Vol. 8(29), Jul. 2018, PP. 3935-3940

Contents list available at IJMEC

International Journal of Mechatronics, Electrical and Computer Technology (IJMEC)

Journal Homepage: www.aeuso.org

PISSN: 2411-6173 - EISSN: 2305-0543

The Effect of Argon/Nitrogen Plasma Jet Irradiation on Optical Properties of Distilled Water

Ziba Matinzadeh[1,*], Farhad Shahgoli[2], Hamed Abbasi[3], Mahmood Ghoranneviss[1], Mohammad Kazem Salem[1]

[1]*Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[2]*Department of Energy Engineering and Physics, Amirkabir University of Technology, Tehran, Iran*

[3]*Department of Photonics, Faculty of Physics, University of Kashan, Kashan, Iran*

Phone Number: *+98- 2144869640*

****Corresponding Author's E-mail:*** *z.matinzadeh@gmail.com*

Abstract

In this work the effect of atmospheric-pressure plasma jet irradiation on some properties of distilled water has been studied. Argon and nitrogen were used as the applied gasses in two similar experiments. The distilled water was irradiated by a cold argon/nitrogen plasma jet. The electrical conductivity, pH, and the absorbance of samples were measured before and after the irradiation of non-thermal plasma jet in various time durations. When the plasma jet was irradiated onto the samples, an absorbance spectral peak was observed at approximately 200 nm for both applied gasses. The absorbance of both samples increased with increasing the irradiation time, but the peak did not move in the spectral range. The electrical conductivity of distilled water increased with increasing the irradiation time for both gasses. The pH of distilled water decreased with increasing argon and nitrogen irradiation time. Also an increase in the absorbance was observed after each irradiation time interval for both applied gasses.

Keywords: *Distilled Water, Plasma Jet, pH, Optical Properties*

1. Introduction

Plasma is considered as the forth state of matter similar to gas state but their particles are ionized. Over the past few years, plasma has proven to be a great promise in the different fields of science and technology ranging from physics, chemistry and engineering to medicine and biology. Plasma jets are ionized local gas flows which are produced by several methods such as high frequency and pulsed direct current [1]. Atmospheric plasma sources include thermal plasma sources, and non-thermal plasma sources [2]. One can find a comprehensive review in [3] which discusses the versatility and applicability of different plasma sources in various areas such as interaction with biomolecules, biomedical treatment, chemical synthesis, removal of volatile organic compounds, electrochemical reaction, nanoscience, surface modification, food engineering and water purification applications. There are two other review papers, the first one of which studies both thermal and non-thermal atmospheric pressure plasma sources and the second one of which focuses on non-thermal atmospheric pressure plasma sources [4, 5]. In another paper, a comparison between atmospheric plasma jets and other plasma sources can be found [6]. Moreover, Laroussi and Akan studied arc-free atmospheric pressure cold plasma jets used in various plasma processing applications [7]. Different applications of the non-thermal atmospheric plasma can be obtained by a variety of electrical

Article History:
Received Date: Apr. 03, 2018
Accepted Date: Jul. 01, 2018
Available Online: Jul. 04, 2018

discharges including corona discharge, dielectric barrier discharge, micro hollow cathode discharge and atmospheric pressure plasma jet [8]. Among the several plasma sources, atmospheric-pressure plasma jets have received significant attention due to their unique capabilities (low temperature, low cost, portable and easy operation), and novel applications such as analytical chemistry [9], surface and material processing [10- 12], synthesis of nanomaterial [13, 14], absorption and reflection of electromagnetic radiation [15, 16], sterilization [17], cleaning and etching [5].

Various types of atmospheric plasma jets are being developed such as remote plasma jet and local plasma jets. Local plasma jets include inductive plasma jet and capacitive coupled plasma jet [18]. One of the most important technologies for decomposition of organic compound in water is discharges and plasma treatment. There are a number of papers which study the generation of various plasma sources in water and in contact with water [19-21]. One can find a good paper which reviews the atmospheric pressure non-thermal discharges in liquids and in contact with liquids [22].

In this research, capacitive coupled argon plasma jet irradiation is propagated from glass tube and hit the surface of distilled water followed by optical emission around region. Further measurements and analysis will be carried out to clarify the mechanism. The effect of plasma discharge on optical properties of distilled water is also studied. The irradiation time and type of gas source are basic variables in this work.

2. Experimental details

In our setup, there was a quarts tube (length 70 mm; inner diameter 9 mm and outer diameter 14 mm) as a plasma jet with a copper tube (inner diameter 7 mm; outer diameter 8.8 mm and length 5 mm) used as a discharge electrode. Another copper tube (length 5 mm; inner diameter 14.1 mm; outer diameter 15.5 mm) was wrapped as a grounding electrode. When a high AC voltage is applied, dielectric barrier discharge is induced in the glass tube between these electrodes, and the inflowing gas was excited to form a plasma environment and then releases into the atmosphere.

