Ignition of a Cold Pulverized Coal Fuel by Means of an Electric Ignition System

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Abstract — **Coal-fired generation has long been, and still is, one of the leaders in global electricity generation. The high share of coal-fired generation in the global energy mix is achieved due to the known advantages of this fuel, including high availability of reserves, relative ease of extraction, and the possibilities of providing its reserves at the plants and reliable equipment operation even in the event of fuel supply interruptions. Coal combustion in modern industry requires the development of modern start-up systems for coal-fired boiler units without the use of fuel oil. Fuel oil is used for starting up boilers and maintaining the flame during transient conditions or at low loads of boiler. At the same time, the use of fuel oil has some disadvantages, both technical and environmental. The greatest challenge in developing high-frequency ignition systems is to understand the chemical kinetics processes for the plasma chemical reaction of fuel mixture ignition. This paper presents experimental and industrial studies on the application of an electric ignition system for coal fuel based on a high-frequency power source. Experimental studies were carried out on a laboratory bench with a thermal capacity of 5 MW. Industrial tests were performed at the operating enterprises of the power sector of the Russian Federation. Lignite and hard coals of different thermal-technical composition were used as fuel samples. The principle behind the effect of this system on the fuel ignition has been shown.**

Index Terms: **coal-fired generation, experiment, principle of operation, electric ignition, ignition, oil-free ignition, ecology, efficiency, economy, experience, lignite, hard coal, low-grade fuel.**

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I. Introduction

Every year, more than 5 million tons of fuel oil are burnt in the Russian Federation to maintain the combustion of pulverized coal in boilers, and since the quality of steam coal declines, more fuel oil is required [1]. Firing up the power boiler needs on average 60–80 t of fuel oil (at its average cost of ~ 15 thousand rubles/ton). One of the important directions for the development of generating companies in the Russian Federation is to increase the economic efficiency and environmental friendliness of the production cycle.

Combustion of coal fuel in the modern industry requires the development of modern systems of starting up coal-fired boiler units without the use of fuel oil [2, 3]. Fuel oil is used for starting up boilers and maintaining the combustion flame in transient conditions or at low loads of a boiler [4]. However, the use of fuel oil has some drawbacks, both technical and environmental [5]. The greatest challenge in the development of high-frequency ignition systems is to understand the processes of chemical kinetics for the plasma-chemical reaction of the fuel mixture ignition.

This study aims to investigate this process.

The potential for the development of electric ignition technology is to reduce the use of fuel oil at the coal-fired power plants in Russia and abroad, to partially or completely convert the plants to oil-free operation, and reduce the costs of maintaining the fuel oil facilities. Abandoning fuel oil at coal-fired thermal power plants (TPPs) will reduce the environmental impact of coal-fired generation, and given the hundreds of pulverized coal-fired boilers, it will affect the environmental situation in Russia.

It is also worth noting that it is possible to save other highly reactive fuels at the plant, which are used to stabilize pulverized coal flare and to start up the boilers. The use of electrically ignited coal for these purposes is, on average, 2 times cheaper than the use of natural gas. Replacement of the highly reactive fuel with coal will reduce the auxiliary fuel consumption of the plant, thereby providing additional profits.

II. Electric Ignition System

A team of authors from Siberian Energy Solutions LLC together with Zio-Energy LLC supported by Novosibirsk

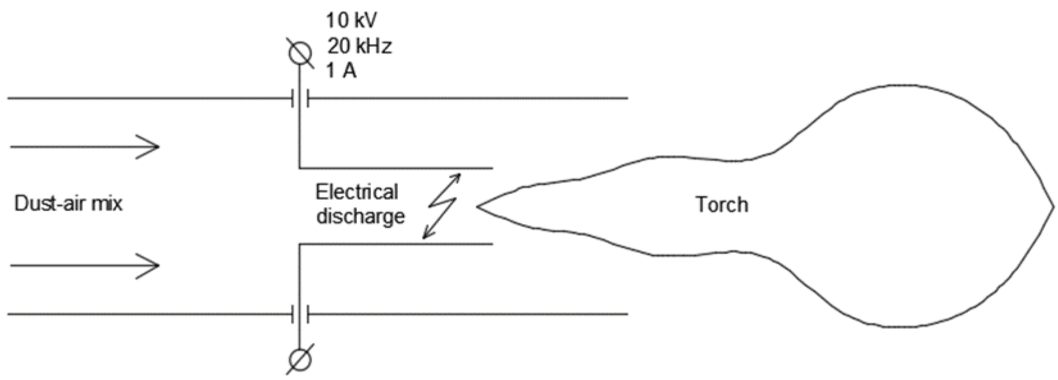

Fig. 1. The operating principle of electric ignition system.

