Plasma Technology for Enhancement of Pulverized Coal Ignition and Combustion.

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Abstract: This paper presents a new effective and ecologically friendly plasma technology for enhancement of pulverised coal ignition and combustion. Plasma-fuel systems (PFS) have been developed to realize this technology. PFS is pulverized coal burner equipped with arc plasmatron. The base of the PFS technology is plasma thermochemical preparation of coal for burning. It consists in heating of coal/air mixture by plasma up to temperature of coal volatiles release and char carbon partial gasification. In PFS the coal/air mixture is deficient in oxygen and the carbon is oxidised mainly to carbon monoxide. At the exit of PFS a highly reactive mixture of combustible gases and partially gasified char particles is formed while the temperature of the mixture is around 1300 K. Further mixing with the air promotes intensive ignition and complete combustion of it.

PFS have been tested at power boilers of 75 to 950 t/h steam-productivity. Power coals of all ranks were used. Volatile content of them was from 4 to 50%, ash varied from 15 to 56% and heat of combustion was from 1600 to 6000 kcal/kg.

Keywords: plasmatron, coal, ignition, thermochemical preparation

1. Introduction

To improve efficiency of solid fuels use, to decrease fuel oil rate in fuel balance of thermal power plants (TPP) and to minimize harmful emissions the large-scale plasma technology of coal ignition, gasification and incineration was developed [1-3]. This technology is thermo-chemical plasma 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). 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 arc extracted, and carbon is partially gasified. This active blended fuel can ignite the main pf flow supplied into the furnace. This technology provides boiler start-up and stabilization of pf flame and eliminates the necessity for additional highly reacting fuel.

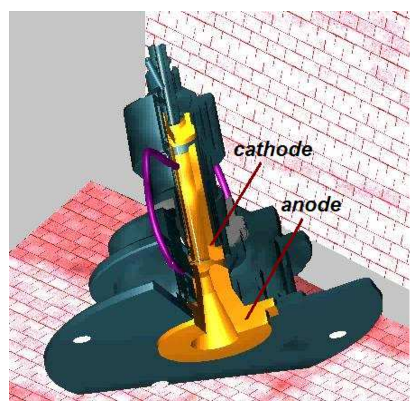

Figure 1. Sketch of the plasmatron.

2. Plasma-Fuel System

The plasma thermo-chemical preparation of coal is schematically illustrated in Fig. 2. The arc plasmatron (Fig. 1) consists of copper water-cooled electrodes (cathode and anode) through which the plasma forming air is blown. The plasmatron power is varied from 100 to 200 kW. Its height and diameter are 0.4 m and 0.25 m, respectively and its weight is 25 kg. The measured energy conversion efficiency of the plasmatron is some 85%.

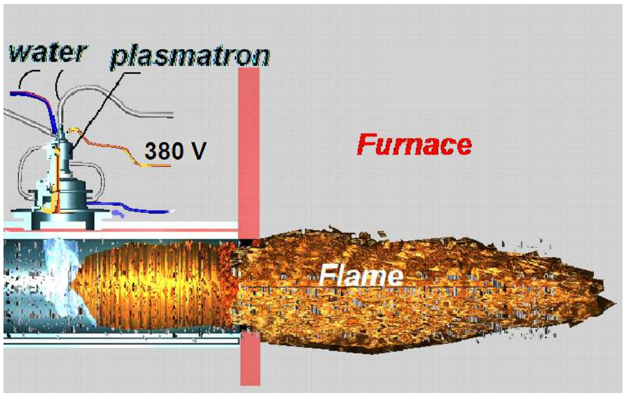

Figure 2. Sketch of the Plasma-Fuel System (PFS).

Features of fuel-air mixture interaction with arc plasma in a 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.

