1.6%, respectively, for 40, 60, and 80 kW. At plasmatron powers of 40, 60, and 80 kW, the concentration of flammable components increases with increasing temperature, reaching 18.6, 29.4, and 41.7% at the exit from the PCB, respectively. These concentration values of flammable components significantly exceed the level of their concentration required for stable ignition of the air mixture at the PCB outlet (>15%). The content of harmful gases is important from the viewpoint of the environment. Figure 2 shows a peak in CO_2 gas content at the half length of the PCB at 40, 60, and 80 kW power levels. Compared to traditional burners, these results are much more environmentally friendly.

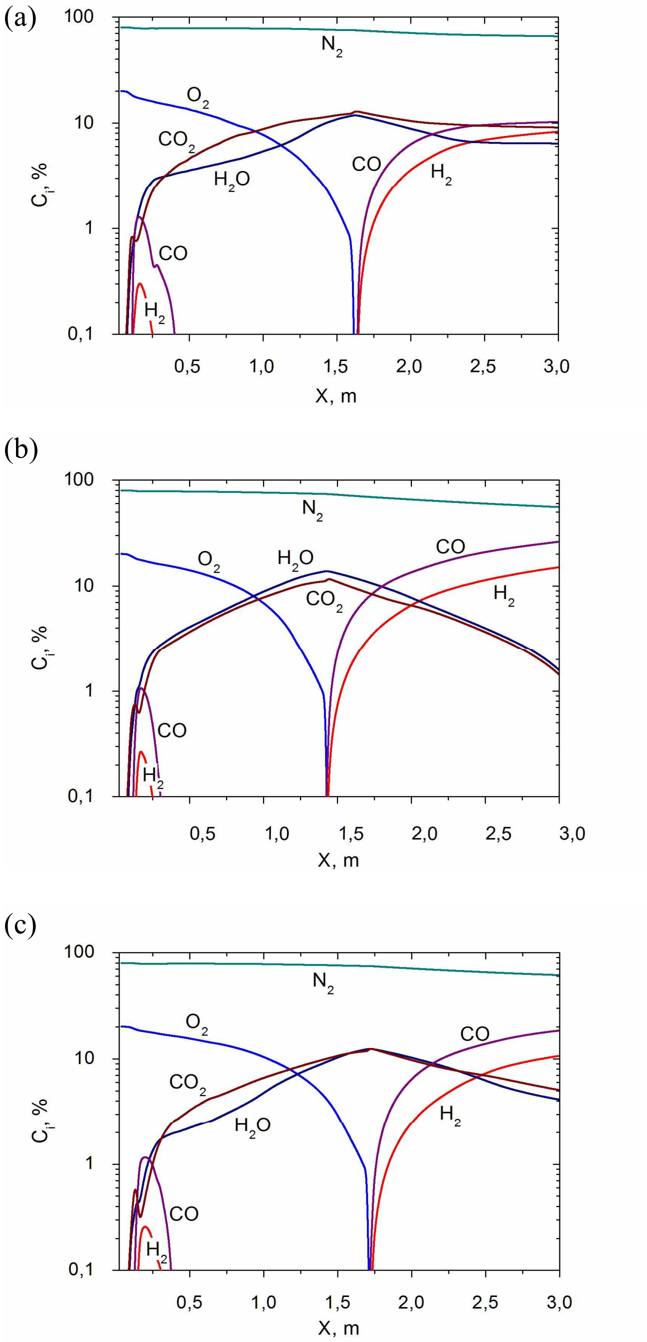

Fig. 2. Change in the composition of the gas phase at a plasmatron power of 40 kW (a), 60 kW (b) and 80 kW (c) along the length of the PCB.

