THERMAL INSULATION OF PLASMA IN REVERSE VORTEX FLOW

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The vortex method of plasma and flame stabilisation is well known. In this method the swirl generator is placed upstream relative to the electric discharge or flame and the outlet of the hot gaseous jet is directed to the opposite side. It is well known that in an intensive vortex stream a central recirculation zone of reverse flow occurs near the swirl generator. The recirculation flow results in an upstream transfer of energy from the centre of the vortex stabilised plasma or flame. The hot reverse flow mixes with the incoming cold direct vortex flow. In gas burners this mixing results in ignition of new gas portions and high intensity and stability of the flame. After mixing the direct vortex of hot mix or flame moves along walls of the plasma torch or gas burner, and a significant part of thermal energy arrives at the device walls and becomes lost.

According to the new concept for insulation of high temperature and reacting zones [1] based on the idea of **reverse vortex** formation [2] the outlet of the plasma or flame jet is directed to the swirl generator side. In this case cold gas should enter the hot central zone from all sides except the outlet side, and no significant recirculation zone should be formed.

This paper is focused on the results of comparative investigation of influence of the conventional and reverse vortex method stabilisation onto the thermal efficiency of MW plasma torch and gas burner.

Plasma experiments were made with a microwave (MW) generator with a MW power input up to 5 kW. This plasma torch is a part of an experimental facility for treatment of inorganic salt solutions [3]. A sketch of the MW plasma torch with supposed flow patterns of gas and plasma is shown in Fig. 1 [1]. The quartz discharge tube 1 (inner diameter 44 mm, length about 140 mm) passes perpendicularly through two wave-guides (90×45 mm^2, not shown) which supply H_{10} mode of the MW energy (frequency 2.4 GHz) from two magnetrons. In the conventional scheme (Fig. 1a) the plasma gas (air or nitrogen) enters the discharge chamber through four inlet openings of the original tangential swirl generator 2, resulting in stabilisation of the plasma 3 on the axis of the quartz tube 1 by the strong rotation of the gas. In the experimental plasma-chemical set-up [3] the MW plasma torch is joined to the uncooled massive steel reactor 4 by an uncooled steel connecting cone 5. For experiments

with **reverse vortex stabilisation** (Fig. 1b) an additional vortex generator 7 with a water-cooled diaphragm 6 (diameter 26 mm) was installed between the quartz tube and the connecting cone. Calorimetric and electrical measurements permitted to determine the MW power input W_p into the discharge and the heat losses W_t to the water-cooled parts of the plasma torch.

The experimental results [1] are presented in Fig. 2 (dots with full curves) in dependence on J - the energy input into the discharge per unit mass of plasma gas consumption. The power input was around 3.5 kW and varies a little due to the fact that changing the gas flow conditions also influences the discharge conditions. The dots of curve 1 were obtained for the "old" scheme (Fig. 1a) **without** the diaphragm and with the plasma-chemical reactor. Curve 2 corresponds to the same scheme, but **with** the diaphragm. Curve 3 corresponds to the "new" **reverse vortex flow** scheme (Fig. 1b) with the reactor. As the heat flux to the plasma torch walls from the reactor was significant, so in two additional series of experiments **with** the diaphragm (Fig. 1b) the reactor was removed and the plasma torch was turned upside-down. Plasma gas might be supplied through the original vortex generator (2,
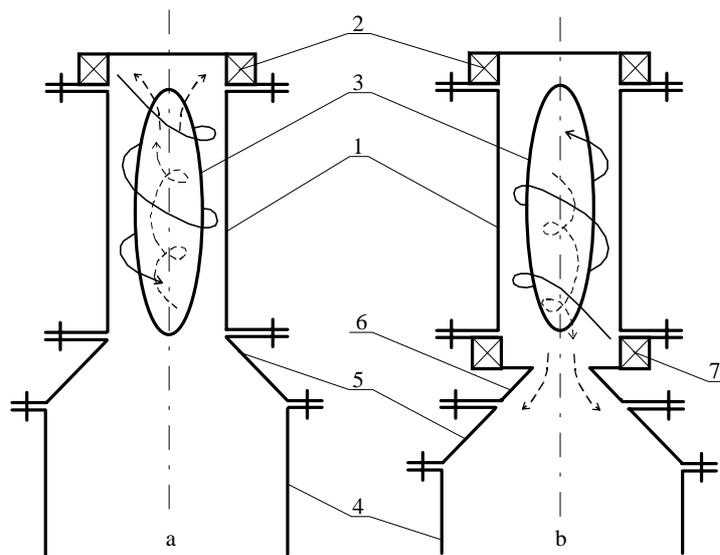

