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Plasma assisted power coal combustion in the furnace of utility boiler: Numerical modeling and full-scale test ☆

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ABSTRACT

This work presents modern plasma technology for solid fuel ignition and combustion. It promotes more effective and environmentally friendly low-rank coal incineration. To implement this technology at coal fired thermal power plants plasma-fuel systems (PFSs) were developed. PFS is a pulverized coal burner equipped with arc plasmatron producing high temperature air stream of 4000–6000 °C. Basis of technology PFS is plasma thermo-chemical preparation of coal for burning. It consists in plasma heating of air–coal mixture up to temperature of coal volatiles release and char carbon partial gasification. In PFS air–coal mixture is deficient in oxygen therefore carbon is oxidized mainly to carbon monoxide. As a result, at the PFS exit a highly reactive mixture is formed of combustible gases and partially burned char particles, together with products of combustion, while the temperature of the mixture is around 1050 °C. Further mixing with air promotes intensive ignition and combustion of the prepared in the PFS fuel.

PFS have been tested for boilers start up and pulverized coal flame stabilization at 30 power boilers of 75–950 t/h steam productivity. The boilers were equipped with different types of pulverized coal burners: direct flow, muffle and swirl burners. At tests of the PFS power coals of all ranks (lignite, bituminous, anthracite and their mixtures) were incinerated. Volatile content of them was in range of 4–50%, ash varied from 15% to 48% and heat of combustion was from 6690 to 25100 kJ/kg.

To show advantages of the plasma technology of coal combustion before conventional one numerical investigation of plasma ignition, gasification and thermo-chemical preparation of air–coal mixture for incineration in a power boiler was fulfilled. The numerical modeling was performed for low-rank bituminous coal of 40% ash content incinerated at a boiler of 420 t/h steam productivity. Both analysis of the numerical modeling and experience of PFS industrial use showed ecological efficiency of the plasma technology. When plasmatrons operate in the regime of plasma stabilization of pulverized coal flame, NO_X emission is reduced twice and amount of unburned carbon is reduced four times. The PFSs reduce the temperature at the exit of the furnace. Tests of the PFS for the boiler BKZ-420 of Almaty TPP-2 cold startup confirmed the possibility of high-ash Ekibastuz coal ignition in the cold furnace without heating of primary air.

1. Introduction

At present, most of the power plants in Russia, Kazakhstan, and some other countries work with coal of low quality, containing a lot of impurities (ash, soil, etc.). Due to this, the problem of providing efficient self-sustained burning of such coals remains increasingly important. Often this problem is traditionally solved by using, for example, fuel oil for the purpose of both ignition and stabilisation of burning. Then the combustion of coal in some industrial boilers goes with up to 40% (in heat equivalent) addition of high-calorific start-up and back-up fuel. However, this solution has shortcomings in terms of high cost, difficulties in storage and supply of fuel oil, high temperature corrosion of heated surfaces, decrease in the overall efficiency, and the appearance of heavy metals and other highly toxic components in the exhaust [1].

Thermal power plants (TPP) fired by pulverized coal are encountered with the problems related to combustion stability during the periods when low quality coal is fed into the boiler's furnace. Usually, fuel oil burners are used for the fire support.

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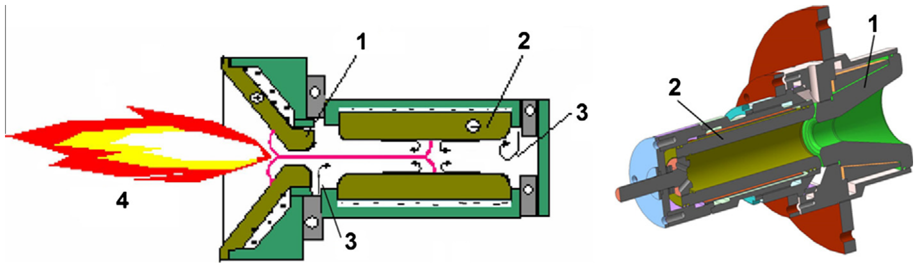

Fig. 1. Sketch of the DC plasmatron: (1) anode, (2) cathode; (3) air and (4) plasma flame.

Annual consumption of fuel oil for start-up and support at TPP in Russia is estimated on 5 million tons with the tendency of increase. In Kazakhstan this amount is 1 million tons per year. Nearly half of this amount was used for the coal flame support. In order to replace existing way of combustion support by oil fuel, modern concept based on plasma generators (plasmatrons) was introduced [2].

