ADVANCED APPROACH TO DEVELOPING EQUIPMENT FOR PLASMA ASSISTED OIL FREE STARTING SYSTEMS FOR PULVERIZED COAL POWER STATION

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Abstract

New generation of the equipment including the series of dc plasma torches with inter electrode insertion and 'diffusion' attachment of arc on anode surface providing an axially symmetric plasma jet outflow, and radial - annular slit injection of pulverized coal into plasma flow are presented. The approach proposed is very attractive when creating the laboratory and model small-scale experiments as well as for industrial application of plasma assisted oil free ignition and stabilization of combustion of the pulverized coal.

1. Introduction

The analysis of known publications (for instance, see the monographs [1, 2]) in the field of plasma assisted oil free ignition and stabilization of combustion of pulverized coal shows that there are a number of scientific and technical problems which overcoming will permits to improve significantly this technology and to increase its competition ability with conventional ones.

First of all, all known workings commonly use the conventional dc plasma torches (with self-adjusting mean length of arc or mean length of arc stabilized by step). This does not provide a stable axially symmetric outflow of plasma jet. The latter causes to spatial and temporal non-homogeneity of thermal and chemical preparation (TCP) of a coal dust and it succeeding ignition and combustion. In the second place, the methods of feeding a coal dust into a plasma flow used by different authors do not provide the maximum efficiency of the TCP-process. In the third place, by now there are absent the scientific concept of optimization and scaling the systems of plasma ignition and stabilization of pulverized coal combustion depending on rating of a boiler unit, the number and capacity of coal burners used, their relative positions in boiler volume, the total consumption of coal dust, the quality of coal, etc.

2. New generation of equipment for plasma assisted oil free pulverized coal combustion

New approach was proposed and now practically was realized by us during last years. It provides the complex solving the first two problems. This approach is based on using the
highly efficient device including the dc plasma torches with inter-electrode insertion (IEI) and 'diffusive' attachment of arc on an anode surface, and axially symmetrical injection of coal dust into axially symmetric plasma flow through the radial-annular slit placed immediately behind the zone of anode attachment of arc. As a consequence the process of ICP of coal occurs within a high-temperature heterogeneous jet resulting its high thermal efficiency. The feasibility of this approach was borne out experimentally.

Taking into account the aforesaid requirements, 1-10, 10-30, 30-50 and 50-120 kW plasma torches with IEI and outlet copper water-cooled nozzle-anode were designed and developed. The main working gases - nitrogen and air (or their mixture with argon) are supplied into the cathode zone. A small amount of argon is supplied into the anode zone. As it was established in [3], at 25% supply of argon into the anode zone a transition to distributed ('diffusion') arc attachment to anode surface takes place, and specific erosion of the anode material can be reduced till $G \approx 10^{-11}$ kg/C, which ensures not only a long operating life of the anode but a high reproducibility of the powder treatment as well. As it was confirmed by experiments, the plasma jet is axially symmetric and the temperature and velocity fields are quite uniform.

Above-mentioned approach seems to be promising not only from technological viewpoint, but it will provides better understanding the basic phenomena under plasma ignition and stabilization of combustion of pulverized coal, since due to axial symmetry of gas-disperse flow generated its prompt optimization is possible on the basis of joint physical experiment and computer simulation.

3. The series of plasma torches with inter-electrode insertion

For practical realization of the approach there was designed the series of dc plasma torches with IEI and distributed ('diffusion') attachment of arc on anode surface of 1-10, 10-30, 30-50 and 50-120 kW covering the demands of the laboratory and model small scale experiments as well as the industrial requirements at creating the systems of plasma assisted ignition and stabilization of combustion of the pulverized coal. Below we shall present only two plasma torches from the enumerated series.

3.1. Plasma torch of 1-10 kW power

General view of 1-10 kW plasma for laboratory and model small scale experimental studying the basic phenomena occurring under plasma ignition and stabilization of combustion of pulverized coals is shown in Fig. 1. Its main electrical and thermal characteristics are presented in Fig. 2.

