LABORATORY AND INDUSTRIAL STUDIES OF GAS COAL IGNITION AND COMBUSTION USING HIGH-VOLTAGE ALTERNATIVE CURRENT PLASMATRON

by

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This paper presents experimental studies and industrial applications of a promising method for igniting and combusting coal fuel using a high-voltage alternative current plasmatron. Experimental studies were carried out at a set-up with a thermal capacity of up to 5 MW. Kuznetsk long flame coal selected after a ball-drum mill with sieve residue R90 = 15%, was taken as an experimental sample. The first experimental data on implementation of the combustion process have been obtained. Introduction and first industrial tests of the high-voltage alternative current plasmatron were carried out using a real power boiler TP-10 with an output capacity of 220 tons of steam per hour with gas and fuel oil replacement by coal during the process of boiler start-up.

Key words: *plasmatron, pulverized-coal power boilers, flame combustion, ignition, arc discharge*

Introduction

To prevent climate changes and preserve valuable resources, the share of RES in advanced economies is increasing, but these energy sources are unstable and without efficient energy storage systems cannot cope with the needs of population and industry [1].

In the long run, coal remains one of the most important resources of the heat and power complex due to abundant global reserves and competitively low prices [2, 3].

Coal is still mainly used to generate heat and electricity (66.5% in 2017). Despite a wide variety of factors affecting coal energy, the share of coal energy in the world remains at the level of 40% over the past 40 years [4].

All over the world great attention is paid to the problem of effective and environmentally friendly combustion of coal [5].

Coal combustion of fuel at thermal power plants consists of a large number of technological processes, including ignition, and burning. The traditional technology is the use of auxiliary fuel: fuel oil. Fuel oil has high reactivity with calorific value (about 44 MJ/kg) two times higher than that of coal commonly used at heat power plants (about 22 MJ/kg). Heated fuel oil with a temperature of about 80-100 °C is sprayed through the nozzles into the boiler and ignited by an arc ignition device. This technology is expensive (the price of fuel oil is increasing every year) and time-consuming (the systems for fuel oil preparing and fire safety

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systems are required). The heat power plants are trying to replace obsolete fuel oil technologies. In addition, the modern development of the world power system is characterized by a reduction in the use of deficit liquid fuels, which are valuable raw materials for the oil refining industry [6].

At coal-fired power plants, boilers are started up (the start-up duration is 3-14 hours) several times a year (up to 25 launches per boiler per year), and the stabilization of pulverized coal flame is performed periodically when the flame is dimmed or the load is reduced [7]. According to forecasts, in the future the number of boilers launches per year will increase, which is associated with an increase in renewable energy sources [8].

Thus, the development of the technology for start-up of pulverized coal boilers and supporting the process of pulverized coal combustion with the replacement of fuel oil is an important task of power systems.

One of the modern technologies is the use of a direct current plasmatron for ignition and stabilization of the pulverized coal flame [9]. This technology is based on heating the flow of a pulverized-coal mixture by a high temperature plasma arc at oxygen deficiency to the temperature exceeding the self-ignition temperature of this coal [10]. Plasma ignition and stabilization of combustion of the pulverized coal flame are studied by well-known energy companies in the USA, Canada, Germany, and China, which have the experience in industrial operation of electric-arc plasmatrons at a number of power plants [11-13].

The main trend of these developments is expanding the range of quality characteristics of coal burned, as well as increasing the service life of electrodes and reducing power consumption. At the moment, the power of the direct current (DC) plasmatron varies from 100 kW to 350 kW, depending on the consumption and quality of fuel, and the service life of the DC plasmatron electrodes is about 500 hours.

To increase the service life of electrodes and reduce the plasmatron power, a high-voltage alternative current (AC) plasmatron was developed. High-frequency cold plasma arcs ionizing the oxidizing agent are generated in the high-voltage AC plasmatron, which helps to accelerate the thermochemical transformations of coal fuel, and, consequently, more complete and faster burnout of the flame. The technical implementation of the high-voltage AC plasmatron is simple. It has low consumption of electric power (in the ignition regime, it is no more than 10 kW), long life of continuous operation (over the years), and it is not necessary to use the cooling systems.

This work is aimed at studying the promising technology for ignition and combustion of coal fuel, based on the use of a high-voltage AC plasmatron.

