Plasma Arc Burner for Pulverized Coal Combustion

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***Abstract*—**Development of new highly efficient plasma arc combustion system of pulverized coal is presented. As it is well-known, coal is one of the main energy carriers by means of which electric and heat energy is produced in thermal power stations. The quality of the extracted coal decreases very rapidly. Therefore, the difficulties associated with its firing and complete combustion arise and thermo-chemical preparation of pulverized coal becomes necessary. Usually, other organic fuels (mazut-fuel oil or natural gas) are added to low-quality coal for this purpose. The fraction of additional organic fuels varies within 35-40% range. This decreases dramatically the economic efficiency of such systems. At the same time, emission of noxious substances in the environment increases. Because of all these, intense development of plasma combustion systems of pulverized coal takes place in whole world. These systems are equipped with Non-Transferred Plasma Arc Torches. They allow practically complete combustion of pulverized coal (without organic additives) in boilers, increase of energetic and financial efficiency. At the same time, emission of noxious substances in the environment decreases dramatically. But, the non-transferred plasma torches have numerous drawbacks, e.g. complicated construction, low service life (especially in the case of high power), instability of plasma arc and most important – up to 30% of energy loss due to anode cooling. Due to these reasons, intense development of new plasma technologies that are free from these shortcomings takes place. In our proposed system, pulverized coal-air mixture passes through plasma arc area that burns between to carbon electrodes directly in pulverized coal muffler burner. Consumption of the carbon electrodes is low and does not need a cooling system, but the main advantage of this method is that radiation of plasma arc directly impacts on coal-air mixture that accelerates the process of thermo-chemical preparation of coal to burn. To ensure the stability of the plasma arc in such difficult conditions, we have developed a power source that provides fixed current during fluctuations in the arc resistance automatically compensated by the voltage change as well as regulation of plasma arc length over a wide range. Our combustion system where plasma arc acts directly on pulverized coal-air mixture is simple. This should allow a significant improvement of pulverized coal combustion (especially low-quality coal) and its economic efficiency. Preliminary experiments demonstrated the successful functioning of the system.

***Keywords*—**Coal combustion, plasma arc, plasma torches, pulverized coal.

I. Introduction

At heat power stations, in combustion of heavily ballasted coals that cannot burn by themselves, especially under conditions of minimum loads, it is necessary to provide a maximum intensification of the pulverized coal flame with fuel oil [1]. In this case, the share of fuel oil in total heat released in a boiler furnace may amount to 30%. Combustion of coal with fuel oil in the above proportions leads to intensive high-temperature corrosion of screens, dramatic decrease in burnout of particles of a solid fuel (its unburned part is emitted together with ash and fume), chemical underburning, increase in the amount of pollutant emissions (compared with coal, fuel oil contains twice as much sulfur), and increase in the rate of accidents with steam superheaters. As a result, this causes reduction in the efficiency of boilers [1]. In order to improve the efficiency of coal combustion, new plasma-fuel system for thermal power plants is developed. It is pulverized coal burner equipped with arc plasmatron. It provides fuel oil-free startup of pulverized coal fired boilers, flame stabilization, and as a consequence, the simultaneous decrease of unburned carbon and nitrogen oxides formation due to two-stage combustion [2]. Plasma-fuel systems procedure is based on plasma thermos-chemical activation of coal for burning. It consists in arc plasma heating of air-fuel mixture up to the temperature of coal devolatilization and carbon residue partial gasification. By that initial coal high or low rank from air-coal mixture, hot combustible gas and highly-reacting coke residue is obtained. When mixed with secondary air at furnace, it can be ignited and burn stably without use of fuel oil or natural gas traditionally used for boilers start up and low-rank coals flame stabilization [3]. The use of plasma-fuel systems at thermal power plants decreases the unburned carbon by 40-50%, nitrogen oxides by 50-60%, and carbon dioxide emissions can be reduced by 1-2%.