Temperature curves in Fig. 3(a)-3(c) are qualitatively similar. The temperature of the gas and coal particles increases along the length of the PCB. For example, for power 60 kW the gas temperature reaches a maximum (Tg=1849 °C) at a length of 1.38 m, but coal particle temperature does not reach its maximum along the entire length of the flow part (X=3 m), but the fine fraction of 10 μm in size reaches a maximum temperature (1415 °C) at a length of 2.06 m. Except for fractions 1 and 2, the temperature of the gas in the PCB is higher than the temperature of all coal fractions. Temperature differences between gas and particle temperatures at exit from the PCB increase with increasing size of coal fractions (Table 2). Carbon oxidation reaction of large coal particles results in reduced heat release due to the slower heating of large particles compared to small ones. In the exiting PCB, the temperature of particle fractions 1 and 2 exceeded the gas temperature by 11 and 13 degrees, respectively, due to the carbon oxidation reaction on the coal surface. Converging trends in gas and particle temperatures indicate that gas and particles tend to thermal equilibrium at the PCB outlet (3 m). In general, from Fig. 3 it follows that

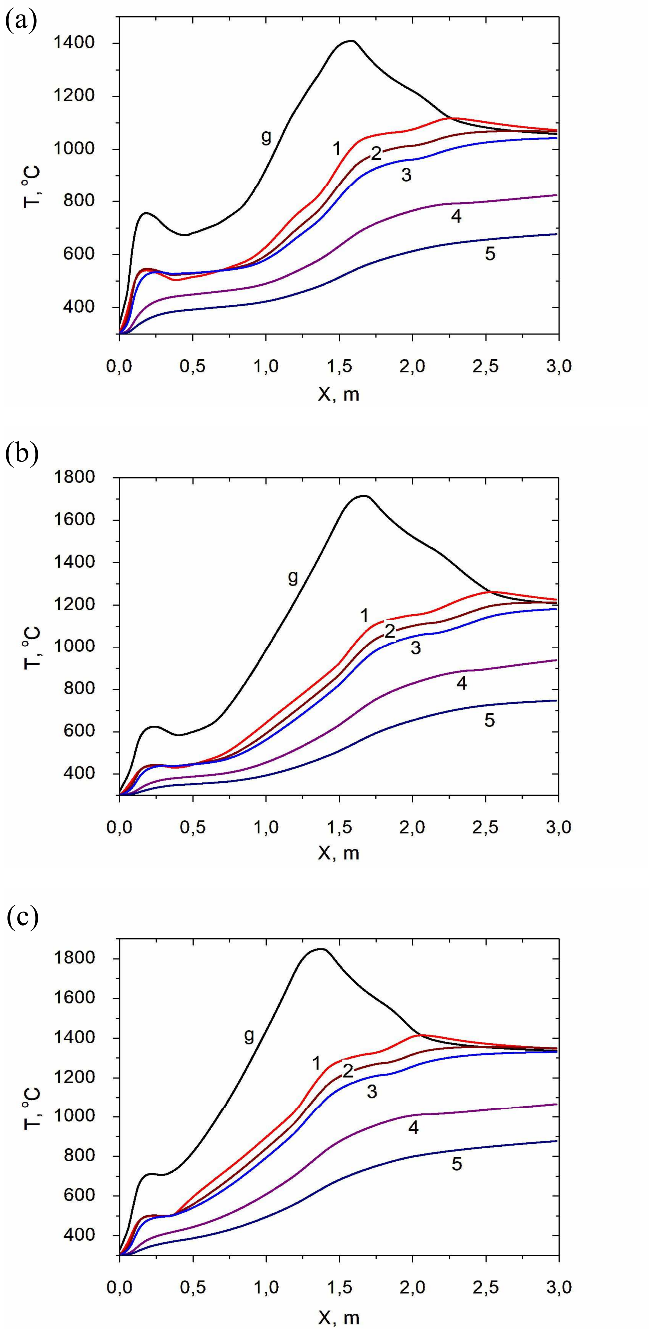

Fig. 3. Change in the temperature of coal fractions at a plasmatron power of 40 (a), 60 (b) and 80 kW (c) along the length of the PCB: 1–5 – size fractions of coal particles according to Table 2.

a plasmatron power of 40, 60 or 80 kW is sufficient to heat and ignite particles, since at the output of the PCB the gas temperature is higher than the ignition temperature (800 °C).

According to Fig. 4, the gas temperature is sufficient to ignite the coal particles for all calculated variants. As the plasma torch power increases, the gas temperature shifts toward the plasma source at the beginning of the PCB channel (X=0 m). The range of maximum gas temperatures is quite narrow and lies between 1409 and 1849 °C.

