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CHARACTERIZATION OF PLASMA TORCH WITH REVERSE VORTEX

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The giant potential of thermal plasma is recognized now in the world and is extensively used for new materials production and improvement of actual processes and/or systems. Unique characteristics of thermal plasma, such as high density of energy and high temperature, well controllable working medium and flow rates of reacting components, high rate of chemical reactions and, as a consequence, high efficiency - all this forms unlimited technological potential of plasma processing. In electric arc heaters an electric energy is effectively transformed in thermal one due to Joule effect. An efficiency of plasma generators depends on effective thermal insulation of plasma that can be achieved by using the peculiarities of vortex flows whose potential incompletely studied yet. A gas-dynamical interaction between electric arc and gas flow inside the plasma torch is responsible for the heat and mass transfer from arc and formation of energetic and electrical characteristics of heater.

While numerous designs of the plasma torches were developed, there are a limited number of the principal schemes, which differ generally by the method of the arc stabilization. The basic characteristics of such plasma torches are well studied and generalized [1]. The most widespread plasma torches are of the linear scheme. Such name they have received because the electrodes (rod or tubular) are arranged in line along a gas stream direction. The design of

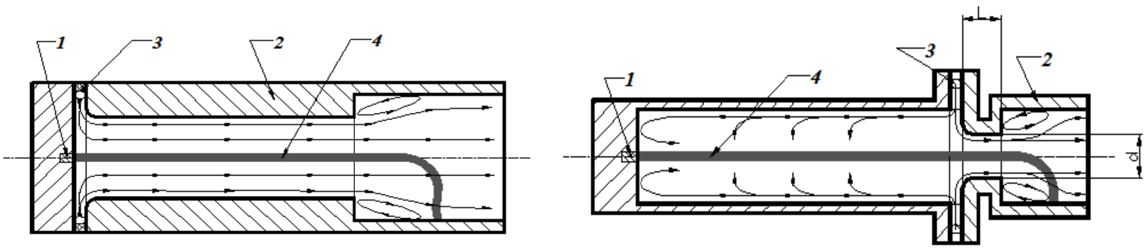

Figure 1. Scheme of the traditional plasma torch (to the left) and one with reverse vortex (to the right). The flow lines of gas are sketched. Radial distributions of pressure $\Delta P=P-P_0$ (P_0=1 atm) are shown at the bottom of the scheme. 1 – thermionic cathode; 2 – anode; 3 – vortex chamber; 4 – electric arc.

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the most simple and most used linear plasma torch (with a step in outlet electrode) is shown in Figure 1.

An original design of linear plasma torch with special cathode for a reverse vortex formation was developed and is shown in the Figure 1. The main peculiarity is that the vortex chamber 3 is found immediately at the outlet end of the cathode. Thus the minimum of static pressure near the axis in cross-section of the vortex chamber forces the gas from the cathode depth to move out from the interior of the hollow cathode as it was shown by direct measurements of a velocities profile by means of a laser anemometer [2]. The anode's diaphragm forms a step in a vortex zone, which increases gas stream into interior of the cathode. The vortex intensity decreases with distance from the vortex chamber that induces increase in axial pressure and stimulates a near-axis reverse flow of gas towards the outlet anode. Such reverse vortex is distinctive feature of the design of plasma torch.

The experiments were carried out on the plasma torch with copper electrodes using a compressed, undrained air as plasma forming gas. The cathode inner diameter was of 20 mm and depth - 95 mm. The total length of the anode (70 mm) and its outlet inner diameter (20 mm) were invariable in all experiments whereas the diaphragm's diameter ***d*** and length ***L*** were varied. For ***d***=6 mm the diaphragm lengths ***L***=23, 27 and 34 mm were used. For ***L***=34 mm its inner diameter was ***d***=6, 7 and 8 mm. Thus, 5 different configurations of the outlet electrode were tested and their effect on plasma torch characteristics was analyzed. For arc ignition a high-voltage high-frequency generator was used. Thermal losses in plasma torch were obtained from the measurement of cooling water flow rate and its heating.