Table 1. Coal characteristics ensuring high performance of the electric ignition technology.

Name	Coal characteristics	Coal dust characteristics
Irsha-Borodinsky brown coal	Qir = 3 880 kcal/kg; Wr = 32.6%; Ar = 5.66%; Vdaf = 48.0%.	R90 = 72.9%; R200 = 21.4%
A mixture of Azeisky, Mugunsky, Golovinsky, Cheremkhovsky, and Irbeisky brown coals:	Qir = 4 000 kcal/kg; Wr = 21.5%; Ar = 17.8%; Vdaf = 48.3%.	R90 = 49.2%; R200 = 11.2%
A mixture of Azeisky and Mugunsky brown coals:	Qir = 3 740 kcal/kg; Wr = 25.8%; Ar = 16.3%; Vdaf = 46.5%.	R90 = 45.0…55.0%
Kuznetsk Basin coal of grades G (gas) and D (long-flame)	Qir = 5 600 kcal/kg; Wr = 15.3%; Ar = 8.2%; Vdaf = 39.8%.	R90 = 20…25%
Ekibastuz KSN coal, Bogatyr mine (with additional power supply)	Qir = 3 990 kcal/kg; Wr = 5.0%; Ar = 40.3%; Vdaf = 31.6%.	R90 = 10…15%

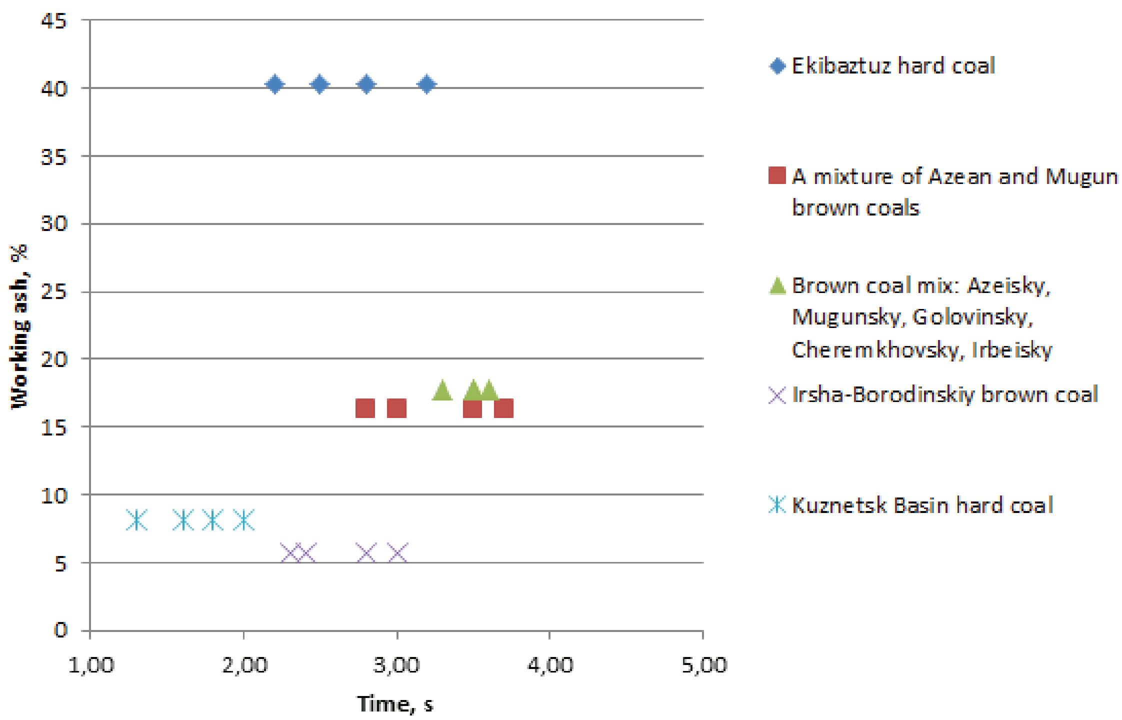

Figure 2. Ignition delay time for coal samples exposed to an electrical ignition system.

State Technical University and Kutateladze Institute of Thermophysics of the Siberian Branch of the Russian Academy of Sciences developed a technology of electric ignition. The first patent was received by Novosibirsk developers in 2009 [6].

