Influence of the gas flow on the microwave torch plasma flame structure

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Received 22 April 2002

The laser visualisation and flow velocity field measuring techniques (e.g. [1]) have become important for the diagnostics of plasmas [2]. In this paper we present results of the laser flow visualisation and Particle Image Velocimetry (PIV) measurement of the flow velocity field in a nitrogen or argon plasma flame generated by the microwave torch in ambient air. This investigation is important for improving the performance of microwave torch plasmas (MTPs), which are attractive for decomposition of gaseous pollutants. The microwave power delivered to the plasma was in the range of 100–300 W. The operating gas (nitrogen or argon) was blown through the microwave torch nozzle at a flow rate of 0.5–2 l/min. Al_2O_3 particles were added as a seed to the operating gas flow for the flow visualization and PIV measurement. The investigation showed that the MTP structure and the flow pattern depend on the kind of the operating gas (different patterns for nitrogen and argon), its velocity and microwave power. The obtained results are useful for optimizing the MTP.

PACS: 52.70.Kz
Key words: microwave torch plasma flame, visualisation techniques, PIV techniques

1 Introduction

Recently, various microwave torch plasmas (MTPs) were developed, either consisting solely of coaxial line components or fed from a waveguide [3, 4]. An MTP generator, based on the TIAGO concept disclosed by Moisan et al. [4], has proved attractive for decomposition of gaseous pollutants [5–7].

In this paper images of the laser flow visualization of the gas flow pattern in the plasma flame generated by the microwave torch are presented. Also results of the measurement of the flow velocity field in the MTP flame using Particle Image Velocimetry (PIV) are presented. This investigation is important for improving the performance of MTPs.

2 Experimental setup

The experimental setup used in this investigation consisted of a 2.45 GHz magnetron generator, MTP generator used in [7] for decomposition of gaseous pollutants, microwave power supplying and measuring system, gas supplying and flow control system, and PIV measuring equipment. The essential concept of the MTP generator is shown in Fig. 1. The torch structure is built in a modified WR 430

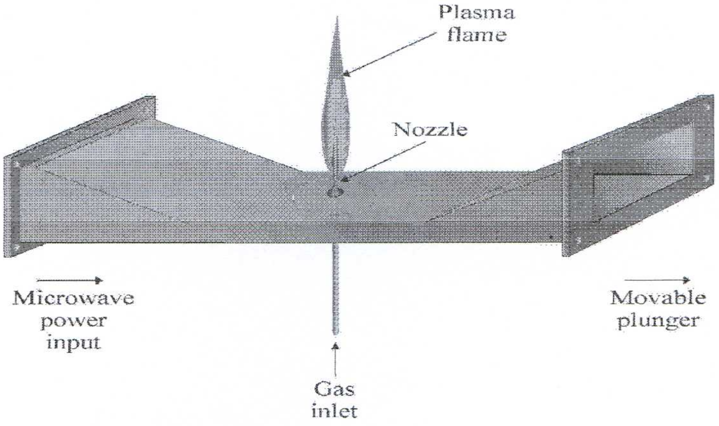

Fig. 1. The MTP generator used in the experiment.

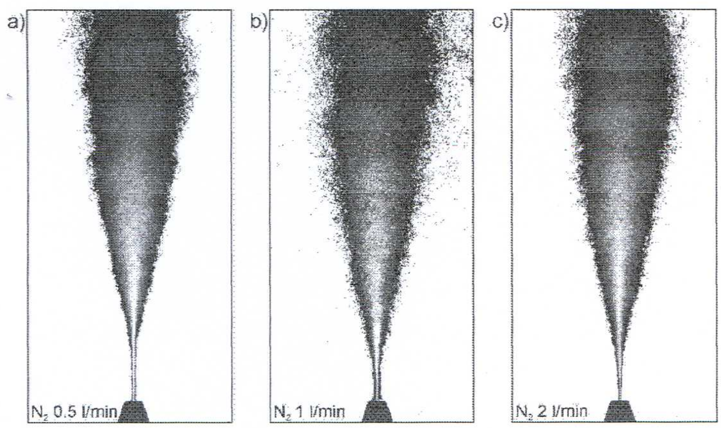

Fig. 2. Images of nitrogen flow structure at the torch nozzle without microwave discharge for different nitrogen flow rates: a) 0.5 l/min, b) 1 l/min, c) 2 l/min.

rectangular waveguide. A tube with a conical nozzle (inner diameter – 1 mm) is placed in a reduced–height section of the waveguide, perpendicularly to the its wide wall. At its gas–inlet side the nozzle tube is attached to the bottom wall of the reduced–height waveguide and protrudes through a circular gap in the opposite wall. The microwave power up to 300 W was fed directly through a waveguide from the magnetron generator at one end of the torch structure, while the opposite end is terminated with a movable plunger. The plasma was generated in the form of

