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PLASMA ENHANCEMENT OF COAL DUST COMBUSTION

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Coal fired enterprises face two problems, the first being the necessity to use expensive oil for boilers start up and the second being the increased commercial pressure requiring operators to burn a broader range of coals, possibly outside the specifications envisaged by the manufacturer's assurances for the combustion equipment. Each of these problems results in a negative environmental impact. Oil firing for start up increases the gaseous and particulate burden of the plant. The firing of poorer quality coals has two disadvantages: reduced flame stability performance necessitating oil support and its consequential emissions and cost implications; and reduced combustion efficiency due to an increased amount of carbon in the residual ash, resulting in an increase of emissions per MW of power generated. Plasma enhancement of coal dust combustion represents a new effective and ecologically friendly technology, which is equally applicable to alternative 'green' solid fuels. Plasma Preparation of Coal Dust for Burning (PPCDB) addresses the above problems in Thermal Power Plants (TPP). The realisation of this technology comprises two main steps. The first includes numerical simulations and the second involves full-scale trials of plasma supported coal combustion in a TPP boiler. This paper presents numerical study of plasma assisted coal combustion in comparison with traditional coal combustion at the boiler of 75 ton per hour steam productivity of Shahtinsk TPP (Kazakhstan). The boiler is equipped with four axial-spade vortex three-channel pulverized fuel (pf) burners arranged in one layer by two ones in the front and in the rear. Coal consumption through the burner is 3.2 tonne per hour. That is bituminous coal with 35.1 % ash content, 22 % volatile content, 10.6%moisture and caloricity of 18550 kJ/kg.

In the framework of PPCDB concept some portion of coal dust air mixture – pulverized fuel is separated from the main pf flow and undergone to activation by low temperature plasma in a special chamber. It is Plasma-Fuel System (PFS) (Fig.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 supplied into the furnace. This technology provides boiler start up and stabilization of pf flame and eliminates necessity in additional highly reacting fuel for it.

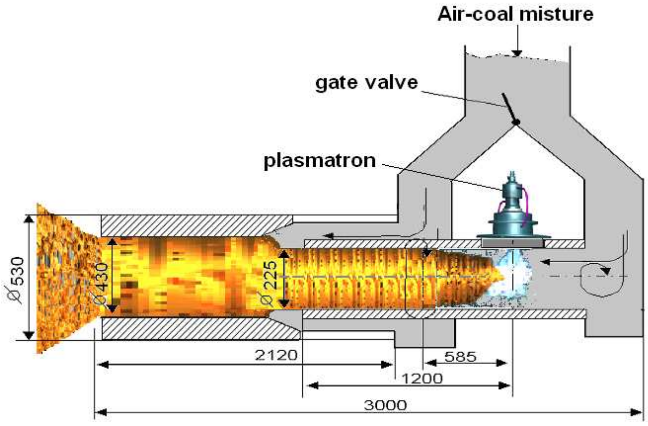

Fig. 1. Sketch of PFS

The process of PPCDB in the PFS (Fig.1) was numerically investigated using the 1-D software code PLASMA-COAL [1]. The code allows the modelling of a biphasic (coal particles and an oxidizing gas) chemically reacting stream with an internal heat source (electric arc, plasma torch, or chemical reactions). The model employs a detailed kinetic scheme of chemical transformations that takes into account not only the volatiles release and coke gasification reactions but also the subsequent conversion of their products in the gas phase. The temperature dependence of the reaction rate constants is given by the Arrhenius law. The kinetic scheme used in the model includes 116 chemical reactions. The first chemical step of coal conversion in PFS is the release of coal volatiles (CO, CO_2, CH_4, H_2, H_2O, C_6H_6, C_5H_5N, C_4H_5N, CH_3SH, C_4H_4S). Then two parallel steps follow, namely the gasification of the coke residue, including the oxidation of fuel nitrogen (seven reactions with H_2O, CO_2, CO, O_2, NO, H_2S), and gas-phase chemical transformations of the products formed. To describe the NO formation process, we considered a model consisting of 36 chemical reactions and taking into account the conversion of fuel, thermal, and prompt nitrogen oxides. The reactions of release of nitrogen-containing volatiles (C_5H_5N and C_4H_5N) from coal to the gas phase, the oxidation of atomic nitrogen present in the coal, and its subsequent transformations to NO through HCN and NH_3 were also taken into consideration.

