Numerical modelling of an atmospheric pressure plasma jet for biomedical applications

G. BARKAOUI[1], N. JOMAA[1], M. YOUSFI[2] and K. CHARRADA[1]

[1]*Ionized and Reactive Media Studies Research Unit,*
Preparatory Institute of Engineering Studies of Monastir,Tunisia
[2]*Plasma and Energy Conversion laboratory*
Paul sabatier university of Toulouse, France

Abstract: A double dielectric barrier discharge setup installed at atmospheric pressure using an argon flow carrier gas was simulated. The jet is formed inside a dielectric tube, than it is ejected into open air. To study the dilution of argon in the air, a hydrodynamic model was developed. The results of the plasma propagation were studied in term of electric field distribution. The results showed that the studied device is able to generate plasma inside the tube. This plasma was propagated then ejected outside the device.

Keywords: Low temperature plasma, Dielectric barrier discharge, atmospheric pressure.

1. Introduction

Low temperature plasma jets at atmospheric pressure are able to generate very active chemical species (at a temperature near to the ambient one. Therefore such plasma is very useful in many fields including in biomedical. Sterilization [1], wound healing [2], dental treatment [3] and cancer treatment [4] are some of the biomedical atmospheric pressure plasma jets applications.

To generate low temperature plasma many interesting works in atmospheric pressure plasma jet were developed in literature for many geometries, electrodes configuration, power supplies and working gases. Dielectric barrier discharge (DBD) [5], microwave plasmas (MW) [6], corona discharge [7] and radio frequency (RF) reactor [8] are some of the atmospheric pressure plasma devices. The carrier gas can be inert gases or air or mixture of inert gas with air [9]–[11].

To more understand the low temperature plasma generation, propagation and applications, reader can find many interesting works in the literature [12]–[16].

The present work presents a numerical simulation of an atmospheric pressure plasma jet, generated by a double dielectric barrier discharge setup and launched in the open air.

2. The model

In this work, the low temperature plasma jet is generated by a double DBD configuration, shown in Fig.1. It is composed of two quartz tubes crossed by an argon flow as a carrier gas. The first tube has a length of 60 mm, an internal diameter of 6 mm and an external diameter of 8 mm. This tube is wrapped by a ring electrode made of aluminum, positioned at 6 mm away from the outlet of the tube. The high voltage electrode (consisted of 40 mm of length and 2 mm of diameter) is composed of copper and located at the center of the tube. This electrode is covered by a dielectric tube of 1 mm of thickness. The second quartz tube, in which the argon is ejected, is positioned at 7 mm away from the inlet of the first one.

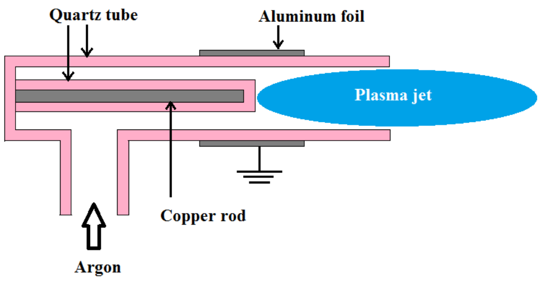

Fig. 1. Schematic overview of the setup for generating and launching a plasma jet in open air

A 3D hydrodynamic model was simulated to estimate the dilution of the argon in the open air. This model was based on the mass, momentum equations assuming a laminar and stationary flow and including diffusion fluxes in a mixture. The gas flow was set under 2.25 l/min to maintain a Reynolds number under 1000.

The simulation of the generation and the propagation of the low temperature plasma are based on the charged particles conservation equations coupled to the Poisson equation.

In our model, we assumed that the air is consisted of the oxygen O_2 and the nitrogen N_2 (the impurities and the humidity were neglected). We considered also the formation of the following ions: Ar^+, N_2^+, O_2^+ and O^-.

In order to propagate the plasma in a relatively low electric field values, both metastable and background states ionizations of argon were taken into account. Which implies the presence of the metastable state: Ar^*.

3. Results and discussion

Fig. 2 display the reduced concentration of argon for argon velocity: v = 5 m s-1.