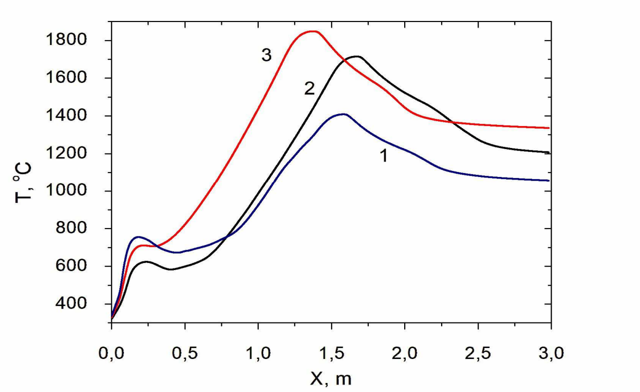

Fig. 4. Change in gas phase temperature at a plasmatron power of 40 kW (1), 60 kW (2) and 80 kW (3) along the length of the PCB.

Velocity curves in Figures 5(a)-5(c) are qualitatively similar. Over the length of the PCB, coal particles and gas and move at an increasing speed. For example, at plasmatron power of 60 kW, gas and coal particles are accelerated along its length of the PCB from 13 m/s to their maximum velocity (Fig. 5(b)). The maximum gas velocity is 84.3 m/s over a channel length of 1.44 m, decreasing to 62.1 m/s at the exit of the PCB. The velocity curves of coal particles accelerated by gas do not have an extremum at the length of the PCB considered. In fraction 1, coal particles reach 75 m/s at a 1.7 m PCB length. At the PCB output, coal particles of other fractions have maximum velocities of 72.7, 72.7, 64.6, and 58.9 m/s (curves 2–5). Gas and coal particle velocities at the exit of the PCB are significantly higher than air mixture velocities at the exit of conventional coal burners (usually 20-30 m/s). Converging trends in gas and particle velocities indicate that gas and particles tend to dynamic equilibrium at the PCB outlet (3 m).

There is an extremum in the gas velocity curves at plasmatron powers of 40–80 kW (curves 1–3) (Fig. 5(a)-5(c)). In response to an increase in plasmatron power, the gas velocity shifts towards the plasma source as its maximum velocity increases (Fig. 6). Note that the maximum gas velocity varies between 64.9 and 84.28 m/s. Plasmatron powers of 40, 60, and 80 kW resulted in maximum gas velocity at lengths of 1.74, 1.64, and 1.44 m. Gas velocity followed the same sequence as temperatures at the burner exit.

At 40 and 60 kW, coal fraction velocities at the PCB exit exceed 50 m/s, which is significantly faster than air mixture speeds during traditional solid fuel combustion. Plasmatron power fractions exceed 15 m/s throughout the PCB, eliminating coal particle separation during horizontal dust pipeline transportation. During traditional solid fuel

