

INTERACTION OF THERMAL PLASMA JET WITH THE STREAM OF INJECTED LIQUID

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Abstract

The structure of the flow in the plasma jet and the interaction of the injected liquid with the jet were investigated by the schlieren method and the emission spectroscopy. The paper illustrates the dependence of the interaction of the injected liquid stream with the jet on the axial position of the injector nozzle. It was found that intensive mixing takes place only in the downstream highly turbulent part of the jet.

1. Introduction

The structure of the flow in the thermal plasma jet is obviously very important factor influencing the process of mixing of the treated substance with the plasma and the subsequent heating and decomposition in high temperature regions [1]. The turbulent plasma flow can substantially increase both the heat transfer to the injected substance and its residence time in the plasma.

The aim of the this work was to investigate the structure of the flow in the plasma jet and the interaction of the injected substance with the jet to find the optimal conditions for the injection. The phenomena effecting the flow structure in thermal plasma jets were studied in [2, 3, 4] for Ar plasma torches. This paper presents the results for extremely low density and high velocity plasma jet produced in water plasma torch.

2. Experimental

The principal scheme of the plasma torch with dc arc stabilized by water swirl is shown in Fig. 1. The description of the torch, its operating parameters and jet exit conditions are given in [5]. The stream of the liquid was injected in various axial positions along

the jet. The treated substance was modelled by pure water or by water with some dissolved compound. The injector nozzle had diameter 0.5 mm and the liquid was injected with the exit velocity 10 m/s.

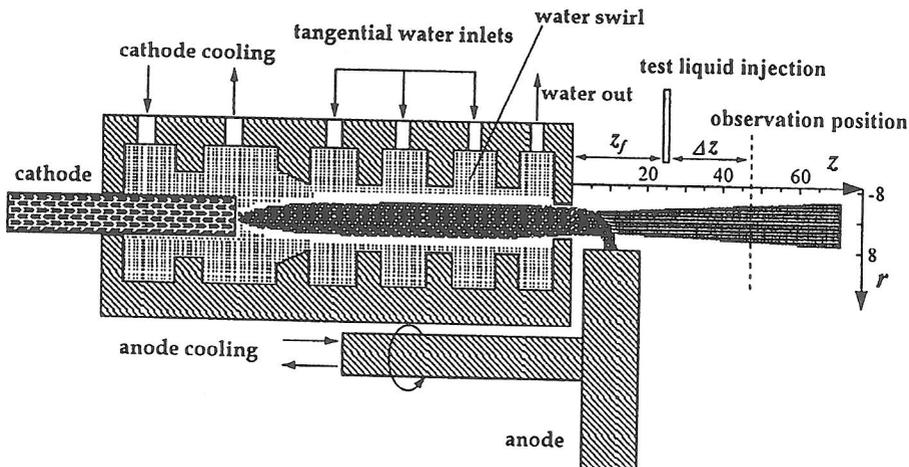


Fig. 1 Principal scheme of water plasma torch. The positions of the injection and the observation are indicated.

The interaction of liquid with plasma was investigated by two methods. The structure of the flow field was visualised by schlieren optical system with pulsed Nd laser (pulse width 35 ns), schlieren lens with $f = 1500$ mm and different radii of circle schlieren disc screen. The diameter of the illuminating beam was 50 - 80 mm, the wavelength 540 nm (2nd harmonic) and the schlieren image was recorded photographically. The decomposition of the dissolved substances was indicated by emission spectroscopy. The radial profiles of the lines of products of decomposition were recorded by OMA system in various axial positions downstream of the injection point.

3. Results and discussion

Fig. 2 presents the schlieren image (the schlieren disc screen ϕ 1 mm) of the jet in the region near the exit orifice above the anode (disc anode is also visible). It can be seen that the flow is laminar in the region close to the nozzle exit and becomes more turbulent near the downstream edge of the anode for $z/d = 3$ ($d = 6$ mm is diameter of the nozzle). The production of the turbulence is effected by the entrainment of the ambient air as well as by the movement of the anode attachment region [5]. Strongly

turbulent downstream part of the jet can be seen in Fig. 3 with high density vortices producing large deflections of the illuminating beam (the schlieren disc screen ϕ 5 mm).

Fig. 2. Schlieren image of the jet in the region near the exit orifice.
Diameter of the schlieren disc screen was 1 mm.

Fig. 3. Schlieren image of the whole jet.
Diameter of the schlieren disc screen was 5 mm.

The interaction of the water stream with the jet in laminar region is shown in Fig. 4. The stream was repelled from the jet due to rapid evaporation of the liquid on the

undisturbed boundary of the jet with high radial temperature gradient. The repelled liquid was spreaded into the downstream part of the jet. If the water stream is injected into more turbulent part of the jet further downstream, the stream is spread into small droplets and mixed with the plasma (Fig. 5).

Fig. 4 Schlieren image of interaction of the liquid stream with the jet.
Injection position $z_f = 17$ mm, diameter of the schlieren screen was 3.3 mm.