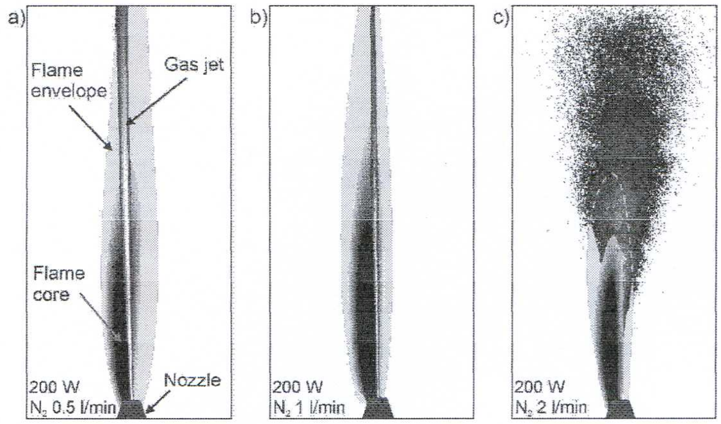

Fig. 3. Images of MTP flame and nitrogen flow structures for different nitrogen flow rates: a) 0.5 l/min, b) 1 l/min, c) 2 l/min. Microwave power 200 W.

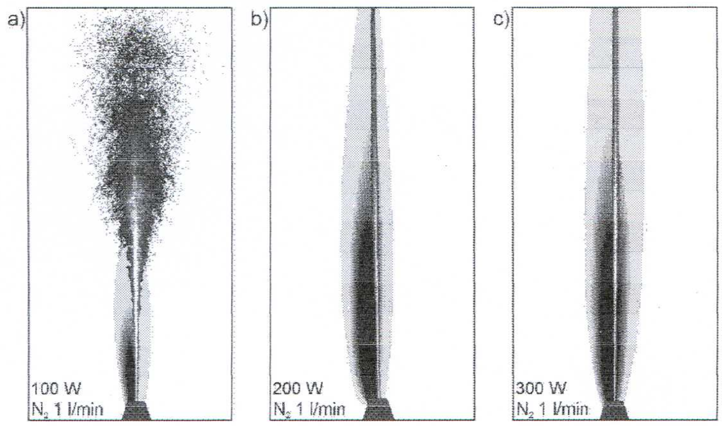

Fig. 4. Images of MTP flame and nitrogen flow structures for different microwave power: a) 100 W, b) 200 W, c) 300 W. Nitrogen flow rate 1 l/min.

a "plasma flame" at the end of the nozzle. The shape and dimensions of the gap in the waveguide wall and of the conical nozzle determined the distribution of the electromagnetic field in the discharge region.

The laser visualization of the operating gas flow pattern with or without a microwave plasma flame was carried out by illuminating with a second harmonic Nd–YAG laser (532 nm) sheet the so-called seeding particles added to the flow.

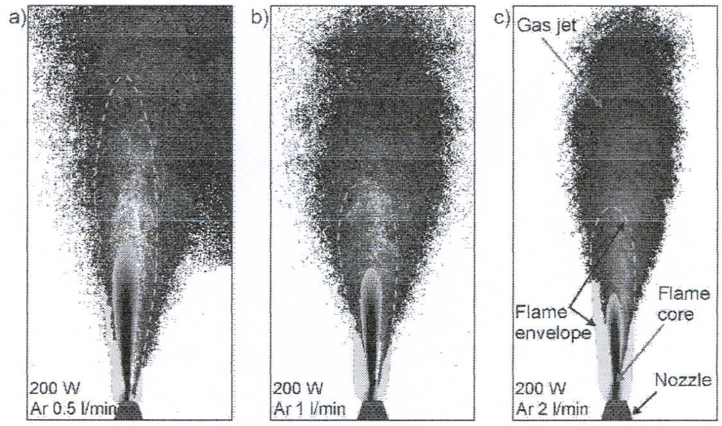

Fig. 5. Images of MTP flame and argon flow structures for different argon flow rates: a) 0.5 l/min, b) 1 l/min, c) 2 l/min. Microwave power 200 W.

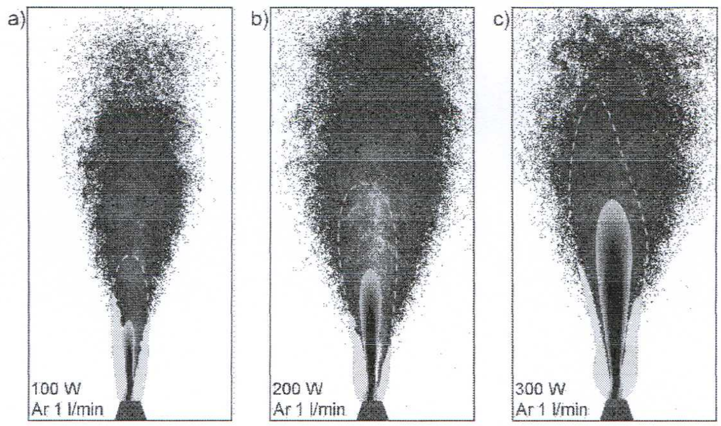

Fig. 6. Images of MTP flame and argon flow structures for different microwave power: a) 100 W, b) 200 W, c) 300 W. Argon flow rate 1 l/min.