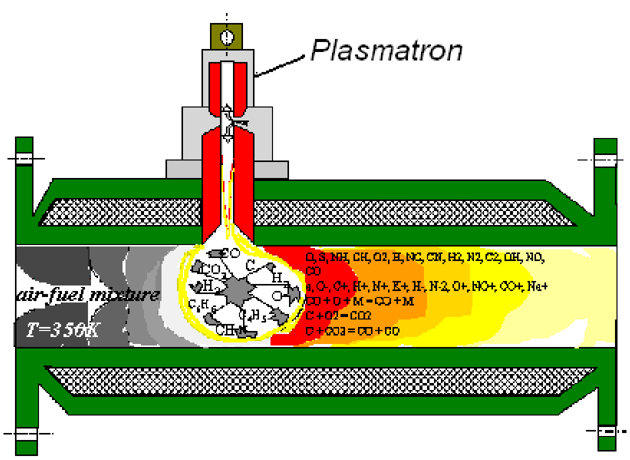

Figure 3. Features of arc plasma interaction with air-fuel mixture in the PFS.

3. PFS Industrial Tests

PFS have been tested for boilers plasma start-up and flame stabilization in different countries at 30 power boilers steam productivity of 75 to 670 ton per hour equipped with different type of pulverized coal burners [4]. At PFS testing power coals of all ranks (lignite, brown, 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.

For example, the PFS has been incorporated in the furnace of a 640 t/h steam full-scale steam raising boiler (Gusinoozersk TPP, Eastern Siberia, Russia). A schematic view of the furnace equipped with the PFS, along with its main dimensions, is shown in Fig. 4. The furnace consists of two symmetrical combustion chambers (semi-furnaces), each provisioned with 8 tangentially directed pf burners in two layers. The combustion chambers are interconnected by a central section. Each burner comprises a primary air/pf delivery section and a secondary air section. Four PFS take the place of the four lower layer burners as shown on the right side of Fig. 4. The plasmatrons operate during the boiler warm-up period and in the case of an unstable flame. When the boiler performance is stabilised, the plasmatrons are switched off and the PFS continue to function as conventional pf burners. In the case of flame instability, the plasmatrons are restarted. The fuel was Tugnuiski bituminous coal of 20 % ash content and 35 % of volatile matter. In total, four of the combustors of this TPP were equipped with sixteen PFS. It is estimated that, since 1995, more than 20000 tons of fuel oil has been saved in this facility. This corresponds to a reduction in the emissions of nitrogen and sulphur oxides, carbon monoxide and vanadium pentoxide of some 13000 tons per year.

Fig. 5 illustrates the scheme of arrangement of the PFS on the boiler combustor BKZ-420 in Ulan-Bator TPP-4 (top view). Twelve corner-fired burners are placed at three elevations. Two PFS were mounted cornerwise on the lower layer. All eight boilers of the power plant were equipped with PFS for fuel oil free boiler start-up. In 2-3 seconds after light-up with the PFS, the temperature of both pulverised coal flames increased up to 1100-1150°C. After one hour, the temperature of the flames had achieved 1260-1290 ^{O}C and were about 7 - 8 m in length. In accordance with the operating instructions, the total duration of the boiler start-up was 4 hours.

