Plasma Candle: A new type of plasma-jet

H. H. Kim[1], Y. Teramoto[1] , N. Takeuchi[1, 2] and A. Ogata[1]

[1]*Environmental Management Research Institute, National Institute of Advanced Industrial Science and Technology (AIST) Tsukuba, Ibaraki, Japan*
[2]*Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, Ookayama, Tokyo*

Abstract: Plasma het has been intensively studied in the last decade, and A new type of atmospheric-pressure plasma jet, referred to as plasma candle hereafter, has been developed. By using a multi-hole tube (honeycomb type) or a porous ceramic plate, we demonstrated that plasma jet can be established with the diameter larger than 20 mm. Preliminary results on the effect of tube geometry, gas flow rate, applied voltage and their effect on plume shape and temperature will be discussed.

Keywords: Plasma candle, plasma-jet, multi-hole tube, porous ceramic, .

1. General

Plasma jet is a type of atmospheric pressure nonthermal plasma, where the plasma afterglow (plume, bullet) is extended from the tip of nozzles. Inert working gases (mostly helium, argon or their mixture) are used to form stable plasma jets. In the last decade, atmospheric pressure plasma jet (APPJ) has been the subject of intensive studies both in fundamental study of physicochemical properties and various applications such as surface modification, biological and medical treatment. Diagnostics of reactive species, gas flow pattern (laminar vs turbulent), have been investigated using laser-induced fluorescence (LIF) [1], Schlieren imaging [2, 7], and fast imaging using intensified charge coupled device (ICCD) camera. Nonthermal aspect of plasma jets is highly important for bio-medical applications and treatment of highly heat-sensitive substrates. Many different arrangements for plasma jet have been reported. Among them, tubular insulator is most popular geometry, where the inert gas flow is energized by AC or pulse high voltage. From the point view of reactor geometry, the plasma jets resemble the dielectric barrier discharge (DBD) reactor. However, most the APPJs have been tested with small tubes having diameter below about 10 mm.

Here we report a new type of plasma jet that can extend the size of tube diameter over 20 mm. This large tube diameter decreases the flow velocity at the tube outlet, that in turn shaping the candle-like plasma plume. Preliminary results on the effect of applied voltage, gas flow rate and temperature measurement will be discussed.

2. Experimental

Plasma candle can be generated with two different reactor configurations. First one is a honeycomb type that has 36 holes on its cross-section. Second reactor has a porous ceramic plate installed in the glass tube. The diameter of the honeycomb ceramic tube and glass tube with porous ceramic were 25 mm and 20 mm, respectively. AC high voltage of peak-to-peak voltage of about ~ 17 $kV_{pk\text{-}pk}$ with the frequency of 15 kHz was applied to the one of the electrodes.

Flow rate of helium was controlled by a mass flow controller (Kofloc Co, Flow Compo FCC-300) in the range of 1- 14 liter per minute (LPM). Intensified charge coupled device (ICCD, Andor iStar DH334T) and digital camera were used to capture the plasma jet. Gas temperature of the plasma jet was measured using a fiber optic thermometer (Anritsu, Amoth FX8500). The tip of optic fiber was covered with insulator and it was positioned directly inside the plasma plume without any interference.

3. Results and Discussion

Generally, plasma jet is not formed when a normal tube with a diameter of about 10 mm is used. However, this size limitation can be overcome by incorporating honeycomb structure (i.e. multi holes) or porous ceramic plate in the tube. Figure 1 shows the snapshots of plasma candles for the two different types of plasma jet reactors. A stable candle-like plasma jets can be seen with the He flow. In the case of honeycomb type, the applied voltage was 13 $kV_{pk\text{-}pk}$ while the He flow was 10 LPM (left) and 12 LPM (right). In the case of porous ceramic plate, an interesting plasma pattern appeared on the inner surface downstream the ceramic plate.