Materials and methods

High-voltage AC plasmatron

The high-voltage plasmatron of AC includes: two frequency converters IRBI 943-1.5-10/0.4 UHL3.1, and each converts an alternating supply voltage of 380 V, 50 Hz to high-frequency (20 kHz) high-voltage (up to 10 kV) voltage and stabilizes the output current. Each converter consists of two cabinets: a cabinet of frequency converter and a high-voltage cabinet with a step-up transformer. Functionally, the power part of the converter consists of a three-phase mains voltage rectifier, a rectified voltage filter, a bridge voltage inverter, and an output high-voltage high-frequency transformer. Under the load, the three-phase mains voltage is supplied to the input of the converter and rectified by a diode rectifier. The transistor switches of the voltage inverter form the specified high-frequency current (amplitude). Both frequency converters have the same characteristics and are located on a common mounting rack. The burner of the system has a mounted electric arc block in the structure, which creates a high-frequency arc in the combustion zone of the pulverized coal flame. The electric arc unit consists of two pairs of electrodes mounted on eight bushing insulators, designed for the maximum output voltage of the frequency converters. During normal operation of the frequency converters, two unconnected high-frequency arcs are ignited in the electric arc unit. A scheme of an electric arc unit with electrodes and bushings is shown in fig. 1.

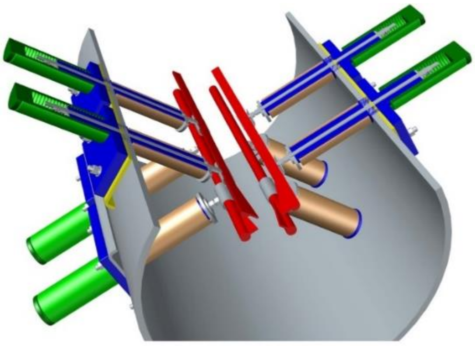

Figure 1. Electrode unit

Experimental set-up

The electric arc unit was mounted on a large-scale set-up with a thermal capacity of up to 5 MW. The technological scheme of the heat set-up is shown in fig. 2.

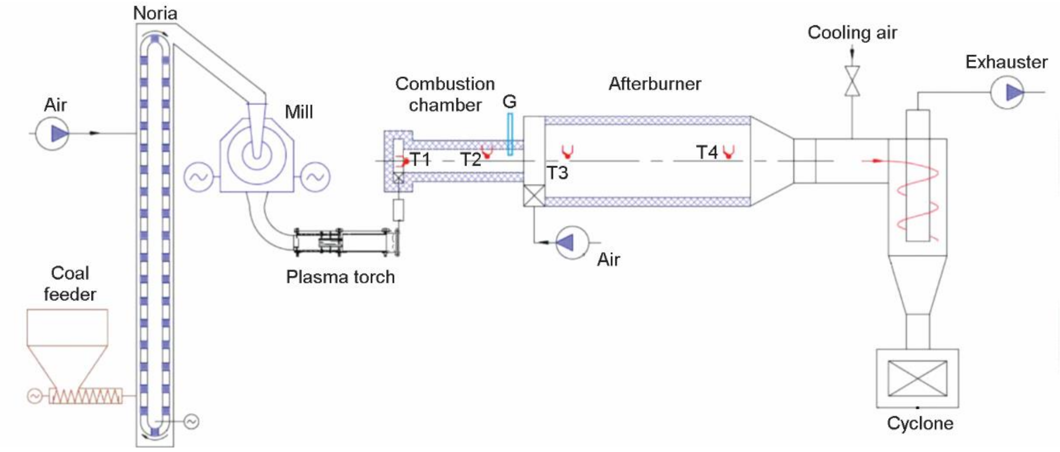

Figure 2. Scheme of experimental set-up

Then, the possibility of starting a large-scale set-up with a capacity of up to 5 MW from cold state by a high-voltage AC plasmatron was studied experimentally.

The experiments were carried out with oxidized Kuznetsk long-flame coal. The results of the proximate and ultimate analysis of coal are given in tab. 1.