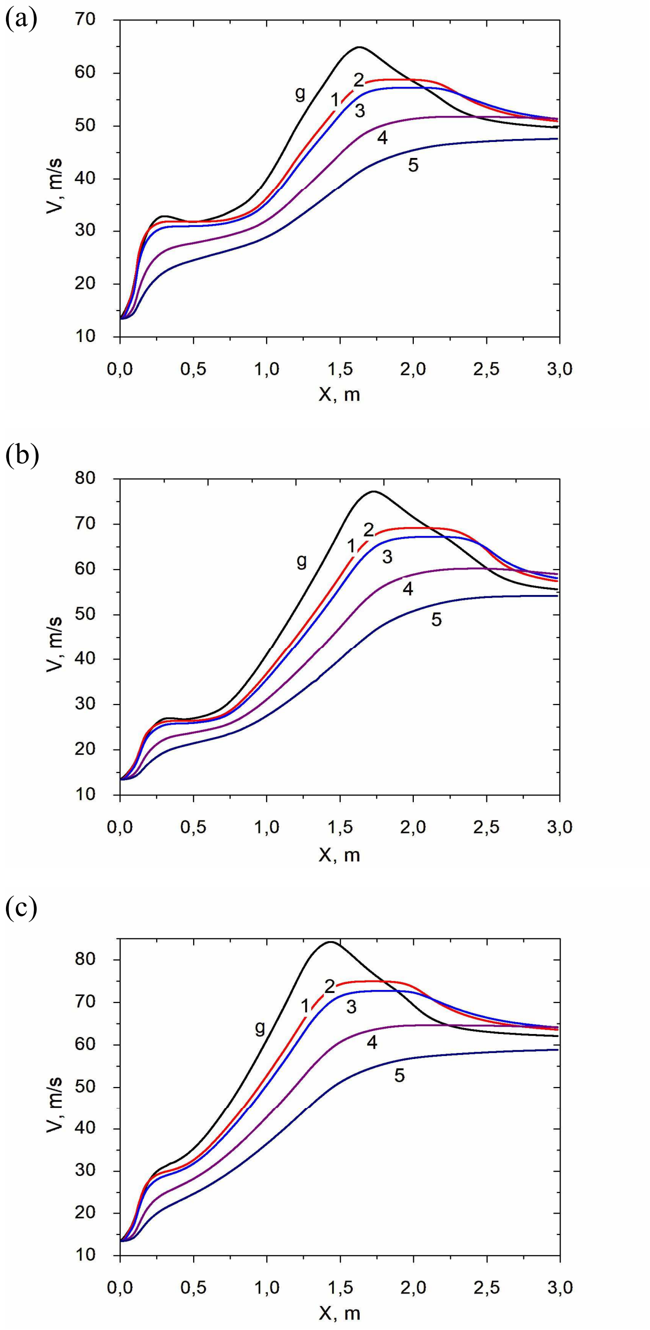

Fig. 5. Change in the speed of coal fractions at a plasmatron power of 40 (a), 60 (b) and 80 kW (c) along the length of the PCB: 1-5 – size fractions of coal particles according to Table 2.

combustion, the coal fraction exits the PCB at a speed greater than 50 m/s for all plasmatron powers. In the horizontal PCB, particle velocities are higher than 15 m/s throughout, preventing particle separation. A significant increase in the speed of the HRTF at the output of the PCB, compared to the speed of the air mixture at the exit of the burner during traditional combustion of solid fuel, increases the range of the HRTF torch.

Using kinetic modeling results, experiments were conducted on the PICS process in PCB.

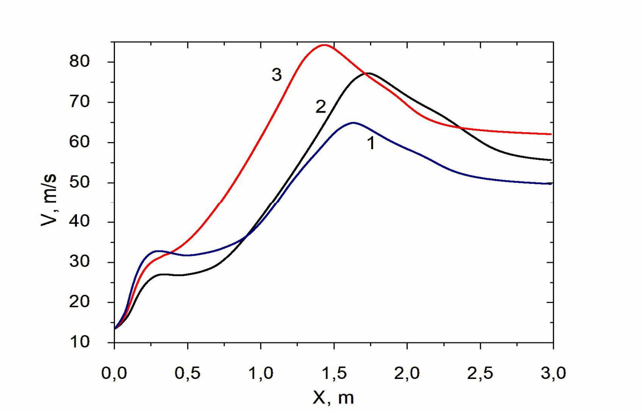

Fig. 6. Change in gas phase velocity at a plasmatron power of 40 kW (a), 60 kW (b) and 80 kW (c) along the length of the PCB.

3. Experiment

PICS experiments were conducted to test and confirm the conditions for stable ignition and combustion of the HRTF torch at PCB output, determined by kinetic modeling, and to compare calculations and experimental results. Experiments were performed on a PCB (Fig. 7). The plasmatron 3 was placed at the beginning of the PCB (the cylinder-lined section 2). Coal dust from hopper 4 is mixed with air from centrifugal fan 6 to create an air mixture. The fan provides an air flow of 1430 kg/h and, accordingly, an initial speed of the air mixture in the PCB of 15 m/s. In the PCB, the air mixture interacts with the flame from the plasmatron 3. Plasma flames