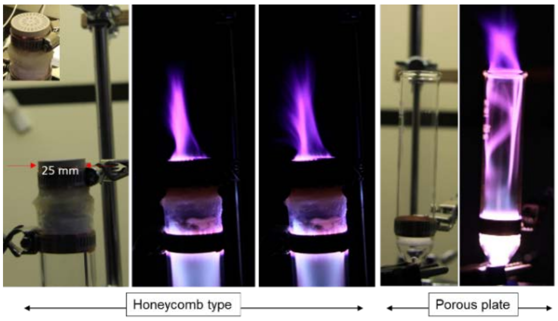

Fig. 1 Plasma candle with two different types of reactors (Honeycomb type (left), and porous ceramic plate type (right).

Table 1 Typical dimension of atmospheric-pressure plasma jet

Tube size (mm)		Power	Gas	Flow rate ($Lmin^{-1}$)	Ref
ID	OD				
4	6	Pulse	He	~5	J. Phys D: Appl. Phys, 50 195203 (2017)
1	4	AC	He	~5.4	J. Phys D: Appl. Phys, 44 155206 (2011)
0.1~0.5	*	AC	He	~0.1	J. Phys D: Appl. Phys 47, 415202 (2014)
1	3	pulse	He	1.3	PSST, 21, 034010 (2012)
2	3	pulse	He/ Ar	~9	Appl. Phys. Lett, 92, 151503 (2008)
1.5	3.5	AC	He	~10	IEEE Trans. Plasma Sci, 44, 107-112 (2016)
0.2	1	AC	He	~8	IEEE Trans Plasma Sci. 43, 1993-1998 (2015)
20	**22**	AC	He	1~15	This study
Multi holes	**25**	AC	He	1~15	This study

* wall thickness = 10 μm

A swirl like flow grew as the applied voltage increased, and eventually formed candle-like plasma plume at the outlet. This plasma candle was easily influenced by the external gas flow near the plasma candle. These large diameter APPJs may be useful for the uniform treatment of large areas for various applications.

4. Summary

New type of atmospheric pressure plasma-jet, referred to as plasma candle, has developed. We incorporated new geometries, such as multi-hole and porous ceramic plate, which enabled stable plasma jet even with tube diameters larger over 20 mm. The effect of several parameters (such as gas flow rate, applied voltage, and their effects on jet temperature and jet shape) has been discussed.

Acknowledgements

This work has been supported by JSPS KAKENHI Grand Number JP18H01208.

Reference

[1] S Reuter, J Winter, A Schmidt-Bleker, D Schroeder, H Lange, N Knake, V Schulz-von der Gathen, and K-D Weltmann, Plasma Sources Sci. Technol. **21**, 024005 (2012).

[2] Y. Fujiwara, H. Sakakita, H. Yamada, Y. Yamagishi, H. Itagaki, S. Kiyama, M. Fujiwara, Y. Ikehara, and J. Kim, Jpn. J. Appl. Phys. **55**, 010301 (2016).

[3] H. Yamada, Y. Yamagishi, H. Sakakida, S. Tsunoda, J. Kasahara, M. Fujiwara, S. Kato, H. Itagaki, J. Kim, S. Kiyama, Y. Fujjiwara, Y. Ikehara, S. Ikehara, H. Nakanishi, N. Shimizu: Jpn. J. Appl. Phys. **55**, 01AB08 (2016).

[4] J. Winter, R. Brandenburg, K.D. Weltmann: Plasma Source Sci. Technol. **24,** 064001, (2015).

[5] J.S. Oh, Y. Aranda-Gonzalvo, J.W. Bradley, J. Phys D: Appl. Phys, **44**, 365202 (2011)

[6] I. Jogi, R. Talviste, J. Raud, K. Piip, P. Paris, J. Phys. D: Appl. Phys, **47**, 415202 (2014)

[7] E Robert, V Sarro, T Darny, D Ries, S Dozias, J Fontane, L Joly, and J M Pouvesle, Plasma Sources Sci. Technol., V23, 012003 (2014)