Table 1. Proximate and ultimate analysis of fuel

Wrt [%]	Ad [%]	Vdaf [%]	Cdaf [%]	Hdaf [%]	Odaf [%]	Ndaf [%]	Sdaf [%]	Qsdaf [MJkg^{-1}]
12.5	17.4	44.6	82.5	5.8	8.3	2.7	0.44	31,2

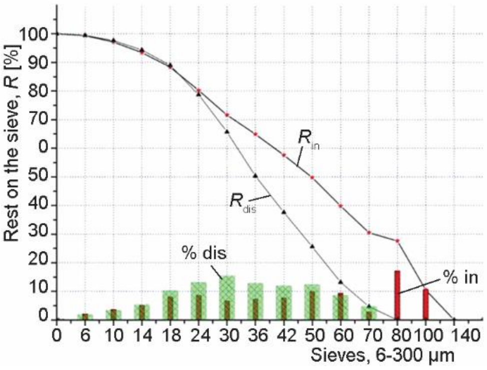

Figure 3. Spectrum of coal particles after disintegrated mills (dis), ball drum mill (in)

Coal was preliminarily ground in a ball drum mill; then it was mechanically activated in a disintegrator. The *initial* particle size distribution obtained at Novosibirsk TPP-2 after grinding in a ball drum mill and after grinding in a disintegrator mill is given for comparison, fig. 3.

The initial coal is fed into the hopper, then, it is sent by a screw feeder into a vertical conveyor. The feeder is equipped with an electric motor with a frequency converter, which allows smooth adjustment of fuel supply. Using a vertical conveyor, fuel is fed to a mill-disintegrator. At the top of the vertical conveyor, there is a primary air supply. Primary air together with fuel is supplied to the mill and provides transportation of dust, obtained in the mill, to the burner. Since the test set-up is under the discharge created by the ejector and the smoke exhauster, the flow rate of primary air flowing through the mill is regulated by a gate mounted at the channel inlet. The mill-disintegrator is equipped with two electric motors with a capacity of 35 kW each. The maximum mill capacity is 2.5 ton per hour. Fuel is supplied to the mill through a nozzle in the middle part of the mill. After grinding, the dust-air mixture is fed into a high-voltage AC plasmatron, where the coal mixture is ignited and fed through a scroll swirler to the combustion chamber. The scroll swirler allows arrangement of a reverse current zone in the combustion chamber, which is necessary to stabilize the combustion process of coal dust in an autothermal regime. The temperature and composition of gases along the length of the burner are controlled by thermocouples and special multicomponent gas analyzer

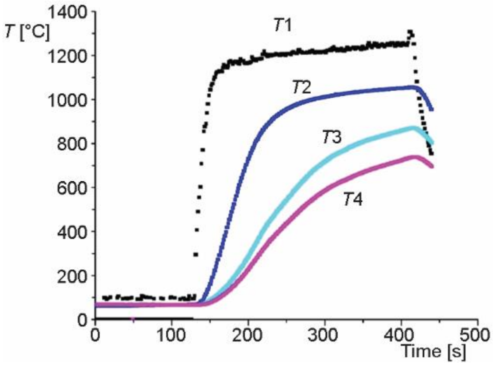

Figure 4. Temperature distribution along the length of combustion chamber in the regime of its start-up from a cold state using a high-voltage AC plasmatron

Results

Initially, the electrode unit was turned on, the power spent on plasmatron operation was 5 kW. The experiments were carried out with an excess air coefficient of 0.4-0.5 and coal consumption of 180 kg/h. After feeding coal dust to the electrode unit, ignition and further combustion were observed in the swirler and in the combustion chamber. The main combustion took place in the initial zone of combustion chamber, where the thermocouple T1 is located, fig. 4. It can be seen that the temperature rises to 1200 °C within 30 seconds after the start of coal supply.

Gas analysis was performed at the end of the combustion chamber, the experimental data on gas analysis are shown in fig. 5. After turning on the plasmatron, the NO_x content increased to 120 ppm, after feeding coal, there was an increase in NO_x to 390 ppm and after combustion chamber heating, there was a drop to 250 ppm. Throughout the experiment, after heating the combustion chamber, the concentration of O_2 did not exceed 0.8%. The maximum values of CO were 11% and the values of H_2 were 5.8%.

Then, the combustible mixture entered the afterburner, where secondary air was supplied to bring the excess air coefficient to 1.2. In the afterburner, the temperature was 800 °C. Photograph of an experimental set-up with a working high-voltage AC plasmatron is presented in fig. 6.