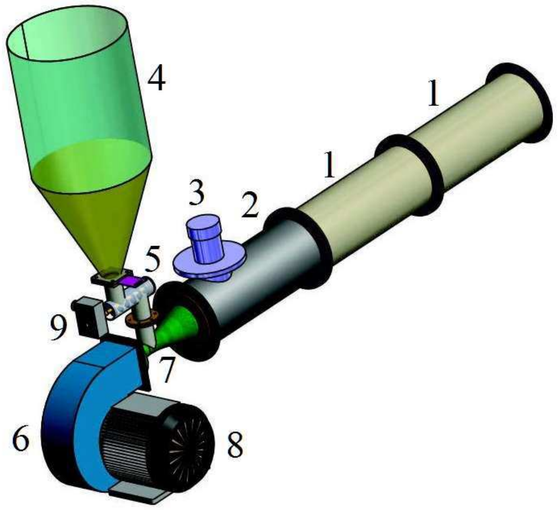

Fig. 7. Diagram of experimental PCB: 1 – muffelized section of the PCB; 2 – plasmatron installation nozzle in muffelized section; 3 – plasmatron; 4 – coal dust hopper; 5 – dispenser for dust; 6 – PCB air supply centrifugal fan; 7 – nozzle confuser-diffuser; 8 – fan drive motor; 9 – the screw mechanism is driven by a motor.

Fig. 8. HRTF torch at PCB outlet during bench testing.

are created by blowing air between electrodes and heating it to the plasma state. Plasmatrons produce flames with temperatures exceeding 5000 °C [13]. PCB with a diameter of 0.15 m and a length of 3 m was used for the experiments. The electrical power of the plasmatron was 70 kW. The efficiency of the plasmatron was 85%. Table 1 shows the coal used in the experiments (Ekibastuz coal). By sieve analysis, coal dust fractional composition is shown in Table 2. An air mixture temperature of 27 °C resulted in coal and air consumption of 1000 and 1430 kg per hour, respectively. After commissioning, two experiments on PICS were carried out. It was the primary objective of the experiments to ignite the air mixture with plasma and to obtain a stable HRTF torch at the PCB outlet, as well as to determine the composition, the temperature, and the degree of carbon gasification of the HRTF torch. An air mixture with 0.7 kg/kg dust concentration was established and maintained in the experiments. As a result of these conditions, an HRTF torch was obtained, which self-ignited and burned steadily at the PCB outlet (Fig. 8). As a general rule, it is more difficult to ignite and burn a HRTF torch in the open air than in the furnace volume of the boiler with an organized secondary air supply. HRTF torch combustion in the open air is more challenging. 4–5 m was the length of the HRTF torch. Digital pyrometer Ircon Ultrimax Plus UX10P was used to measure the torch's temperature, which ranged from 600 to 3000 °C. Taking into account the temperature range in which the measurement is made is important when determining the measurement error. As a result, measuring temperatures below 1500 °C may result in an error of up to 0.5% of the measured value, higher temperatures may result in an error of up to 1%, and temperatures over 2000 °C may result in an error of as much as 2% of the measured value. One degree is the minimum temperature resolution. Even in the case of ignition of high-ash Ekibastuz coal, the HRTF torch's temperature varied between 1150 and 1180 °C, ensuring stable ignition and combustion when mixed with air oxygen. With the help of a specialized heat-resistant probe, gas samples were collected for analysis. Figure 9 illustrates the sampling scheme. Gas samples were taken using the following steps. When the centrifugal fan 2 is turned on, coal dust is supplied from the hopper 3 and an air mixture is formed, ignited by the plasma flame. A stainless steel probe with a diameter of 5mm was attached to a section of the PCB in the volume of the HRTF torch. By using a gas extraction syringe 6, a high-temperature filter 4 and three-way valve 5 were used to collect the required amount of gas. The filter is made of replaceable superfine basalt fiber. The Chromatek-Gazochrom-2000 gas chromatograph was connected to the syringe containing the sample in order to determine its composition.

There is no slag on PCB inner surfaces, which is the main advantage of this technology. The coal dust concentration in the air mixture is kept at 0.7 kg/kg, preventing solid fuel combustion in PCB and limiting the PICS process temperature below the coal ash softening temperature (here, Ekibastuz coal). Ash from Ekibastuz coal softens at t_3=1250 °C. As a result of this process, the solid residue was passed through a high-temperature filter with a replaceable filler 4 to determine the residual carbon content (Fig. 9). An absorption gravimetric method was used to determine the carbon content of condensed PICS products.

