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Plasma Torch for Plasma Ignition and Combustion of Coal

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This paper describes direct current arc plasma torch. The cathode life of the plasma torch exceeds 1000 hours. To ensure the electrodes long life the process of hydrocarbon gas dissociation in the electric arc discharge is used. In accordance to this method atoms and ions of carbon from near-electrode plasma deposit on the active surface of the electrodes and form electrode carbon condensate which operates as "actual" electrode. Complex physicochemical investigation showed that deposit consists of nanocarbon material.

1. Introduction

To increase efficiency of solid fuels utilization, to decrease fuel oil and natural gas flow rate, and dangerous emissions at thermal power plants plasma technology of coal ignition was developed [1]. It is based on plasma thermo-chemical preparation of fuel to burning. In this technology pulverized coal is replaced traditionally used for the boiler start up and pulverized coal flame stabilization fuel oil or natural gas. In accordance with this conception a part of pulverized fuel (pf) undergoes activation by arc plasma flame in a pf burner equipped with plasma torch – plasma-fuel system (PFS) (Fig.1). The plasma torch is the main element of the PFS.

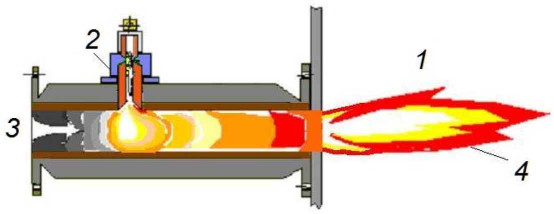


Fig. 1. Sketch of the PFS: 1 – furnace; 2 – plasma torch; 3 – primary air/coal mixture; 4 – plasma activated pulverized coal flame.

Simplicity and reliability of the industrial arc plasma torches using cylindrical copper cathode and air as plasma forming gas predestine their application at heat and power engineering for plasma aided coal combustion [1]. Life time of these plasma torches electrodes is critical and usually limited to 200 hours. This paper describes a new direct current (DC) arc plasma torch and the method to prolong its electrodes operational life.

2. Plasma torch

Considered in this paper DC arc plasma torch has the cathode life significantly exceeded 1000 hours. To ensure the electrodes long life the process of hydrocarbon gas dissociation in the electric arc discharge is used. In accordance to this method atoms and ions of carbon from near-electrode plasma deposit on the active surface of the electrodes and form electrode carbon condensate which operates as "actual" electrode. To realize aforesaid the construction of plasma torch with air plasma forming gas has been developed and tested. Figure 2 sketches the scheme of the plasma torch. Using special orifices 2 propane/butane mixture is supplied to the zone of the arc conjunction to the copper water-cooled electrodes (cathode and anode). As a result inside the cathode cavity and internal surface of the anode medium of carbonic gas is formed. Linked with the arc in series, the magnetic coils 3 guaranty stabilization of the discharge on the electrodes.

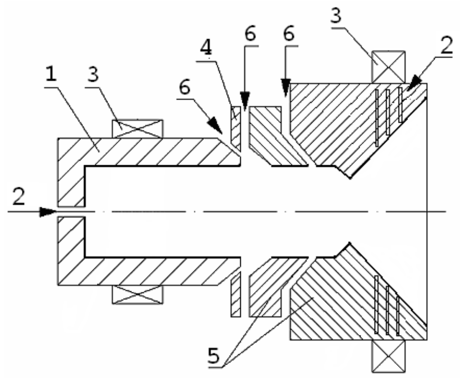


Fig. 2. The scheme of the long life DC arc plasmatron: 1 – Copper cathode; 2 – orifices for hydrocarbon gas supply; 3 - solenoid; 4 – starting electrode; 5 – copper anode; 6 – orifices for supply of plasma-forming gas (air).

The arc is initiated using oscillator and starting electrode 4. The processes of propane/butane molecules dissociation and carbon atoms ionization start with the rise in temperature. Arisen from ionization positive carbon ions deposit onto the electrodes surface under the influence of near-cathode decline in potential and form layer of the electrode condensate. This layer is "actual" cathode, deterioration of which is compensated by the flow of carbon ions and atoms. The layer thickness depends mainly on ratio of the flows propane/butane and air and the arc current.

Some measurements of the long life plasma torch work regimes are gathered in Table 1. It is seen that when power of the plasma torch was in interval 76 – 132 kW and propane/butane flow in range of 0.4 – 0.7 l/min thermal efficiency of the plasma torch (η) reached 90 %. At that mass averaged temperature at the exit of the plasma torch (T) increased to 5000 K.