II. Plasma Assisted Start-Up of Coal Burners

The idea behind a plasma-assisted pulverized coal burner (PAPCB) is to blow plasma torch into the pipe through which pulverized coal in air flows (Fig. 1) [4]. The procedure of plasma assisted start-up of a pulverized coal-fired boiler is similar to the procedure of start-up of a boiler using heavy oil.

The essence of plasma assisted start-up procedure is that the plasma assisted pulverized coal burners (PAPCB) with installed plasmatrons are fired first. The remaining pulverized coal burners are started gradually after reaching the required thermal parameters of the furnace and other elements of the boiler [4].

Fuel-air mixture interaction with plasmaflow in a plasma-fuel system (PFS) is given in Fig. 2. Across the plasma flame, coal particles with an initial size of 50-100 mm experience ‘heat shock’ and disintegrate into fragments of 5-10 mm. This increases the active interface of the particles, significantly accelerating the devolatilization (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 [5], [7].

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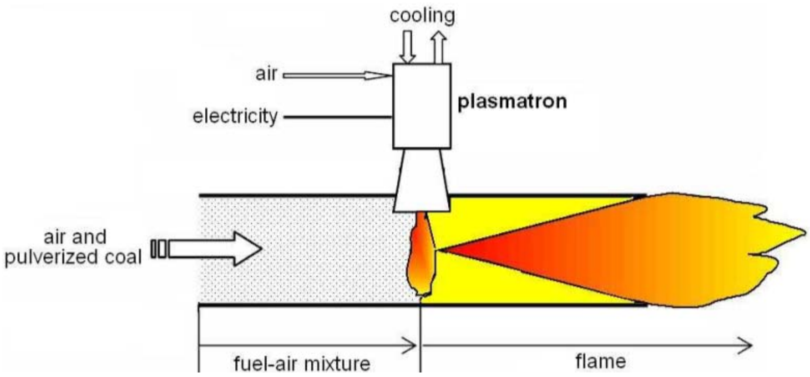

Fig. 1 Working principle of the plasma assisted pulverized coal burner (PAPCB)

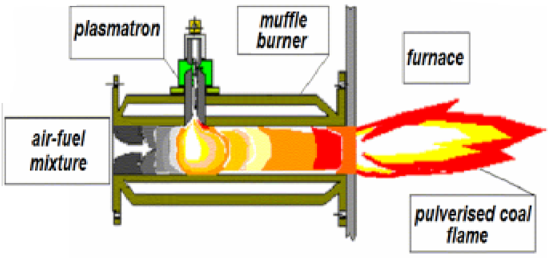

Fig. 2 Plasmatron and scheme of its mounting onto direct flow pulverized coal burner (PFS) [7]

Figs. 3 and 4 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 [5], [6].

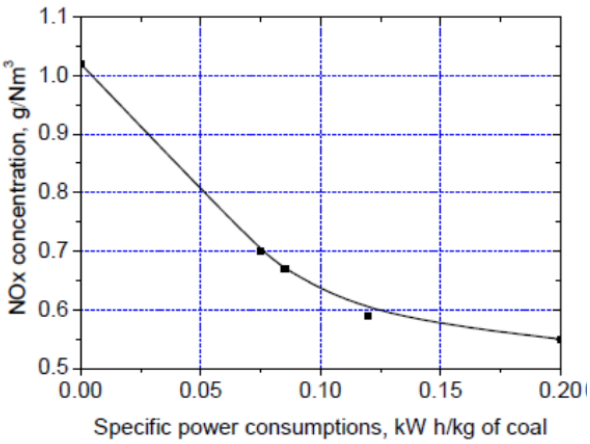

Fig. 3 Specific power consumption influence onto reduction of nitrogen oxides concentration at plasma aided pulverized coal combustion [6]

Numerous studies have shown and proved the ecological and financial efficiency of the use of plasma technology for coal combustion.

For more complete environmental effect, it is most rational to increase quantity of the PFS on the furnace and to mount them on all burners. It will allow decrease of unburned carbon and nitrogen oxides to the maximum permissible concentration and even less [7].