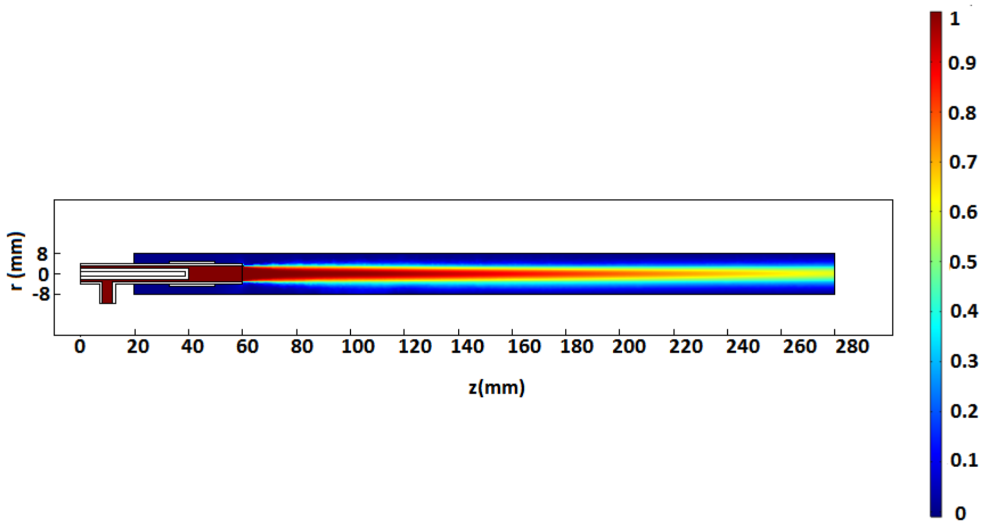

Fig. 2. Reduced argon concentration for argon velocity: v = 5 m s^{-1}

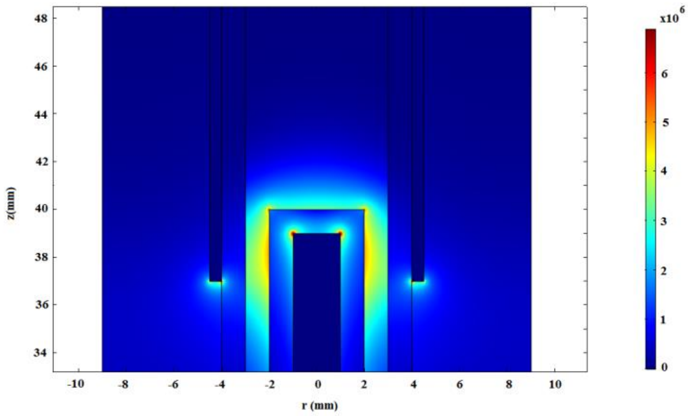

Fig. 3. Initial electric field distribution for V_0 = 6.5 kV

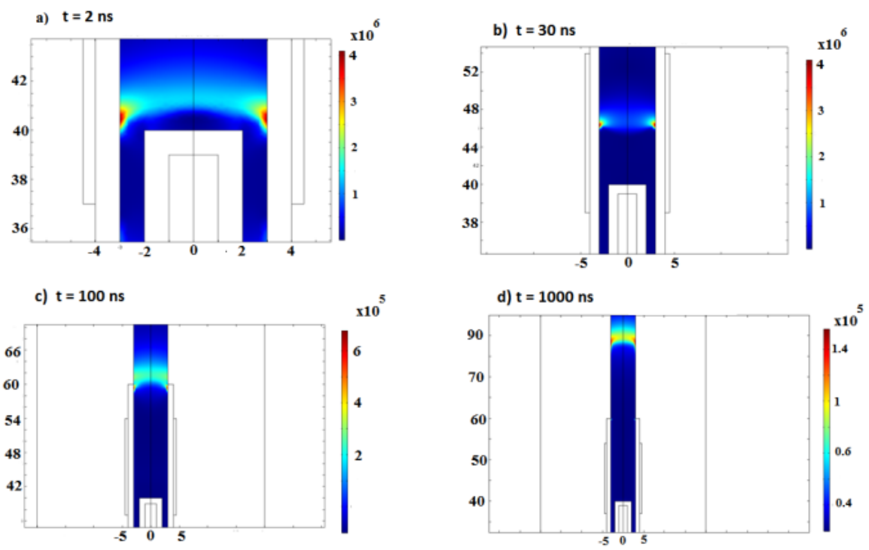

Fig. 3. Electric field distribution for V_0 = 6.5 kV

As it's expected, the argon gradually dilutes in ambient air and it takes the form of a beam. The reduced argon concentration decreases as it moves away from the tube exit and the radial dilution is faster than the axial dilution, which is important in order to reach a target located away from the tube.

The initial or geometric electric field created by the device, shown in Fig.3, is the initiator of the plasma jet. This field depends only on the geometry of the device.