To improve efficiency of solid fuels use, to decrease fuel oil rate in fuel balance of TPP and to minimize harmful emissions a plasma technology of coal ignition, gasification and incineration was developed [2,3]. This technology is plasma thermo-chemical preparation of coal for burning. In the framework of this concept some portion of pulverized solid fuel (PF) is separated from the main PF flow and undergone the activation by arc plasma in a special chamber with plasmatron – PFS (Figs. 1 and 2, stage (1). The air plasma flame is a source of heat and additional oxidation, it provides a high-temperature medium enriched with radicals, where the fuel mixture is heated, volatile components of coal are extracted, and carbon is partially gasified. This active blended fuel can ignite the main PF flow (Fig. 2, stage (2) supplied into the furnace. This technology provides boiler start-up and stabilization of PF flame and eliminates the necessity for additional highly reactive fuel.

Plasma assisted combustion is rather popular by now and it is disseminating around the world widely [1,3–8]. The value of PFS to reduce fuel oil consumption during low load, start-up, and commissioning periods has been demonstrated by its installation in over 500 coal-fired utility boilers worldwide. Despite the ability to maintain a stable flame for most coals, however, PFS do encounter difficulty to ignite some lignite, high ash coals and anthracite. Computational fluid dynamics can be a useful tool for the development and customization of PFS to address this problem. Numerical experiment on plasma assisted combustion in coal-fired utility boiler of 420 t/h steam productivity demonstrated a way of the problem solution of high ash coal ignition and combustion.

2. Plasma-fuel system

The plasma thermo-chemical preparation of coal is schematically illustrated in Fig. 2. In this technology pulverized coal is replaced traditionally used for the boiler start-up and pulverized coal flame stabilization fuel oil or natural gas. Part of the coal/air mixture (stage 1) is fed into the PFS where the plasma-flame from plasmatron, having a locally high concentration of energy, induces gasification of the coal and partial oxidation of the char carbon. As coal/air mixture is deficient in oxygen, the carbon being mainly oxidized to carbon monoxide. As a result, a highly reactive fuel (HRF) composed of mixture of combustible gases (at a temperature of about 1300 K) and partially oxidized char particles is obtained at the exit of the PFS. In the case of high ash coal the second stage of PFS can be organized. First stage HRF interacts with the second part of air/coal mixture producing by this more HRF. On entry to the furnace, HRF is easily ignited mixing with the secondary air (Fig. 2).

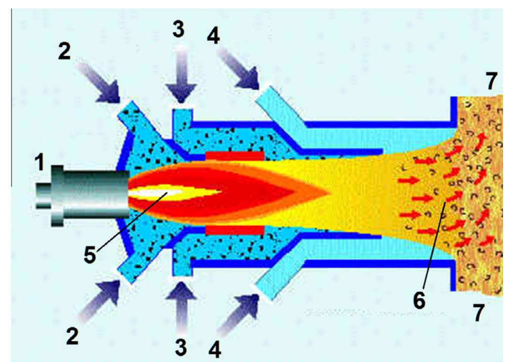

Fig. 2. Sketch of the plasma-fuel system (PFS): (1) plasmatron, (2) primary air/coal mixture (stage 1), (3) primary air/coal mixture (stage 2), (4) secondary air, (5) plasma flame, (6) plasma activated pulverised coal flame and (7) furnace.

Table 1
Technical characteristics of the DC arc linear plasmatron.

Plasmatron power, kW	50–200
Voltage, V	250–400
Arc current, A	200–500
Weight of the plasmatron, kg	25
Resource of continuous work, h	250 (cathode); 500 (anode)
Plasma-forming gas (air) consumption, kg/h	50–100
Temperature of the plasma flame, K	3000–6000

The core of PFS is an arc linear plasmatron (Fig. 1). It consists of copper water-cooled electrodes (cathode and anode) through which the plasma forming air is blown. The plasmatron power is varied from 50 to 200 kW. Its height is 0.4 m, diameter – 0.25 m, and its weight is 25 kg. The measured thermal efficiency of the plasmatron is 85%. Technical characteristics of the DC arc linear plasmatron are shown in Table 1.

Features of fuel–air mixture interaction with arc plasma in the PFS are given in Fig. 3. Across the plasma flame, coal particles with an initial size of 50–100 μm experience 'heat shock' and disintegrate into fragments of 5–10 μm. This increases the active interface of the particles, significantly accelerating the devolatilisation (CO, CO_2, H_2, N_2, CH_4, C_6H_6 and others) and 3–4 times accelerates the process of oxidation of fuel combustibles.

3. PFS industrial tests

The PFS have been tested for boilers plasma start-up and PF flame stabilization in different countries at 30 power boilers steam productivity of 75–950 t/h equipped with different type of PF burners [3]. At PFS testing power coals of all ranks (shale, lignite, bituminous, anthracite and their mixtures) were used. Volatile content of them varied from 4% to 50%, ash – from 15% to 48% and calorific values – from 6700 to 25100 kJ/kg.