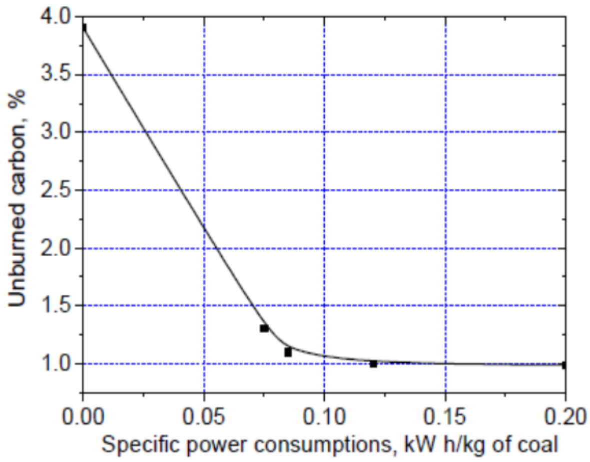

Fig. 4 Specific power consumption influence onto reduction of unburned carbon at plasma aided pulverized coal combustion [6]

III. Plasma ARC Burner

PFS provide fuel oil-free lighting up of pulverized-coal boilers, stabilization of flame and, as a result, simultaneous decrease in mechanical underburning of fuel and formation of nitrogen oxides and sulphides [1]. Advantages of using plasma assisted technologies for pulverized coal combustion are proved by many researches and they work in many countries. All these systems are equipped with different types of DC Non-Transferred plasma torches. This means that the plasma arc burns between the cathode and the anode inside the Torch.

As shown in Fig. 5, it has a complex design need for a working gas to create a plasma flow, an anode cooling water system, and in some cases the magnetic field coils for compressing and stabilizing plasma arc.

In the case of using high powers (more than 20 kW), the serves life of the electrodes (especially the anode) is decreased, the instability of the plasma arc and the energy loss due to anode cooling are increased, and the design of the torch becomes more complicated.

Our research team has developed the lab model of plasma arc burner and its power source (15 kW). As it shown in Fig.

6, in our proposed system, pulverized coal air mixture passes through the long plasma arc area that burns to carbon electrodes directly in pulverized coal burner.

Advantages of the proposed plasma arc burner in comparison with the using DC non-transfer plasma torches are following: there is no need for a working gas to create a plasma flow, hence, devices for it; the costs of carbon electrodes are low and they can be made from the same coal that is pulverized; the electrodes are not cooled, so there is no need for a cooling system for them, and there is no energy loss on this unit; total power of long plasma arc (radiation of arc column), directly impacts on coal-air mixture that accelerates the process of coal devolatilization and carbon residue partial gasification.

As already mentioned, an arc burns inside of moving mixture, therefore there are rapid changes of arc resistance, so arc stability is a key point.

In our case, the power supply has a volt-ampere characteristic that ensures an almost constant current during arc burning, and the oscillation of the arc resistance is automatically compensated by voltage change. Hence, stability of the arc is achieved. Also, we can regulate plasma arc length and preliminary value of amperage.

Our combustion system, where a long plasma arc acts directly on a pulverized coal-air mixture, is technically simple compared to systems using plasma torches, and has the ability to adjust the arc length as needed.

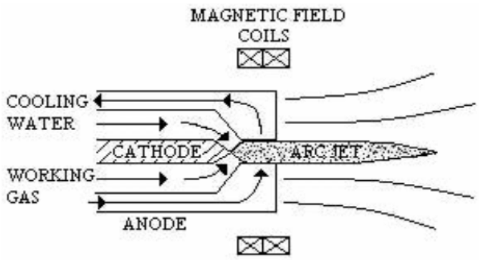

Fig. 5 Non-transferred plasma torch typical scheme

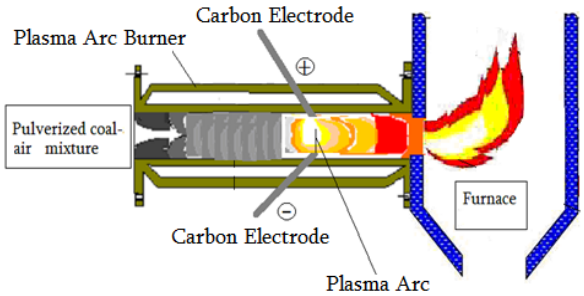

Fig. 6 General scheme of plasma arc burner system for pulverized coal combustion

In Fig. 7, pulverized coal flame of plasma arc burner is shown.