Argon and nitrogen gases used as a source gas for discharging and the results of which will be compared. A plasma jet was generated at pure argon and nitrogen gas flow rate of 5 L/min with 99.999% purity using a high-voltage power source with a frequency of 23 kHz and an applied voltage of 5.4 kV. This plasma jet was directly irradiated from 1 to 11 min onto 10 ml distilled water in glass Petri dishes. The distance between the end of the glass tube and the surface of the distilled water sample was approximately 20 mm. Gas currency was 5 L/min which turned on the HV system in order to produce irradiation towards the sample. A streamer discharge reached the surface of the distilled water sample.

The pH of the distilled water is measured with pH meter (metrohm 744), the absorbance spectra of the distilled water samples were obtained from spectrophotometer (hach DR500) and the conductivity of samples was measured with conductometer (metrohm 712).

3. Results and discussion

Fig. 1 indicates the dependence of the absorbance spectrum of the distilled water sample on the plasma jet irradiation time. When the plasma jet was irradiated onto the sample for 1 min, an absorbance spectral peak was observed at approximately 200 nm; the absorbance increased with an increase in irradiation time at 200 nm.

This result indicates that some substances were generated in the distilled water sample during plasma jet irradiation and that it increases with irradiation time. It can be deduced from these graphs that the absorbance of nitrogen in 200 nm is much more than that of argon. Besides, one peak was observed at 201 nm which is the absorbance spectrum of NO_3^- in $NaNO_3$ aqueous solution [23].

Therefore, the substance causing the peak near 200 nm upon plasma jet irradiation was identified to be NO_3^-.

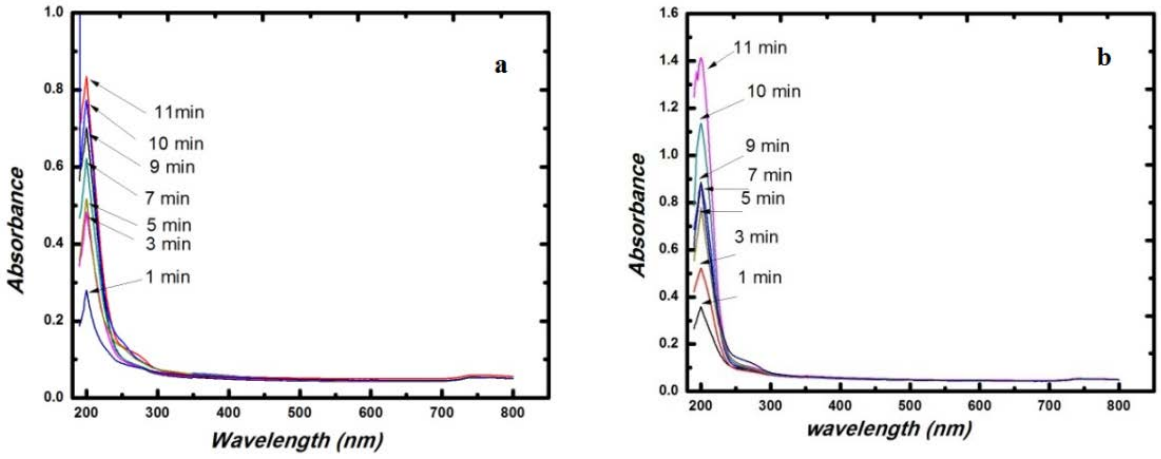

Figure 1: Dependence of absorbance spectrum of distilled water sample on plasma jet irradiation time for (a) argon and (b) nitrogen.

Fig. 2 (a) and (b) show the absorbance at 200 nm plotted versus plasma jet irradiation time for argon and nitrogen gas source, respectively. It can be seen from this figure that for both gas sources the absorbance gradually increases with an increase in irradiation time. However, for argon gas source it reaches 7% after 9 minutes of irradiation and then remains constant, i.e. the saturation state. For nitrogen gas source the saturation takes place after 9 minutes of irradiation at the lower extent of absorbance of 5%.