3.2. Plasma torch of 50-120 kW power

For future industrial application it was necessary to develop the plasma torch with IEI having the diapason of power of 50-120 kW and operating at high voltage and relatively low current of arc. This problem was successfully solved, and Fig. 3 illustrates the plasma torch designed. The similar integral characteristics are shown in Fig. 4.

In order to provide the necessary operation modes of plasma torch (power variation within the limits 50-150 kW with operating voltage not exceeding 550 V) the power supply module has been elaborated. The open-circuit voltage is 820 V, and the maximal level of power is up to 256 kW. The range of operating current is 120 - 400 A. It consists of two connected in series commercial power supplies APR-404 usually used for air plasma cutting. The flow rate of plasma-forming gas (air) has been varied within 3-7 g/s. Air has also been
applied as a shielding gas. It has been supplied between ultimate section of IEI and the anode with steady flow rate being equal to 1 g/s. The volt-ampere characteristics obtained are shown in Fig. 4, a. It is obvious that within the limits of diapason of regime parameters studied as a whole the weakly dropping volt-ampere characteristics have been derived. The determination of heat losses in plasma torch allowed to obtain the dependencies of heat efficiency of the plasma torch as function of the arc current and flow rate of plasma-forming gas. The results are indicated in Fig. 4, b. It is clear that regardless the value of plasma-forming gas flow rate the dependencies of efficiency versus arc current have a linear behavior. At increasing the arc current the less heat efficiency of the plasma torch takes place. It deals with radiation losses in the channel and heat losses into the electrodes. At increasing the mass flow rate of working gas the heat efficiency of the plasma torch increases. This connects with the fact that the increase of mass flow rate of gas causes the zone of contact of thermal layer of burning arc and cold boundary layer forming lengthwise the channel wall to move downstream. Because of this, the decrease of convection heat transfer happened to be more essential in comparison with their increase as result of growth of turbulence degree.

4. Axially symmetrical injection of coal dust into plasma jet

The productivity and efficiency of process of a powder material treatment in plasma jet are determined to a large extent by the method of introducing the particles into a high-temperature flow. At the specific thermal power of plasma torch the efficiency of interface heat, mass and momentum exchange between particles and carrier plasma flow depends on the duration of their travel within a high-temperature zone of the processing flow. The selection of the injection position and initial velocity of the particles should be matched in such a manner as to ensure penetration of the powder into the core of jet. Analysis of different methods of powder injection has been done in paper [4].

In our opinion, developing the facilities for radial-annular slit injection of powder materials is of principal importance since by arrangement of such injection it is possible to provide the uniform filling the high-temperature jet by a coal dust. Unlike the one-sided injection, one can essentially increase the efficiency of the technological processes.

In order to studying a two-phase flow exhausting from a radial-annular slit injector the photograph of trajectories of particles appearing in the plane of the slot at the enter of cylindrical nozzle was conducted. Of principle optical diagram of the installation created is shown in Figures 5. For proper visualization of motion of the particles injected the lighting by laser radiation was used. Using the collimators L1 and L2 the beam of the Ar+-laser (HLA-120, the output power l=500 mW, l=0.488 µm) was expanded to the beam with diameter being slightly less than that of the inner cylindrical channel of the injector (D=7 mm). Using the mirror M makes the beam enter as the coaxial one into the channel.

For modeling the alumina powder and pulverized coal jet flow in the opposite side of the channel of radial-annular slit injector the exhaust ejector was installed. Constructing their intermediate images provided the photos of the particle trajectories by the objective L1, the back-scattered laser radiation entering the ring aperture 1 laser radiation scattered by particles moving along the channel beyond the plane of the slot causes the presence of background radiation. To decrease level of this background radiation the light shade D1 located on the axis of collimated beam and the shading diaphragm D2 were applied.