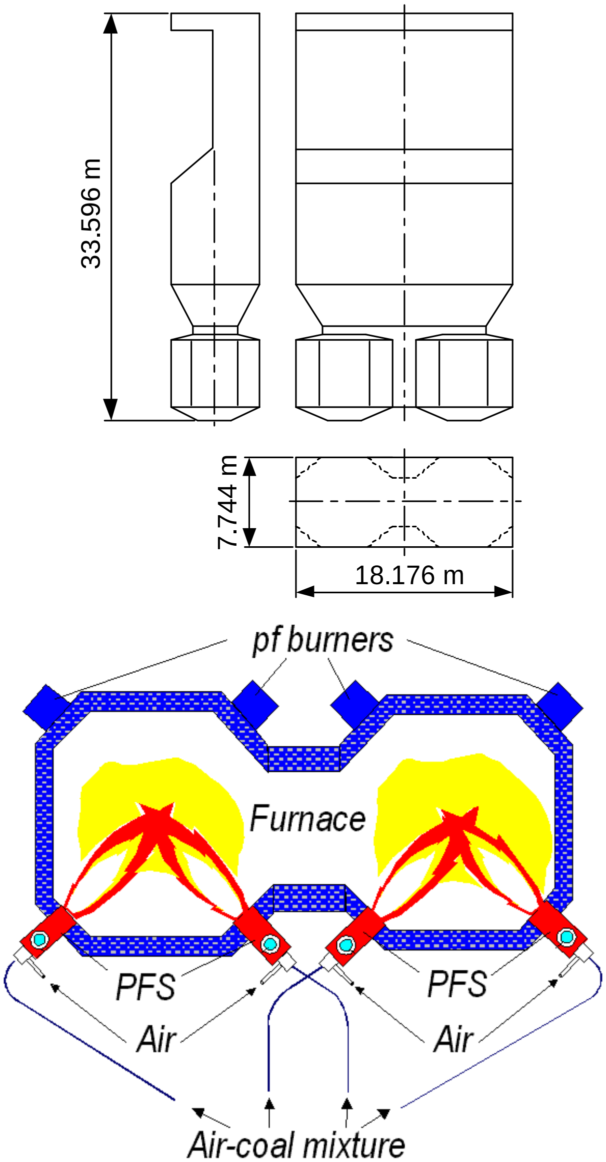

Figure 4. Scheme of the industrial furnace of BKZ 640-140 boiler and the boiler furnace equipped with four PFS (top view).

Fig. 6 demonstrates a scheme of arrangement of three plasma generators on a direct-jet flat-flame pulverised-coal burner of the low layer of BKZ-640 boiler at Gusinoozersk TPP (from the left it is the top view; from the right it is the cross section).

Knowledge of the specific power consumption of a plasmatron is required to estimate PFS efficiency. This parameter is defined as the ratio of plasmatron electric power to pf consumption in the PFS. Figs. 7 and 8 present experimental results for NO_X reduction and the decrease of unburned carbon during PFS operation versus specific power consumption for the plasmatron. It is seen that the NO_X concentration is halved, and the amount of unburned carbon is reduced by a factor of 4. The NO_X decrease is caused by the fact that the fuel nitrogen, released from the coal inside the PFS in conditions of oxygen deficiency, forms molecular nitrogen in the gas phase. Since the fuel nitrogen is evolved inside the PFS and converted to molecular nitrogen there, mainly thermal nitrogen oxides are formed within the combustor volume. However, fuel nitrogen is the main source of nitrogen oxide emission from conventionally-fired pf combustors [5]. As to unburned carbon (Fig. 8), its decrease indicates a fuel reactivity increase which is explained by enlargement of the coal particles reactive surface due to 'heat explosion' and fragmentation as a result of their interacting with arc plasma.

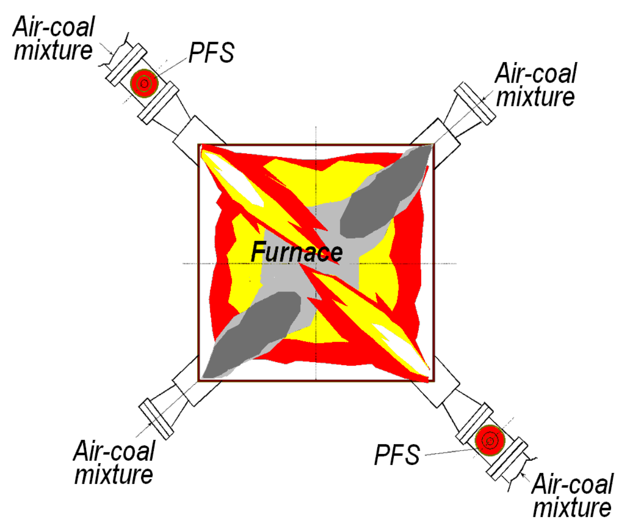

Figure 5. BKZ-420 boiler furnace equipped with two PFS (top view).

Conclusions

Developed, investigated and industrially-tested plasma-fuel systems improve coal combustion efficiency, while decreasing harmful emission from pulverized-coal-fired Thermal Power Plants.

PFS eliminate the need for expense gas or oil fuels on start-up, stabilisation of pulverized-coal flame and stabilization of liquid slag output in furnaces with liquid slag removal.

PFS improve coal ignition and burnout without the need for such remedies as increasing the mill temperature, augmenting the excess air factor, or finer grinding.

Power consumption for PFS does not exceed 2% from heat capacity of the reequipped pf burner and payback period is not more than 18 months.