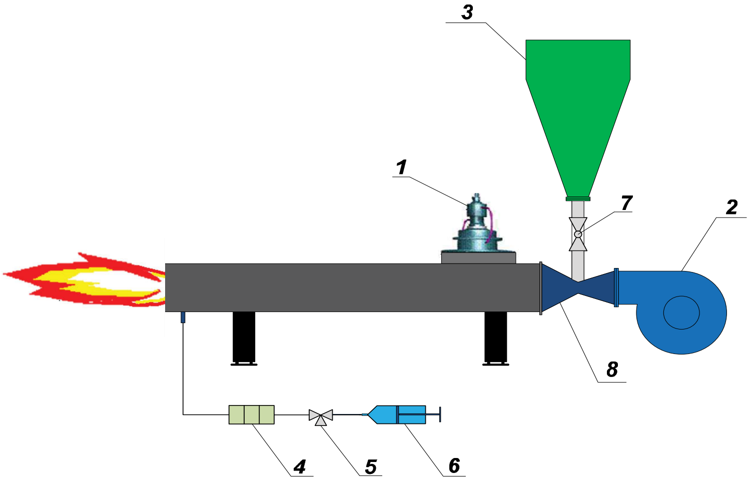

Fig. 9. Diagram of exhaust gases extraction from PCB: 1 – plasmatron; 2 – centrifugal fan; 3 – dust hopper; 4 – filter made of superfine basalt fiber with replaceable filler for high temperatures; 5 – three–way valve; 6 – syringe for gas extraction; 7 – shut-off valves; 8 – diffuser.

4. Experimental and canculation results comparison

A comparison of the experimental results and calculations of PICS is presented in Table 3. Experimental and numerical studies are compared based on identical initial data (plasmatron power, coal and air consumption, PCB geometric parameters and dust concentration in the air mixture). According to the Table 3, the HRTF temperature varies within a narrow range of 1170–1180 °C and differs by no more than 1% from the calculated temperature. There was little difference between the calculated value (41.7%) and the actual value (32.1% to 37.1%) of combustible components ($CO + H_2$). There was a variation between 53.8 and 60.5% in the degree of carbon gasification, which differed only by 1% from the calculated value. The discrepancy between experimental and numerical values of key PICS parameters is not greater than 24%. In multicomponent heterogeneous plasma systems, such a discrepancy between experimental and calculated data is to be expected given the complexity of plasma two-phase PICS processes. In addition, PlasmaKinTherm is suitable for engineering calculations of PCB, as it adequately reflects the basic laws of PICS.

5. Conclusion

In order to calculate plasma-coal burners and describe the patterns of plasma flame interaction with the air mixture under various initial conditions of the process, the PlasmaKinTherm program and the plasma thermochemical preparation model for combustion of pulverized coal fuel are developed. This model describes the PICS process along a PCB by tracking temperature distributions, velocity distributions, and concentrations of PICS products based on thermodynamic and kinetic approaches.

In this work, the operating parameters of the PCB were numerically studied, the distribution of temperature and velocity of coal particles and gas, and the concentrations of PCB products along its length. When using a plasmatron power in the range of 40–80 kW, stable ignition of high-ash coal is ensured at an air mixture flow rate of 2430 kg/h. At the output of the PCB, high temperatures (>1050 °C), velocities (>50 m/s) and concentrations of flammable components (>18.6%) are observed, sufficient for stable ignition of the HRTF.

When plasmatron power is increased, the temperatures and velocities maxima of PTPC products shift upstream (towards the plasma source).

Table 3. PCB parameter comparison between experimental and numerical values

Method	THRTF, °C	C_i, vol. %				X_C, %
		CO	H_2	CO_2	N_2	
1st experiment	1170	24.6	7.5	3.2	64.7	53.8
2nd experiment	1180	27.8	9.3	2.2	60.7	60.5
Calculation	1184	26.5	15.2	1.4	55.5	57.6

At this a narrow range of maximum temperatures and velocities was observed, and the plasmatron's power had little effect on them.