The operating principle of this technology is shown in Fig. 1. Electric current applied to cylindrical electrodes has the following parameters: voltage 3–10 kV, frequency 18–22 kHz, and rated current strength 1A. As a result, a high-frequency breakdown occurs in the interelectrode space. Electric field strength in the interelectrode space is 0.3–1 kV/cm. A coal-air mixture is then fed into the interelectrode space, which results in the ignition of the mixture. One of the advantages of the power supply used is the input voltage of 380 V, which allows the power supply to be used without additional electrical equipment and guarantees electromagnetic compatibility with the auxiliary networks of thermal power plants.

The efficiency of this technology has been confirmed at the industrial facilities and by the laboratory tests using coal with the parameters presented in Table 1. The experience gained until now in the use of electric ignition systems allows switching to oil-free combustion of pulverized coal and excluding the use of fuel oil facilities of coal-fired plants (for coal with an ash content less than 20–25%).

Based on the experiments carried out at the firing bench of the Institute of Thermal Physics of SB RAS (Novosibirsk) with a thermal capacity of 5 MW and industrial tests of the technology, the following relationships between ignition delay time and ash content (Fig. 2) were obtained for the cold fuel with the characteristics presented in Table 1. The ignition of Ekibastuz coal in cold state failed, which can be explained by the high ash content. The ignition delay time for this coal is given after warming up the burner with Irsha-Borodinsky lignite to the temperature of about 400 °C.

The following processes can explain the principle behind the effect of this technology on ignition:

- Thermal ignition by electrical discharge (the discharge temperature reaches 7000 K [7]). This effect is localised and confined to the breakdown area of the interelectrode space. Once in this area, the carbon particles experience a thermal shock, which leads to their rapid heating and the release of volatile components. The interaction of coke residue with plasma leads to sublimation of carbon and its interaction with oxygen C + O = CO, which proceeds homogeneously. When exposed to high temperatures, the oxygen-containing groups break down releasing CO, CO_2, H_2O [8, 9].
- High-frequency electric field has an advantage over the constant electric field. Experimental work [10] shows that starting with a frequency of 150 Hz at a voltage of 1 kV, high-frequency electric field leads to a marked increase in the flame velocity compared to the constant electric field.
- Under the influence of high voltage electric field, fuel atoms transition to an excited state (electrochemical effect). The electrochemical effect produces high velocity electrons, radicals, ions, and excited molecules in the pre-flame zone, which directly change the chemical composition of the flame [11–15].

The latter thesis can be generalized to the theory of active center formation [16]:

$$q \approx pQ\sqrt{wa}\,, \tag{1}$$

where q is the amount of heat released by the reaction; p is the reacting mixture density; Q is heat of fuel combustion; w is reaction rate; a is temperature conductivity of fuel.

According to Semenov's theory of chain reactions [17], the rate of a stationary reaction is

$$w = \frac{\delta \nu_1^2}{2\nu_2^0}\left(\sqrt{1+\frac{4w_0\nu_2^0}{\delta_1^2\nu_1^2}}+1\right), \tag{2}$$

where w_0 is the rate of active centers generation; δ is the probability of chain branching; ν is an average length of the respective process chain.

Under the assumption that the rate of active centers generation is a function of the electric field strength

$$\Delta w_0 = f(E / p), \tag{3}$$

the application of an electric field to the reaction region results in its acceleration.

Reduction in ignition temperature was recorded by Kuzmin [18], who studied ignition temperature of luminous gases under the influence of electrostatic discharge.

III. Conclusion

An electric ignition technology, which implements a thermoelectric ignition mechanism, has been developed and tested for the combustion of hard coal and lignite. This technology makes it possible to achieve stable ignition of pulverized coal within 2–4 seconds after feeding into the burner. The application of this technology to intensify the ignition of a pulverized coal flare creates additional possibilities for fuel oil-free ignition and the economical and environmentally friendly combustion of various coals. The possibility of ignition (with additional power supply) for Ekibastuz coal with an ash content of 40% should be mentioned separately. The ignition delay time for this coal is given after warming up the burner with Irsha-Borodinsky lignite to the temperature of about 450 °C and makes up about 3 seconds. The energy input for ignition is less than 1% of thermal output of the burner for lignite and 2–3% for high-ash hard coal (including preheating). The industrial tests of the burner equipped with electric ignition technology using Ekibastuz coals are planned to be carried out in 2023.

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