Fig. 5 Schlieren image of interaction of the liquid stream with the jet.
Injection position $z_f = 45$ mm, diameter of the schlieren screen was 3.3 mm.

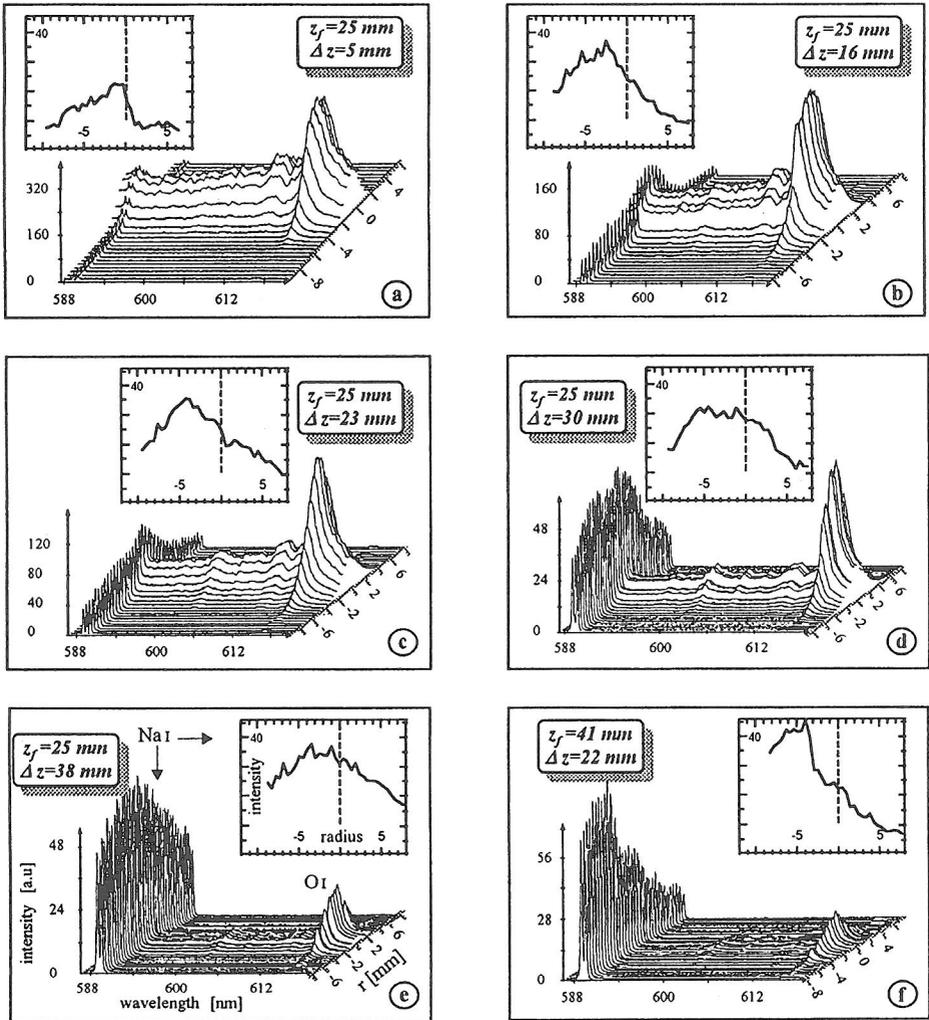


Fig. 6. Spatially resolved spectra with Na I doublet (589.18 nm, $E_{exc}=2.10$ eV) and O I multiplet (615.73 nm, 12.75 eV). Radial distribution of Na I integral line intensity is also shown. z_f - position of the test liquid injection, Δz - distance of the observation position from the injection point.

Additional information about the mixing and decomposition was obtained by spectroscopic measurements. The water solutions of several salts (NaCl, KMnO_4 , Na_2CO_3) were injected into the jet and the intensities of the lines of Na, K and Mn relative to oxygen and hydrogen lines were measured at various positions.

Fig. 6 presents the radial profiles of part of the spectra with the lines of Na I and O I taken for the case of injection of NaCl solution in two different axial positions. The radial intensity profiles of Na I are shown in the upper parts of each figure. The dotted lines indicate the position of the axis of the nozzle. Spectra in Figs. 6a - e were obtained for injection position $z_f = 25$ mm that corresponds to the end of the laminar jet zone. The increase of the cross section of the jet with increasing distance from the nozzle exit is seen from the shape of radial profiles of the O I line. Subsequent spreading of the injected substance into the cross section of the jet is indicated by changes of the radial profiles of Na I line in Figs. 6a - e. The spectra in Figs. 6e and f correspond to the same distance from the nozzle exit $z = 63$ mm. From the comparison of these spectra we can conclude that better mixing into the whole cross section of the jet was achieved for injection at the position $z_f = 25$ mm although the liquid is repelled from the jet at this position (Fig. 4). The entrainment of the ambient gas is probably the cause of the mixing of this liquid with the jet further downstream. The same conclusions were obtained by the measurements of the other spectral lines.

Acknowledgement

This work has been supported by Grant Agency of the Czech Republic under contracts 104/94/0417 and 102/95/0592.

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