The experiments performed show the possibility to ignite gas coals with a high yield of volatiles and to start up combustion chamber from a cold state using a high-voltage AC plasmatron, which can be recommended for industrial tests.

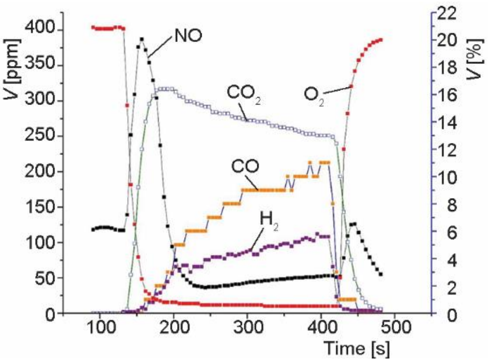

Figure 5. Concentration of gas phase components at the end of combustion chamber in the regime of its start-up from a cold state using a high-voltage AC plasmatron

Industrial test

Industrial tests of a high-voltage AC plasmatron were carried out by JSC "Sibtekhenergo", Novosibirsk, at a boiler unit of type E-220-100-540 (TP-10): single-drum, vertical water-tube boiler with natural circulation, gas-tight, designed to produce superheated steam when burning coal fuel. The industrial tests were carried out with long-flame coals. The results of the proximate and ultimate analysis of coal are given in tab. 2.

Figure 6. Photograph of an experimental set-up with a working high-voltage AC plasmatron

The boiler is designed to burn pulverized coal in the regime of solid slag removal. The combustion chamber with a cross-section of 9792×7040 is equipped with four blocks of direct-flow burners installed in a tangential pattern with a conditional circle diameter of 1000 mm. Each burner includes three channels of secondary air and three channels of air mixtures alternating in height.

The boiler is equipped with two individual dust preparation systems including an intermediate dust bin with ball drum mills.

A muffle burner is located on the front wall of the combustion chamber at point +10200 m, 270 mm below the axis of the main burners. Locally, the burner is shifted to the left relative to the boiler axis. The rated design power of the muffle burner is 8 MW.

Table 2. Proximate and ultimate analysis of coals

Coal Deposit	Wrt [%]	Ad [%]	Vdaf [%]	Cdaf [%]	Hdaf [%]	Odaf [%]	Ndaf [%]	Sdaf [%]	Qsdaf [MJkg^{-1}]
Mugun	12.5	17.4	44.6	82.5	5.8	8.3	2.7	0.44	31,2
Irbeysky	12	9	40	79	5.5	12.6	2.4	0.5	30.6
Cheremkhovo	13	15	39	86	5	6.3	2	0.3	31.8

Before technical modernization carried out by JSC "Sibtekhenergo", the muffle burner consisted of a vortex burner in the dust stream, where a fuel oil nozzle and a cylindrical chamber lined inside with chamotte brick were installed. The tangential nozzles of secondary air were installed along the muffle burner length: totally three groups of air nozzles at an angle of 120° to each other. A general view of the muffle burner before technical modernization is shown in fig. 7.