It was determined the following parameters of the layer. It consists of carbon of 96.74-98.47 wt. %, hydrogen of l.24-2.26 wt. % and cuprum of 0.30-1 wt. %. Interplanar spacing is 0.333 (100%), 0.207 (1%), and 0.168 (5%). Specific electrical resistance of the electrode condensate is less than 10-8 Ω·m. Thus the layer of the cathode condensate is current installing polycrystalline graphitic material.

N	I, A	U, V	Qgas, l/min	η	T, K
1	200	380	0.4	0.9	3500
2	300	360	0.4	0.89	4100
3	400	330	0.4	0.88	4800
4	300	360	0.7	0.89	4800
5	300	380	0.7	0.9	5000

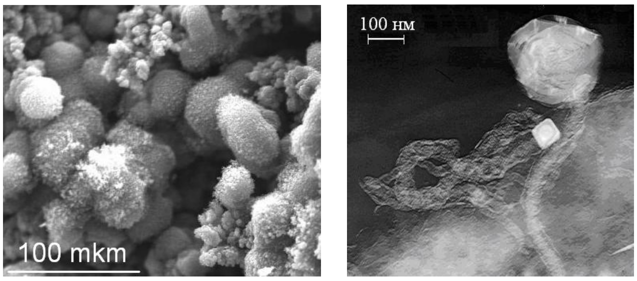
Table I. The results of the experiments.

Raman-spectra of the cathode condensate layer was made using infrared laser with wave-length of 1.064 mkm. Cathode condensate is mechanically firm film of carbon. The surface of the film is black, its structure is flocculent and filiform. Carbon fibers are oriented in parallels with each other and normally to the surface of the cathode. The surface faced to arc zone of the plasma torch is shiny, continuous and of a gray colour. In the Raman-spectra there are three intense bands of 1290.0 cm^{-1}, 1581.9 cm^{-1}, and 2564.5 cm^{-1} with their intensity 0.04, 0.05, and 0.05 of relative unit respectively. The first two intense bands are lines of Raman-spectrum of the first order. They are known as D- and G-lines of nanocluster graphite correspondingly. Abnormally strong band 2564.5 cm^{-1} is the first upper partial of the main D-oscillation at 1290.0 cm^{-1} and it is Raman-spectrum of the second order. Accordingly, the band 3191.23 cm^{-1} is the first upper partial of the G-line. The band 2876.64 cm^{-1} is also Raman-spectrum of the second order, but it is the main tone generated at composition the main oscillations (D + G) of nanocluster carbon. Weak band 1335.58 cm^{-1} can be inclusion of diamond-like carbon into the cathode condensate.

Comparison of the Raman-spectra of the condensate with the spectra of carbon materials [2, 3] gives their coincidence with Raman-spectra of multi-walled carbon nanotube (MWNT) with some injection of the other forms of carbon, including single-walled carbon nanotube (SWNT). Some quantity of copper atoms falling into the carbon condensate is a catalyst for producing of carbon nanotubes. The diameter of the nanotubes from the cathode condensate calculated in accordance with [4] is varied from 0.82 nm to 1.32 nm.

Beside Raman spectroscopy investigation the electrode condensate was examined using atomic microscopy, scanning electron microscope (SEM) (Fig. 3, a) and transmission electron microscope (TEM) (Fig. 3, b). As it is seen the basic mass of the carbon sample (about 80 %) is represented as film and band graphite particles collected to aggregates of various size and density. Basal cleavage spacing of these particles is a little more than one of “ideal” graphite. It is d_{002} = 3.45-3.55 Å, in contrast to d_{002} =3.35 Å of “ideal” graphite. Width of the bands varies from 4 to 40 nm. Sometimes film and band particles collected into stratified packages.

The “nanoflower” with the “stem” made from a bundle of carbon nanotubes is clearly seen in Fig. 2 and a rhombic multilayered copper nanoparticle - the growth center of a nanocarbon structure - is seen near the flower.



a **b**

Fig.3. SEM (a) and TEM (b) images of a sample of the cathode condensate.

3. Conclusion

On the base of the investigation, it can be concluded that the cathode condensate is composite carbonic stuff made of carbon nano-clusters which consists mainly of single and multi-walled carbon nanotubes and other carbonic forms including some quantity of the copper atoms intercalated to the carbonic matrix.

Lifelength of the cathode totals more than 1000 hours. The experiments confirmed principal possibility for unlimited life of the cathode filmed with composite nanocarbon layer.

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