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STUDY OF PLASMA-FLOW INTERACTION IN LOW TEMPERATURE PLASMA JETS

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Abstract. The influence of the plasma generation and propagation in an atmospheric pressure plasma jet on the gas flow is experimentally studied. Two plasma action mechanisms have been identified and quantified: electrohydrodynamic force mechanism and thermal mechanisms due to fast localized heating. These two mechanisms appear to be counterbalancing or supporting, in dependence on the experimental conditions. Besides, it was shown that plasma can cause decrease of the gas velocity, probably depending on the dominant presence of the negative or positive ions in the jet. The complexity of the experimental conditions, such as initial gas flow, applied voltage shape and polarity, has been systematically studied and the results of these investigations are presented in this manuscript in a form of the main conclusions.

1. INTRODUCTION

Gas flow may be induced or modified by plasma. This fact inspired work on the development of efficient plasma flow control devices and detailed studies of flow generating mechanisms. Additionally, plasma devices attracted attention of scientists and engineers due to their positive features, such as fast control and absence of the motion of the mechanical parts. The influence of the plasma on the gas flow parameters in atmospheric pressure plasma jets is also documented by many studies utilizing the different methods (Darny et al., 2017; Iseni et al., 2019; Oh et al., 2011). This article is devoted to the presentation of our efforts on the quantitative determination of the flow changes induced by plasma and on the identification of plasma-flow interaction mechanisms (Sretenović et al., 2021, 2018).

2. EXPERIMENTAL SETUP

Two types of helium atmospheric pressure plasma jets were used in this study. Both plasma jets have the same electrode geometry, see Figure 1. The powered electrode is placed inside the glass tube, while the grounded electrode is wrapped around it. Both plasma jets worked with helium that freely flowed into the ambient air. The only, but crucial difference was the use of different power supplies. The first power supply was laboratory-made power source operating at 12.65 kHz of sinusoidal voltage signal with variable amplitude and the second one pulsed high voltage power supply both with positive and negative polarities (pulse duration 3 μs, rise and fall time 1 μs, frequency 1- 5 kHz, voltage 2-11 kV). The plasma jets were pointed downwards.

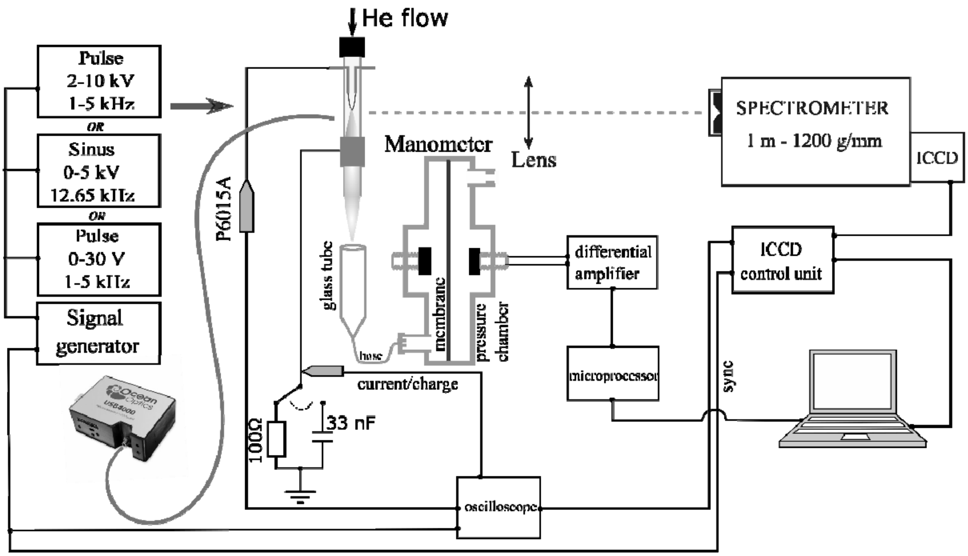

Figure 1: The scheme of the experimental setup.

The apparatus for the flow change measurements was a laboratory made manometer with the membrane and electrooptic sensors for the membrane movement detection, also depicted in Figure 1 (Iskrenović et al., 2020). The experiment was supported by the electrical and spectroscopic measurements.

3. RESULTS

The manometer operating range and sensitivity are flexible and may be set by a proper selection of the material and thickness of the membrane. For the current study, rubber and latex membranes were used, which enabled sensitivity of 0.4 Pa in a pressure range 1-20 Pa for the latex membrane and 1 Pa in a pressure range 1-140 Pa for the rubber membrane, see calibration curves in Figure 2. The first graph presented in Figure 2 (a) demonstrate the sensitivity of the sole. Figure 2 (b) presents the response of the manometer for the flow changes in the experimental configuration presented in Figure 1. The gas flow is controlled using Omega FMA-2606A mass flow controller. The device enabled observation of the flow changes caused by plasma in plasma jets.