The electric field reaches 6.10^{6} V/m which is high enough to generate a plasma bullet (the breakdown field strength of argon in atmospheric pressure is 0.6 MV/m).

The electric field distribution is shown in Fig.4. The propagation of the plasma stars jet inside the tube (in the gap between the quartz tube and the tube covering the HV electrode) then it's ejected outside the tube into the air.

4. Conclusion

Numerical investigation of atmospheric pressure jet generated by a double dielectric discharge has been simulated. This work allowed us to predict the concentration of argon in the gas mixture and the profile of the electric field distribution.

5. References

[1] M. Laroussi, "Low Temperature Plasma-Based Sterilization: Overview and State-of-the-Art," *Plasma Process. Polym.*, vol. 2, no. 5, pp. 391–400, Jun. 2005.

[2] S. Bekeschus, A. Schmidt, K.-D. Weltmann, and T. von Woedtke, "The plasma jet kINPen – A powerful tool for wound healing," *Clin. Plasma Med.*, vol. 4, no. 1, pp. 19–28, Jul. 2016.

[3] V. Arora, "Cold Atmospheric Plasma (CAP) In Dentistry," *Dentistry*, vol. 04, no. 01, 2013.

[4] H.-R. Metelmann *et al.*, "Head and neck cancer treatment and physical plasma," *Clin. Plasma Med.*, vol. 3, no. 1, pp. 17–23, Jun. 2015.

[5] M. Kuchenbecker, N. Bibinov, A. Kaemlimg, D. Wandke, P. Awakowicz, and W. Viöl, "Characterization of DBD plasma source for biomedical applications," *J. Phys. Appl. Phys.*, vol. 42, no. 4, p. 045212, 2009.

[6] F. Bozduman, A. Gulec, T. Aktan, and L. Oksuz, "Atmospheric pressure microwave plasma torch," in *2011 Abstracts IEEE International Conference on Plasma Science*, 2011, pp. 1–1.

[7] C. Labay, C. Canal, and M. J. García-Celma, "Influence of Corona Plasma Treatment on Polypropylene and Polyamide 6.6 on the Release of a Model Drug," *Plasma Chem. Plasma Process.*, vol. 30, no. 6, pp. 885–896, Dec. 2010.

[8] J. Park, I. Henins, H. W. Herrmann, G. S. Selwyn, and R. F. Hicks, "Discharge phenomena of an atmospheric pressure radio-frequency capacitive plasma source," *J. Appl. Phys.*, vol. 89, no. 1, pp. 20–28, Jan. 2001.

[9] R. Abidat, S. Rebiai, and L. Benterrouche, "Numerical simulation of atmospheric Dielectric Barrier Discharge in helium gas using COMSOL Multiphysics," in *3rd International Conference on Systems and Control*, 2013, pp. 134–139.

[10] B. Min, S.-H. Lee, and H.-G. Park, "New combination of a three-component gas, Ne–Xe–Ar, for a high efficiency plasma display panel," *J. Vac. Sci. Technol. Vac. Surf. Films*, vol. 18, no. 2, pp. 349–355, Mar. 2000.

[11] J. Berndt, K. Makasheva, H. Schlüter, and A. Shivarova, "Wave-sustained discharges in helium–argon gas mixtures," *J. Appl. Phys.*, vol. 92, no. 11, pp. 6461–6470, Dec. 2002.

[12] I. Adamovich *et al.*, "The 2017 Plasma Roadmap: Low temperature plasma science and technology," *J. Phys. Appl. Phys.*, vol. 50, no. 32, p. 323001, 2017.

[13] R. Brandenburg, "Dielectric barrier discharges: progress on plasma sources and on the understanding of regimes and single filaments," *Plasma Sources Sci. Technol.*, vol. 26, no. 5, p. 053001, Mar. 2017.

[14] M. G. Kong, B. N. Ganguly, and R. F. Hicks, "Plasma jets and plasma bullets," *Plasma Sources Sci. Technol.*, vol. 21, no. 3, p. 030201, Jun. 2012.

[15] M. Laroussi, X. Lu, and M. Keidar, "Perspective: The physics, diagnostics, and applications of atmospheric pressure low temperature plasma sources used in plasma medicine," *J. Appl. Phys.*, vol. 122, no. 2, p. 020901, Jul. 2017.

[16] M. Laroussi, "The Biomedical Applications of Plasma: A Brief History of the Development of a New Field of Research," *IEEE Trans. Plasma Sci.*, vol. 36, no. 4, pp. 1612–1614, Aug. 2008.