Figure 1. Scheme of the MW plasma torch: (a) - "old" scheme with flow patterns for conventional vortex plasma stabilisation; (b) - "new" scheme with flow patterns for **reverse vortex** plasma stabilisation.
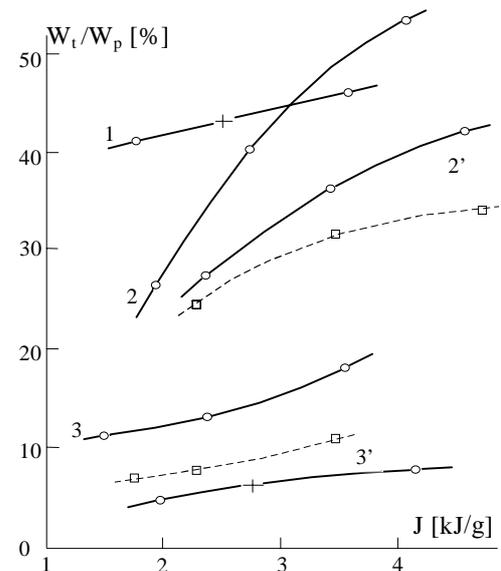
Figure 2. Heat losses in the microwave plasma generator: full curves - experiments, broken curves – numerical simulations.

Fig. 1) for realising the conventional vortex stabilisation scheme, or through the additional vortex chamber (7, Fig. 1) for realising the **reverse vortex** scheme of plasma stabilisation. Curves 2' and 3' (Fig. 2) correspond to these two cases.

The numerical simulations of the MW plasma torch were made using the fluid flow and heat transfer simulation program FLUENT. Figure 3a shows the stream lines, profiles of axial velocity and the temperature distribution on the axial plane for the conventional vortex scheme, and Figure 3b - for the "new" **reverse vortex flow** scheme. In these two modelling cases the heating zone (3.5 kW) was in the centre of MW plasma torch quartz tube (1, Figure 1). Gas (nitrogen) enters tangentially into discharge chamber (conventional scheme) or into additional vortex chamber ("new" **reverse vortex flow** scheme). It is easy to see (Fig. 3b) that the **reverse vortex** "compresses" the heat zone and protects the plasma torch walls from overheating. The calculated energy losses for the appropriate cases are shown by dots of the broken curves on Fig. 2 (curve 2' - for the conventional vortex scheme, curve 3' - for the "new" **reverse vortex flow** scheme).
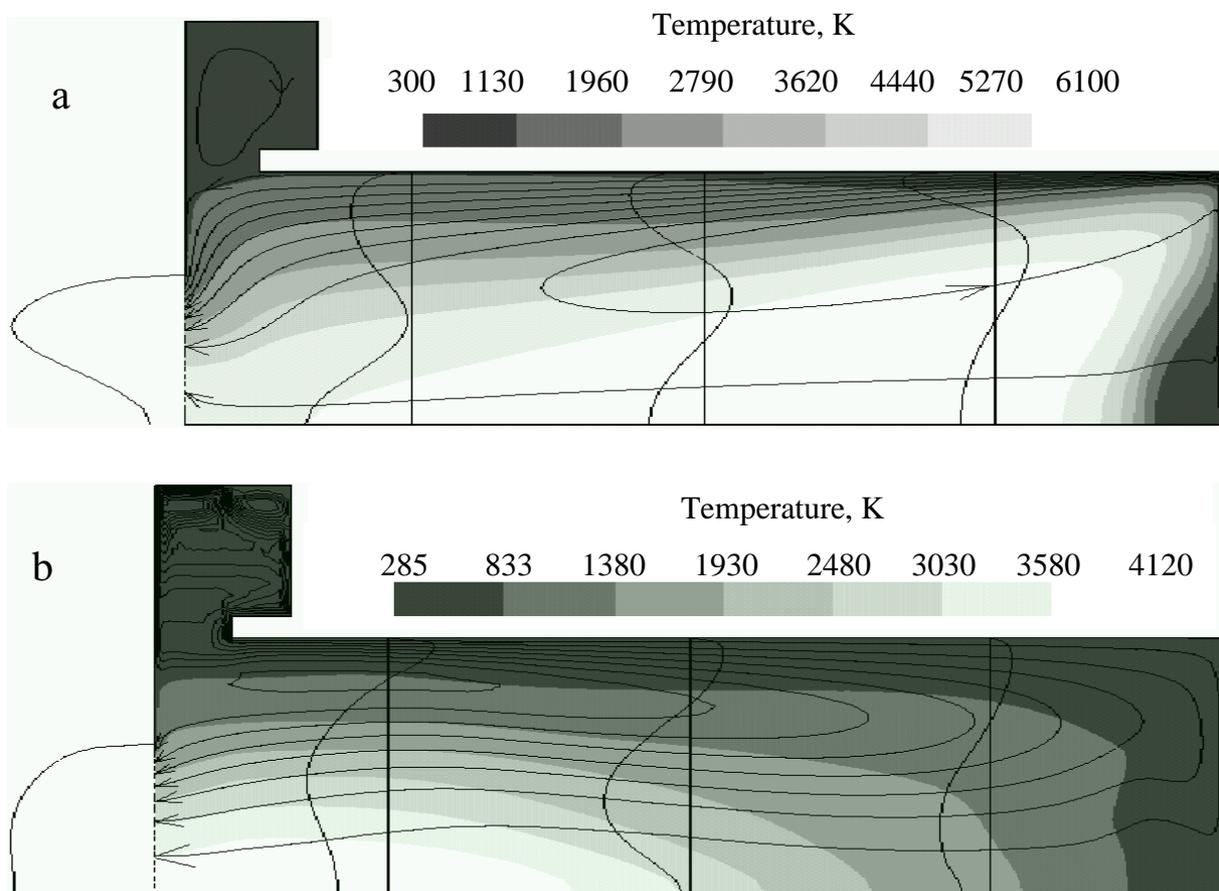