Al_2O_3 particles with a diameter of 1 μm were used as a seed. The flow images resulted from the laser light scattered by the seeding particles following the flow were recorded by a CCD camera equipped with a filter (532 nm). Simultaneously with the laser flow visualization, images of the MTP flame were recorded using a video camera. Then the corresponding images of the flow pattern and the MTP flame were merged, resulting in a combined image.

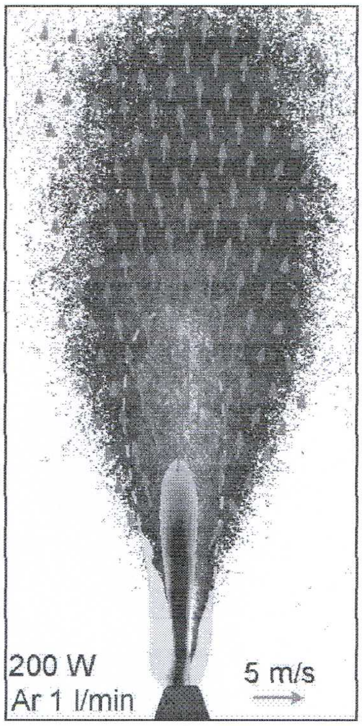

Fig. 7. Velocity field in the argon jet in the MTP measured by PIV. Argon flow rate 1 l/min, microwave power 200 W. The velocity scale is shown by the arrow at the bottom.

The flow velocity field measurement using PIV technique (e.g. [1]) is based on observation of the movement of the seeding particles following the flow, like in the laser visualization. However, the distance and direction along which the seeding particles go with the flow in a given time are measured, resulting in a velocity vector. An ensemble of the velocity vectors obtained from all the particles seeding the flow results in the flow velocity map. The seeding particles movement is observed by recording images obtained owing to the light scattered by the particles. Usually a strong laser beam in the form of a thin sheet is used as a light source. Due to the sheet form of the laser beam the PIV measurement is two–dimensional (planar).

In this experiment the PIV measurement of the velocity field in the MTP was carried out with a standard PIV equipment (Dantec) consisting of a twin second harmonic Nd–YAG laser system, image processor (PIV 1100) and Kodak Mega Plus ES 1.0 CCD camera. The area of the measured velocity field was 85 mm $\times$ 42 mm. Similarly, as in the flow visualization, Al_2O_3 particles added to the operating gas were used as the seed.

3 Results

The images of nitrogen flow structure at the torch nozzle without microwave discharge for different nitrogen flow rates are shown in Fig. 2. The nitrogen flow structure at the nozzle without microwave discharge is typical for turbulent jet [8]. When argon flowed through the nozzle, the flow pattern was similar.

The MTP consists of a "candle–like" flame and an operating gas flow from the nozzle (Figs. 3–6). In the candle–like flame at least two zones are visible: an inner core and an outer "envelope" which is hotter than the core (Fig. 3). The operating gas flow structure can exhibit various forms, depending on kind of the gas, its flow rate and microwave power.

When nitrogen was the operating gas, the MTP flame core was not located coaxially with the nozzle but moved on the nozzle edge around the nitrogen jet (Figs. 3 and 4). The nitrogen flow was usually a laminar jet (Figs. 3a, b and 4b, c), which became turbulent with increasing the flow velocity to 2 l/min (Fig. 3c) or decreasing the microwave power to 100 W (Fig. 4a).

The argon MTP flame structure is different than nitrogen one. The argon exiting the nozzle flows through the center of the candle–like flame and the flame core is located almost coaxially with the nozzle (Figs. 5 and 6). The argon flow has a typical structure of the turbulent jet which is not much influenced by the microwave power and gas flow rate.

The example of the flow velocity field measured with the PIV technique in the turbulent argon jet is shown in Fig. 7. At the argon flow rate of 1 l/min and microwave power of 200 W, the argon flow velocity at 4 cm and 8 cm above the nozzle was 8 m/s and 3 m/s, respectively. Increasing the argon flow rate to 2 l/min increases velocity by about 50 %. The changes in the microwave power in the range of 100–300 W did not influence the argon flow velocity significantly.

4 Conclusions

Our investigation showed that the structures of the MTP flame and the operating gas flow depend on the kind of the operating gas, its velocity and microwave power delivered to the plasma. The symmetric position of the nitrogen flow relative to the MTP flame, observed in this experiment, may be a shortcoming of the MTP, when its using for processing gases is considered. The position of the operating gas flow relative to the MTP flame is important for the chemical kinetics of the processed gases in it.

This research was sponsored by the Foundation for Polish Science (Fundacja na Rzecz Nauki Polskiej, subsidy 8/2001) and by the Institute of Fluid Flow Machinery, Polish Academy of Sciences under programmes IMP PAN O3Z3T2 and O3Z1T1.

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