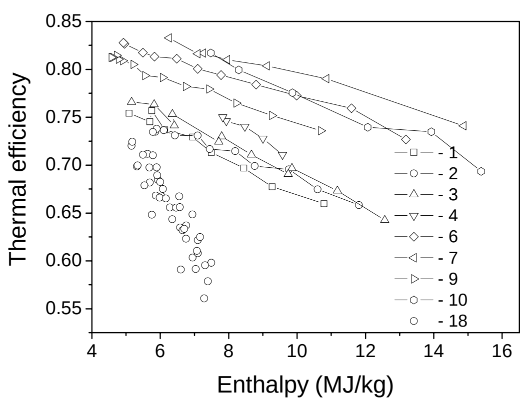

Figure 2. Thermal efficiency of plasma torch versus enthalpy of plasma jet. *L*/*d*: 1 – 23/6; 2 – 27/6; 3 – 34/7; 4 – 34/8. Items 5 – 8 the same as 1 – 4, but different impedance of power supply; 9 – plasma torch PDS-3.

The main heat losses of traditional plasma torches occur within the anode and affect both the thermal efficiency of plasma torch and enthalpy of plasma jet. It is convenient to use the dependence of thermal efficiency versus enthalpy of plasma jet for comparison of energy characteristics of two different schemes of plasma torches. The experimental data for the traditional scheme plasma torch PDS-3 [3] with direct vortex were added for this in Fig. 2. PDS-3 has found wide application in plasma chemical processing and is actively used for many years. The total length of outlet electrode of this torch (170 mm) is close to total length of electrodes of the plasma torch with reverse vortex (cathode and anode overall length is 167 mm). Both torches have been tested in similar working conditions and with use of the same power supply. The bulk enthalpy of plasma jet and thermal efficiency of the plasma torches were measured by a traditional method of calorimetry of cooling water. Experiments were carried out by series where the flow rate of plasma forming gas was varied while the external parameters (of the power supply) remained invariable. Lower limit of gas flow rate was determined by arc initiation on the anode diaphragm.

The current-voltage characteristics of the plasma torch with reverse vortex (shown in Figure 3) are slightly decreasing (that is typical for plasma torches with the self-established length of arc) instead of ascending ones as it was expected, which is typical for arc with fixed length. It occurs probably because the principal part of the arc is situated in the hollow electrode, whose diameter (20 mm) exceeds essentially the arc diameter. With arc current increasing from 60 A to 110 A an increase of the arc diameter was negligible and, accordingly, was insignificant the alteration in the heat exchange between the arc and electrode wall. An observed voltage decrease can be explained by growth of temperature of the conducting channel and increase of electrical conductivity. An increase of the gas flow rate results in increase of arc voltage at constant current, as it can be seen from Figure 3.

The heat fluxes in cathode Q_c and anode Q_a versus arc current and gas flow rate G_{air} for different geometrical configurations of a diaphragm of the outlet anode are shown in Figure 4. For comparison the same characteristics of the plasma torch with self-established length of arc (outlet electrode diameter of 10 mm and length of 115 mm) were used. The heat fluxes Q_c and Q_a grow linearly with arc current. By its absolute value Q_c exceeds the ones for a typical plasma torch due to its major inner surface, whereas Q_a is significantly lower. The effect of gas flow rate on Q_c for two