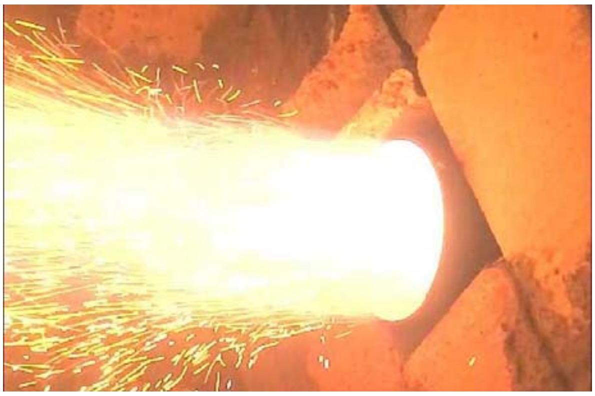

Fig. 7 Pulverized coal flame of plasma arc burner

In addition, the results of chemical analysis of the metal that has been smelted from coal ash are shown in Figs. 8-13.

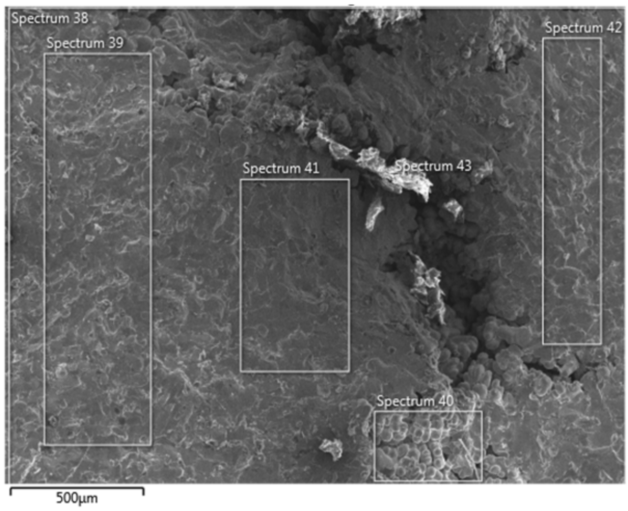

Fig. 8 Electron image

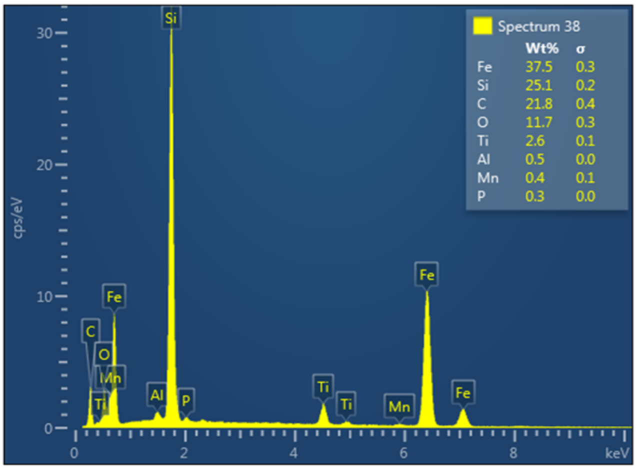

Fig. 9 Composition of materials on Spectrum 38

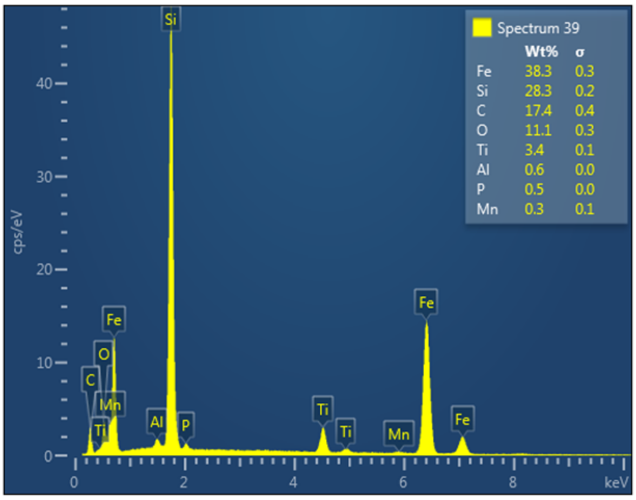

Fig. 10 Composition of materials in Spectrum 39

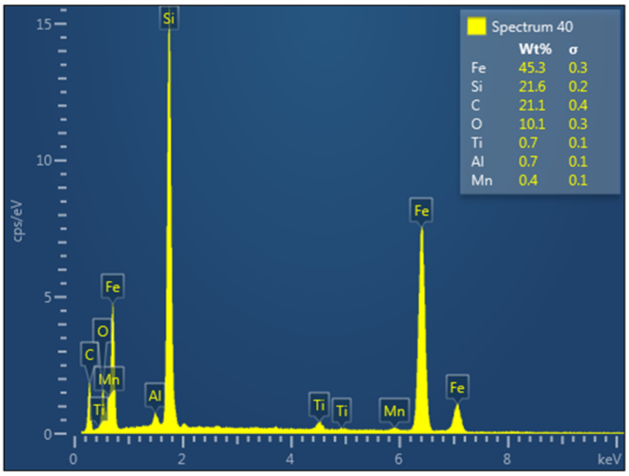

Fig. 11 Composition of materials in Spectrum 40

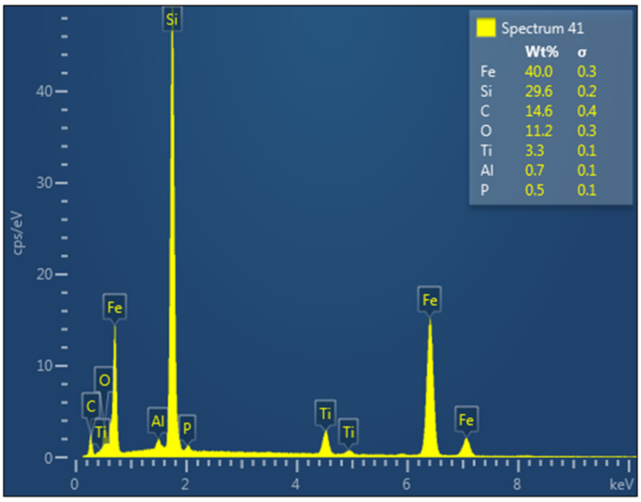

Fig. 12 Composition of materials in Spectrum 41

Result Type	Weight %					
Spectrum Label	Spectrum 43	Spectrum 38	Spectrum 39	Spectrum 40	Spectrum 41	Spectrum 42
C	31.12	21.82	17.43	21.15	14.64	14.59
O	22.10	11.67	11.07	10.08	11.20	11.40
Al	0.39	0.54	0.60	0.70	0.70	0.52
Si	10.41	25.12	28.34	21.58	29.63	28.90
P	0.15	0.35	0.51		0.46	0.53
S	1.02					
Cl	0.19					
Ca	0.36					
Ti	0.78	2.63	3.41	0.74	3.34	3.04
Mn		0.36	0.31	0.42		0.37
Fe	33.50	37.51	38.33	45.34	40.03	40.64
Total	100.00	100.00	100.00	100.00	100.00	100.00

Statistics	C	O	Al	Si	P	S	Cl	Ca	Ti	Mn	Fe
Max	31.12	22.10	0.70	29.63	0.53	1.02	0.19	0.36	3.41	0.42	45.34
Min	14.59	10.08	0.39	10.41	0.15	1.02	0.19	0.36	0.74	0.31	33.50
Average	20.13	12.92	0.58	24.00					2.32		39.22
Standard Deviation	6.21	4.53	0.12	7.30					1.24		3.91

Fig. 13 Average composition

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