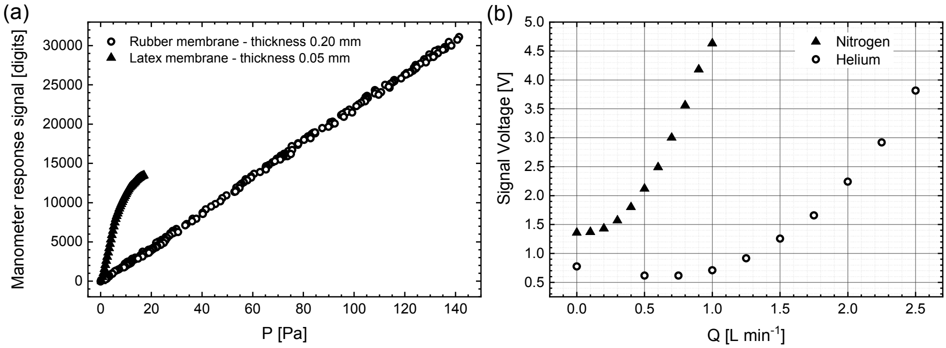

Figure 2*:* Calibration curves of the manometer for: (a) different membranes and (b) different gases flowing through the tube of the plasma jet.

The influence of the discharge on the gas flow is studied for helium flow ranging from 0.75 to 2.0 l min^{-1} for different applied voltages of the sinusoidal plasma jet. Applied voltages ranged from the breakdown voltage of the inter-electrode discharge to the maximal voltage where discharge is relatively stable. For a part of the voltage range, the discharge consists only of dielectric barrier discharge between the HV electrode and the isolated grounded ring. When the voltage becomes high enough, the plasma jet exceeds the glass tube. The results presented in Figure 3 show the gas flow increase that depends on the applied voltage value.

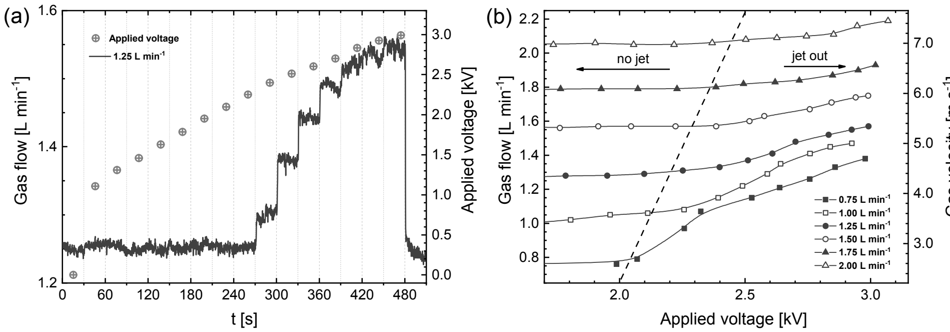

Figure 3: Influence of the plasma on the gas flow for the sinusoidal helium plasma jet. (a) Raw signal for the initial flow rate of 1.25 Lmin^{-1}. (b) Flow changes for the different flow rates and the different applied voltages.

In order to identify the mechanisms of the plasma-flow interaction and separate the dominant effects, the same discharge cell is supplied with voltage pulses of different polarity. The results are presented in Figure 4. Interestingly, besides the expected increase of the gas flow rate with the applied voltage, the evident decrease is recorded for some experimental conditions. In some cases, the change of the sign of the flow change is evidenced for the same voltage polarity, but different voltage values. These findings indicated that there are at least two competitive plasma-flow interaction mechanisms under the studied experimental conditions.

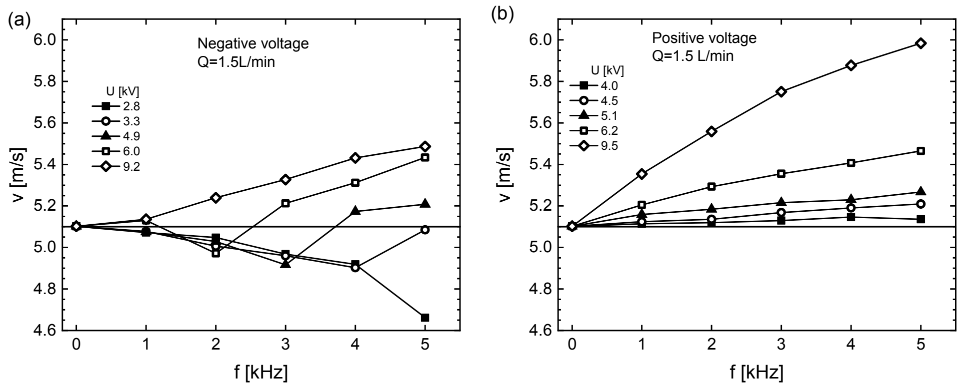

Figure 4: Influence of the plasma on the gas flow in the pulsed helium plasma jet for different applied voltages for: (a) negative and (b) positive voltage.

There are three basic plasma-flow interaction mechanisms: electrohydrodynamic (EHD), thermal, and magnetohydrodynamic (MHD). Having in mind low current in plasma jets, MHD effect may be neglected and the most probable two effects considered in the further investigations were EHD and thermal effect. EHD effect is due to the collisions of the charged particles that move under the influence of the electric field end collide with the neutral particles transferring the momentum. The thermal effect is due to the fast heating of the localized area due to the input of the electrical energy that induces acoustic pressure waves, which finally affects the global flow. In case of the used plasma jets, the rapid localized heating appears close to the high voltage electrode that acts as cathode when supplied with the negative voltage pulses. The experimental simulation of the fast localized heating of the high voltage electrode is performed through its pulsed Joule heating and the measurement of the heating effect. It is found that pulsed heating of the high voltage electrode causes overall gas flow increase. Furthermore, it is concluded that EHD force may induce both increase and the decrease of the total gas flow.

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