Figure 3. Temperature distribution, stream lines and profiles of axial velocity for three different cross-sections and for outlet of the MW plasma torches with conventional vortex flow (a) and with reverse vortex flow (b).

We have carried out a comparative investigation of the experimental vortex gas burners with conventional "direct" flow and with **reverse** one. Principal schemes of the burners were similar to that of MW plasma torch (Fig. 1). Additionally propane-butane mixture was

injected through the opening in the centre of the top wall and plasma gas was displaced by air as oxidant. In all experiments consumption of fuel gas and air was constant and calculated power of the burner was 1800 ± 300 Wt. Energetic characteristics of the burners were examined using gas temperature measuring and calorimetric water-cooled tube which was connected with the outlet of burner or acted for the burner side wall. These characteristics are presented in Table 1 as gas temperature T_g and gas heat power W_g after calorimetric tube, calorimetric power W_c, total power W_Σ and concentration of nitrogen oxides C_{NO}.

Type of burner	W_c, Wt	T_g, K	W_g, Wt	W_Σ, Wt	C_{NO}, %
Reverse-vortex	1570±30	780±10	400±15	1970±40	0,35
Direct-vortex	1250±25	490±10	155±10	1405±30	0,41
Cooling direct vortex	1400±30	560±10	215±10	1615±35	0,46

Table 1. Energetic characteristics of the examined burners.

The quartz wall of the conventional direct vortex burner was heated up to shining while the reverse vortex burner may be hand hold without any special cooling. So, heat loses to the wall of the reverse vortex burner can not be more than 100 Wt.

So, simple design modification of vortex stabilisation system leads to a significant decrease of the heat flux to the walls of MW plasma torches and gas burners (approximately from 30% to 5%). Advanced numerical simulation methods permit reliable predictions of heat losses in plasma torches with conventional as well as **reverse vortex flows** stabilisation. Experimental investigations and numerical simulations show that **reverse vortex** systems are very promising for various plasma-chemical processes and other technical applications of different types of plasma devices as well as for gas burners.

References

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