The calculations were performed for the PFS (Fig.1) equipped with a 200 kW plasma torch. The wall temperature of the PFS was 700 K, the average diameter of coal particles was 60 μm, the temperature of the feed air–fuel mixture at the PFS inlet was 418 K, and the PFS coal throughput was 3.2 t/h. The heat efficiency of such a plasma fuel system was taken to be 90% on the basis of experimental data [1]. The results of numerical simulation by the PLASMA-COAL code are summarized in Table 1. These data obtained for the PFS exit were taken as initial parameters for 3-D computation of the furnace of a power-generating boiler equipped with PFS. This computation was performed using CINAR ICE ‘CFD’ code [2] to demonstrate advantages of plasma aided coal combustion technology. CINAR ICE ‘CFD’ code has been designed to provide computational solutions to industrial problems related to combustion and fluid mechanics. This code solves equations for mass, momentum and energy conservation. Physical models are employed for devolatilisation, volatiles combustion (fast un-premixed combustion), the combustion of char and the turbulence (k-ε).

Table 1. Composition of the products of the pulverized coal plasma activation.

Composition of the gaseous phase (vol.% & kg/h)								Ash, kg/h	Char carbon, kg/h
H_2	CO	CH_4	C_6H_6	CO_2	H_2O	N_2	O_2		
14.2	18.4	0.3	0.6	6.8	2.9	56.4	0.3	1123.2	816.0
88.5	1599.0	14.0	133.8	931.2	162.8	4911	31.0		

Gas temperature (K)	Solids temperature (K)	Velocity of the stream (m/s)
1270	1270	189.4

Two variants were calculated: conventional coal incineration and plasma aided coal combustion. To compute the second variant it was supposed that two PFS were mounted instead of two neighbour pf burners.

The grid for the mathematical simulation is defined by 116 x 96 x 69 grid lines in three directions (x, y and z).

Fig.2 demonstrates temperature fields on the level of the burners at conventional regime of coal incineration and at incineration of coal in the boiler equipped with two PFS destined for the boiler plasma start up and low-rank coals flame stabilization. The flames from opposite burners form common core mass averaged temperature of which is about 1650^{o}C (Fig. 2 a), wile at PFS operation mode (Fig. 2 b) mass averaged temperature of the flames core is more than 1900^{o}C. Under such conditions, the area of the maximal temperatures is removed to the exit of the burners without plasmatrons. It is consequence of high velocities and temperatures flowing out of the PFS high-reactive two-component fuel had been formed because of PPCDB (Table 1).

Fig. 3 shows temperature fields along the furnace height in the mean cross-sectional plane parallel to the burners’ disposition plane. Like the previous figure, here there is an express area of the opposite burners flames interaction. When the coal combustion is in conventional mode, it looks like a five-point star with temperature up to 1700^{o}C (Fig.3 a), but when PFS are used this area takes larger volume of the furnace while temperature achieves 1900^{o}C at more uniform distribution. Temperature in the upper part of the furnace is 400-450 degrees higher when the furnace works in the regime of the coal plasma activation.