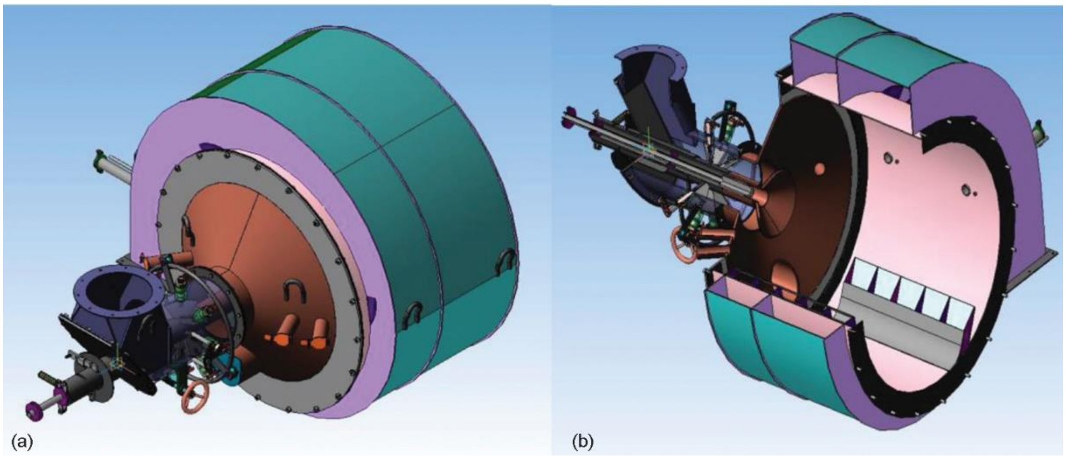

Figure 7. General view of the muffle burner before technical modernization; (a) general view, (b) sectional view

In the framework of technical modernization, a vortex burner installed at the input of a muffled pre-furnace was replaced by a burner with an electrode unit of a high-voltage AC plasmatron torch.

Pulverized coal is ignited due to the impact of high-voltage and high-frequency electric arcs on the dust-air mixture. The burner with the high-voltage AC plasmatron is located on the input wall along the muffle burner axis.

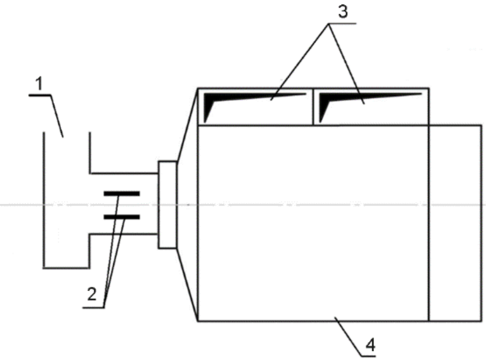

Figure 8. Scheme of the muffle burner with a high-voltage AC plasmatron; *1 – coal powder-air mixture inlet, 2 – plasmatron electrodes, 3 – secondary air inlet, 4 – muffle burner*

On March 26, 2017, the first oil-free start-up of the TP-10 drum boiler was carried out at station No. 1 of HP-10 of PJSC *Irkutskenergo* branch.

The location of the muffle burner with the experimental system of electrochemical fuel combustion relative to the boiler furnace is shown in fig. 8.

The start-up was carried out using a muffle burner equipped with a high-voltage AC plasmatron. The fuel used for the start-up is coal dust stored in the intermediate hopper of boiler dust preparation systems. The experimental program during the start-up period is shown in tab. 3.

Table 3. Industrial test program

Fuel-flow rate [kgs^{-1}]	Primary and secondary air temperature [°C]	Primary air-flow rate [m^3s^{-1}]	Secondary air-flow rate [m^3s^{-1}]
0.6	37	0.8	1.5-2.1

The electric power consumed by the plasmatron is 5 kW. The thermal power of burners is up to 8 MW. The system provides stable ignition of coal dust when starting the boiler from a cold state. The burner ensures the supply of a burning flame with a temperature of 1250-1350 °C to the combustion chamber. During plasmatron operation, the flame from the muffle burner extends deep into the combustion chamber by 3-5 m. Fuel oil was not supplied to the boiler furnace during the entire start-up. The temperature of drum walls before starting ignition was ~105 °C. The temperature of gases behind the steam superheater was 70 °C.

In total, by March 2018, the TP-10 (E-220-100-545) boiler has been started up from various thermal states without using fuel oil five times.

Conclusions

Experimental studies were carried out on coals of varying degrees of metamorphism at a set-up with thermal capacity of 5 MW. The maximum velocity of the dust-air mixture in the cross-section of electrode unit (electric arc unit) is 20 m/s. A further increase in velocity leads to carry-over of the plasma arc from electrodes. The minimum velocity of the dust-air mixture in the cross-section of electrodes is 6 m/s. The experimental results demonstrate the possibility of lighting from a cold state of gas coals with a large yield of volatiles using a high--voltage AC plasmatron torch; this technology can be recommended for industrial tests. The method can be recommended for replacing fuel oil at lighting and maintaining the combustion at coal plants and boiler houses, as well as for reducing NO_x. Further experiments will allow the use of technology for organic waste processing. Introduction and first industrial tests of the high-voltage AC plasmatron were carried out using a real power boiler TP-10 with an output capacity of 220 tons of steam per hour with gas and fuel oil replacement by coal during the process of boiler lighting.

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