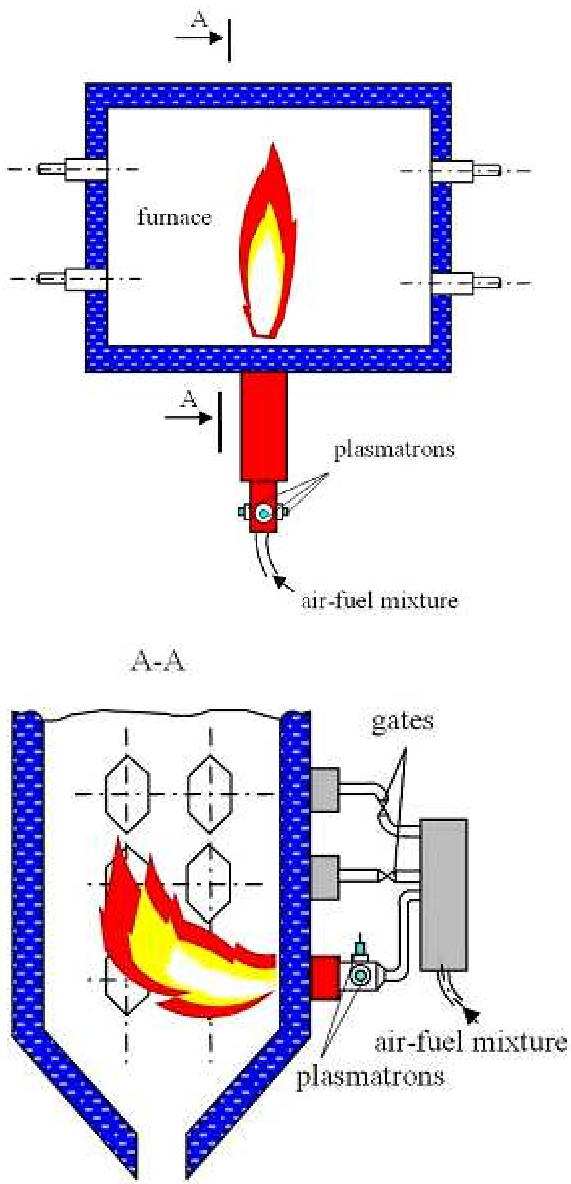

Figure 6. Scheme of arrangement of burners and PFS on BKZ-640 boiler (Gusinoozersk TPP).

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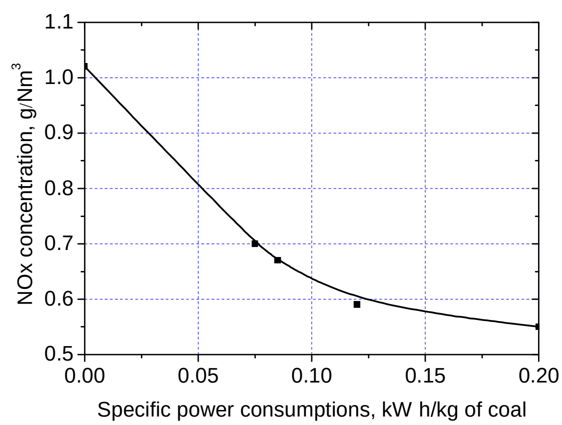

Figure 7. Specific power consumption influence onto reduction of nitrogen oxides concentration at plasma aided pulverised coal combustion.

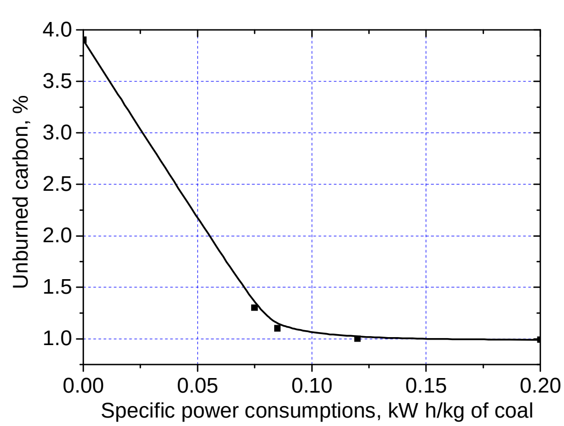

Figure 8. Specific power consumption influence onto reduction of unburned carbon at plasma aided pulverised coal combustion.