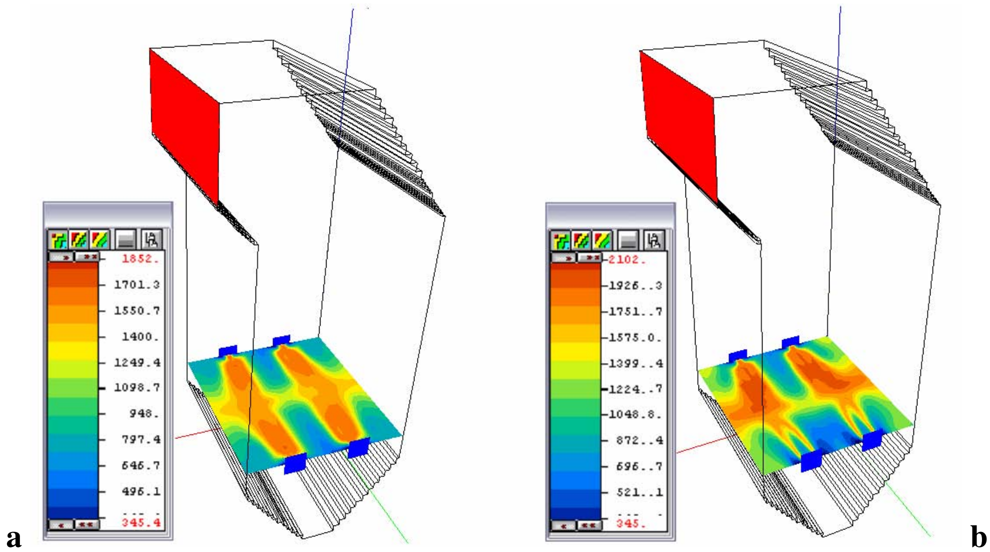

Fig. 2. Temperature fields on the level of the burners. (a) is conventional coal combustion, (b) is plasma supported coal combustion using 2 PFS instead of 2 nearby pf burners.

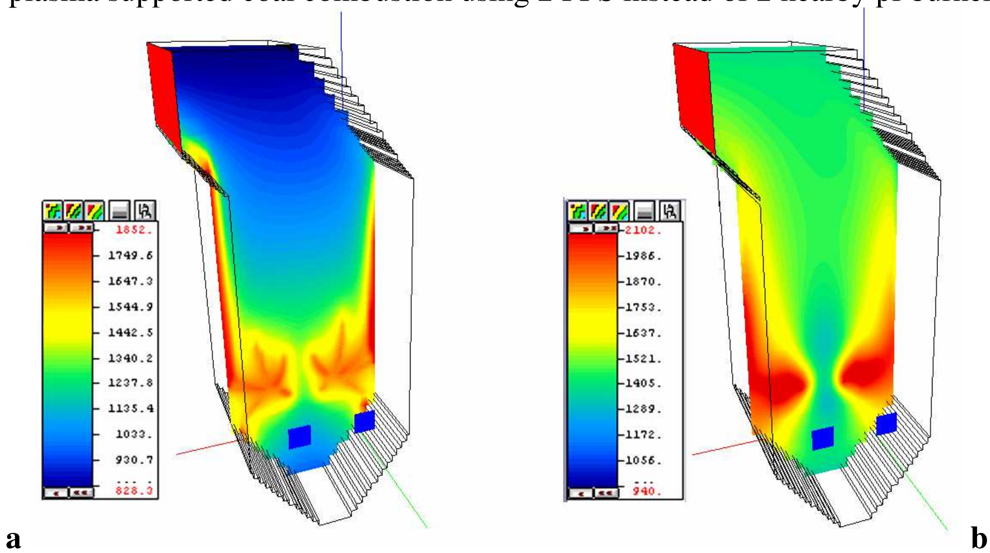

Fig. 3. Temperature fields along the furnace. (a) is conventional coal combustion, (b) is plasma supported coal combustion using 2 PFS instead of 2 nearby pf burners.

Averaged temperature of the flue gas is 875^{o}C under conventional coal combustion, and it is 1435^{o}C when two PFS work. This is a result of the coal burnout improvement on application of plasma. Specifically, unburned carbon concentration decreased two times form 1.4 to 0.7%. That compensates power inputs for two PFS operation, specific power consumption of which is 0.6 % of the boiler heat capacity.

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[2] Gorokhovski M.A., Jankoski Z., Lockwood F.C., Karpenko E.I., Messerle V.E., Ustimenko A.B. Enhancement of Pulverized Coal Combustion by Plasma Technology // Combustion Science and Technology, 2007. Vol.179: N.10, P.2065–2090