PICS experiments were conducted to test and confirm the conditions for stable ignition and combustion of the HRTF torch at PCB output, determined by kinetic modeling, and to compare calculations and experimental results.

Analysis of comparison of calculation results with experimental data confirms that the assumptions made during the development of the model reflect reality, and the PlasmaKinTherm program can be used for the calculation and design of plasma-coal burners.

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Численное и экспериментальное исследование плазменного воспламенения низкосортного угля

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АННОТАЦИЯ

Плазменно-угольная горелка исследована с использованием модели плазменной термохимической подготовки угля к сжиганию, реализованной в виде программы PlasmaKinTherm. Плазменно-угольные горелки не требуют мазута или газа для растопки котлов и стабилизации горения угля. Программа PlasmaKinTherm объединяет термодинамику и кинетику для описания термохимической подготовки топлива в объеме плазменно-угольной горелки. Целью моделирования было определение условий плазменного воспламенения низкосортного угля. Было проведено численное исследование влияния мощности плазмотрона на воспламенение аэросмеси (уголь + воздух). В расчетах использован высокозольный экибастузский уголь. Были рассчитаны распределения температуры и скорости газа и угольных частиц и концентраций продуктов плазменной термохимической подготовки угля к сжиганию по длине горелки. В результате анализа процессов плазменного воспламенения угля выявлены их основные закономерности, в том числе смещение максимальных температур и скоростей продуктов термохимической подготовки угля к сжиганию вверх по потоку (в сторону плазмотрона), а также то, что максимальные значения температур и скоростей продуктов не зависят от мощности плазмотрона. Проведены эксперименты по проверке и подтверждению условий устойчивого воспламенения и горения факела высокореакционного двухкомпонентного топлива при мощности плазмотрона, определенной кинетическим моделированием. Сделанные при разработке математической модели допущений, были подтверждены сравнением расчетов с экспериментальными данными.

Ключевые слова: уголь, плазменное воспламенение, плазменно-угольная горелка, высокореакционное двухкомпонентное топливо, моделирование

Төмен сортты көмірдің плазмалық тұтануын сандық және эксперименттік зерттеу

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АҢДАТПА

Плазма-көмір оттығы PlasmaKinTherm бағдарламасы түрінде іске асырылған көмірді жағуға плазмалық термохимиялық дайындау үлгісін қолдану арқылы зерттелді. Плазмалық-көмір оттықтары қазандықтарды жағу және көмірдің жануын тұрақтандыру үшін мазут немесе газды қажет етпейді. PlasmaKinTherm бағдарламасы плазмалық көмір оттығының көлемінде отынның термохимиялық дайындығын сипаттау үшін термодинамика мен кинетиканы біріктіреді. Модельдеу мақсаты төмен сұрыпты көмірдің плазмалық тұтану шарттарын анықтау болды. Ауа қоспасының (көмір+ауа) тұтануына плазматрондық қуаттың әсеріне сандық зерттеу жүргізілді. Есептерде күлділігі жоғары Екібастұз көмірі пайдаланылды. Оттықтың ұзындығы бойынша газ және көмір бөлшектерінің температурасы мен жылдамдығының таралулары және көмірді жағуға арналған плазмалық термохимиялық дайындау өнімдерінің концентрациялары есептелді. Көмірдің плазмалық тұтану процестерін талдау нәтижесінде олардың негізгі заңдылықтары анықталды, соның ішінде көмірді жағуға арналған термохимиялық дайындау өнімдерінің максималды температуралары мен жылдамдықтарының жоғары ағынға (плазмалық алауға қарай) жылжуын, сондай-ақ өйткені өнімдердің температуралары мен жылдамдығының максималды мәндері плазматронның қуатына тәуелді емес. Кинетикалық модельдеу арқылы анықталған плазматрондық қуатта жоғары реактивті екі компонентті отын алауының тұрақты тұтану және жану шарттарын сынау және растау үшін эксперименттер жүргізілді. Математикалық модельді жасау барысында жасалған болжамдар есептерді эксперименттік мәліметтермен салыстыру арқылы расталды.

Түйін сөздер: көмір, плазмалық тұтану, плазмалық көмір оттығы, жоғары реактивті екі компонентті отын, модельдеу.