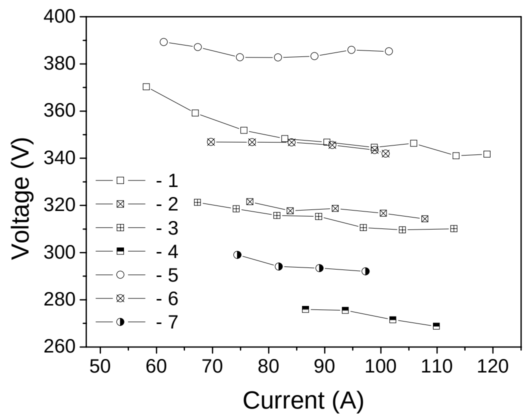

Figure 3. Arc voltage versus arc current.
1-7 – G_{air}=const and I=var: 1-4 length of diaphragm L=34mm, diameter of diaphragm d=8mm; 5-7 L=23 mm, d=6mm. Gas flow rate G_{ar} in g/s: 1 – 3.77; 2 – 2.59; 3 – 2.32; 4 – 1.45; 5 – 3.26; 6 – 2.22; 7 – 1.38.

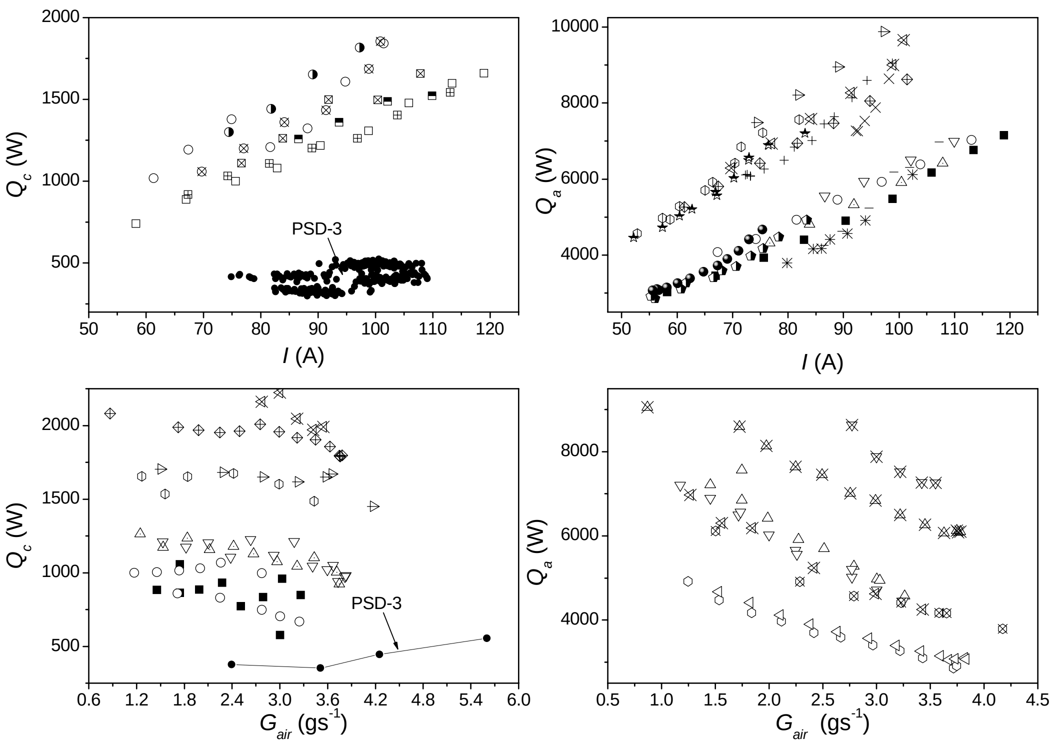

Figure 4. Thermal characteristics of plasma torch with reverse vortex for different configuration of diaphragm and working conditions.

compared plasma torches is opposite. An increase of G_{air} leads to intensification of the reverse vortex and growth of radial gradient of pressure, which intensifies a radial cross-flow of gas from the wall of cathode to its axis, hence blocking a convective flux to the cathode wall. Decrease of length of anode diaphragm increases the heat fluxes into outlet electrode owing to increase of the total anode surface and especially surface down-stream of shunting zone where the heat transfer is the most intensive.

Diameter of the diaphragm affects the vortex intensity, which is responsible for reduction of convective thermal flux into cathode. On the other hand, the diaphragm length exerts also essential effect upon hydro-dynamical drag force and stability of the vortex.

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