The presented optical diagram allowed one to fix trajectories of particles leaving the radial-annular slot for small powder consumption \( G_r = 0.1 \) g/s at different exposures chosen.
For increasing the value of the powder consumption at given exposure of the background radiation proved to exceed useful radiation scattered in the plane of the slit.

In Figs. 5, b, c the photographs of paths of the alumina particles with diameter $D_p=20 \pm 80 \mu m$ and coal particles with diameter $D_p=50 \pm 80 \mu m$ are presented. The range of the regime parameters changing was following the mass flow rate of powder particle $G_p=0.05 - 0.12$ g/s, the flow rate of carrier gas $G_t=0.1 - 0.5$ g/s.

The comparison of this method with two-sided injection of pulverized coal into air plasma jet has been done all other factors the same. With this purpose the plasma torch of 1 kV kW power was equipped by two easily attaching nozzles, i.e. injectors of pulverized coal-air mixture: (1) two-sided injection at angle of 30° to the axis of plasma jet, and (2) radial-annular slit injection. At the model experiments the pulverized coal consumption controlled by this units has being fixed at ~1.2 g/s. The flow rate of carrier gas (air) was equal to 0.3 g/s and 0.5 g/s. The results of comparison (see Fig. 6) permit to conclude that without any commentaries the preference of radial-annular slit injection in comparison with first method.

5. Conclusions

1. There have been developed and tested high-efficient plasma torches with inter-electrode insertion and 'diffusion' arc attachment on anode surface of 1-10, 10-50, 50-120 kW power providing axially symmetric plasma jets flow out.
2. The concept of radial-annular slit powder injection into plasma flow was effectively applied at designing the system of plasma assisted pulverized coal ignition and combustion.
3. The combination of above two devices permits to generate compact highly reactive air plasma jet loaded by pulverized coal that provides stable ignition and combustion as result of interaction with secondary air.
4. The further developing this approach will permits to design new generation of plasma assisted fuel oil free pulverized coal burner.

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References

Fig. 1 The photos of 1-10 kW plasma torch. (a) without casing, (b) with casing.

Fig. 2 Volt-ampere characteristics (a) of 1-10 kW torch. Flow rate of working gas (air): 0.1 (1), 0.2 (2), 0.3 (3), 0.5 (4) and 0.7 (5) g/s. Flow rate of shielding gas on anode (air): 0.1 g/s. Thermal efficiency (b): 0.7 (1); 0.5 (2); 0.3 (3) and 0.1 (4) g/s. Mean mass temperature at the exit cross-section of channel (c): 0.1 (1); 0.25 (2) and 0.5 (3) g/s. Flow rate of shielding gas (argon): 0.1 g/s.

Fig. 3 The photos of 50-120 kW plasma torch with and without casing.

Fig. 4 Volt-ampere characteristics (a) and thermal efficiency (b) of 50-120 kW plasma torch. Flow rate of plasma forming gas (air): 1 7 g/s, 2 5 g/s, 3 3 g/s. Flow rate of shielding gas of anode (air): 1 g/s.
Fig. 5. The optical scheme (a) of registration of trajectories of particles. L₁, L₂ - collimators, D₁ - light shade, M - mirror, D₂ - limiting diaphragm, L₃ - detecting objective, trajectories of Al₂O₃ particles through G₁ = 0.1 g/s, G₂ = 0.05 g/s, the exposure time - 1 250 μs; trajectories of coal particles through G₁ = 0.1 g/s, G₂ = 0.12 g/s, the exposure time - 1 250 μs.

Fig. 6. Comparison of the combustion processes occurring in an air plasma jet flowing out into a surrounding atmosphere under different conditions of pulverized coal injection. a, c - first method of coal dust injection, b, d - second one; the flow rate of carrier gas: a, b = 0.3 g/s, c, d = 0.5 g/s.