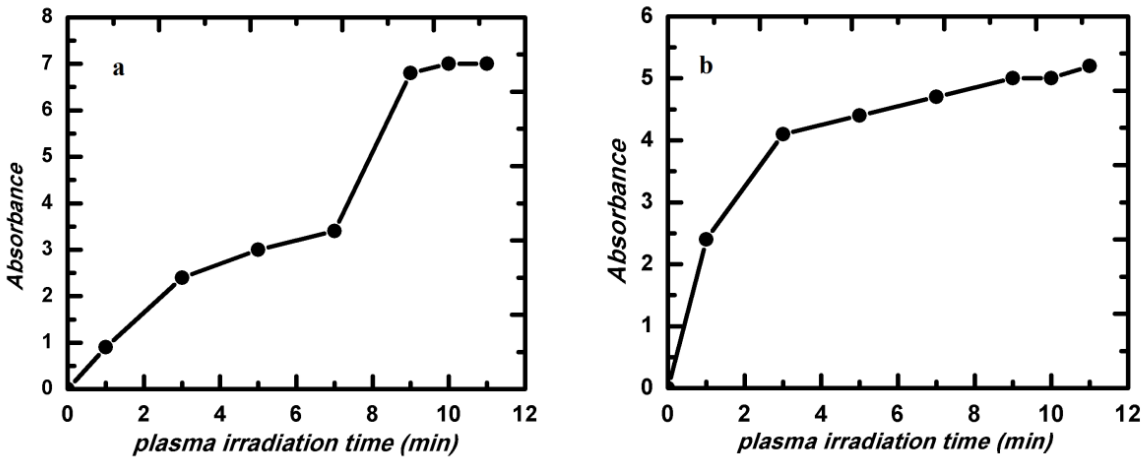

Figure 2: Absorbance at 200 nm plotted against plasma jet irradiation time for (a) argon gas source and (b) nitrogen gas source.

On the other hand, frequency changes according to equation 1 which shows the relationship between gas source type and plasma intensity [24].

$$\nu_{\varepsilon} \sim 10^{-12} \frac{\sqrt{\mu_1}}{\sqrt{\mu_2}} \frac{Z_1^2 Z_2^2}{(T_1/e)^{3/2}} S^{-1} \qquad (1)$$

Where μ represents the mass in units of the proton mass. Z_1 and Z_2 are the atomic numbers of oxygen and the plasma gas type respectively. We used two types of gas at the same temperature where all parameters are constant except Z and μ. It can be deduced that ν_ε depends on the atomic structure of the plasma gas source which directly affects absorbance. This is the reason why absorbance of argon gas source is more than that of nitrogen gas source.

Fig. 3 shows the electrical conductivity of distilled water sample plotted against plasma jet irradiation time for both types of gas sources. The electrical conductivity of sample irradiated with argon source starts at 10 ms/m. After a little decrease at 3 minutes, it gradually increases over irradiation time and reaches 22 ms/m after 11 min of irradiation.

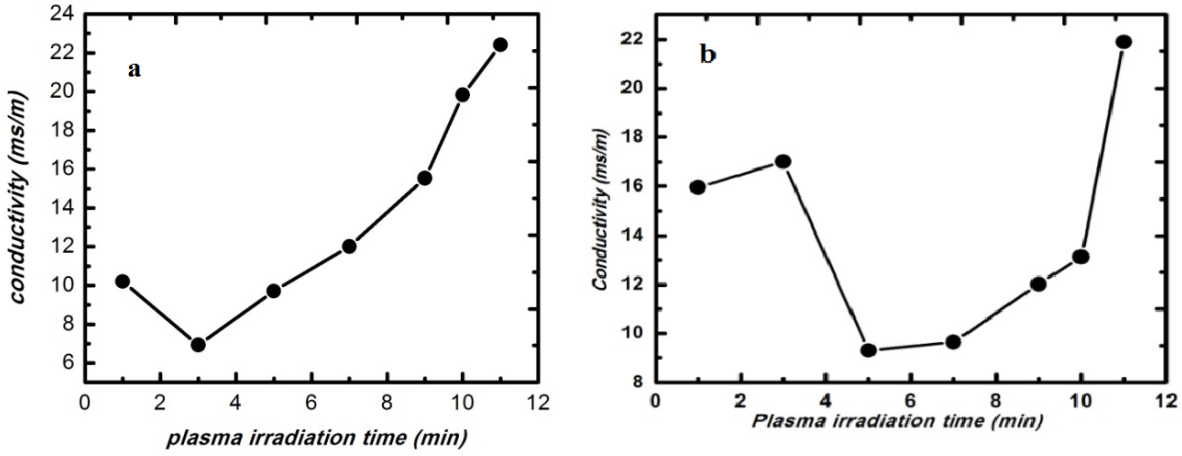

Figure 3: Electrical conductivity of distilled water sample plotted against plasma jet irradiation time for (a) argon and (b) nitrogen gas source.

However, for nitrogen gas source there was a random fluctuation of conductivity as a function of irradiation time finally reaching 22 ms/m. This result indicates that the concentration of some types of ion that conduct electricity in the distilled water samples increases over irradiation time.

Fig. 4 shows the diagram of pH for the distilled water sample plots against plasma jet irradiation time.

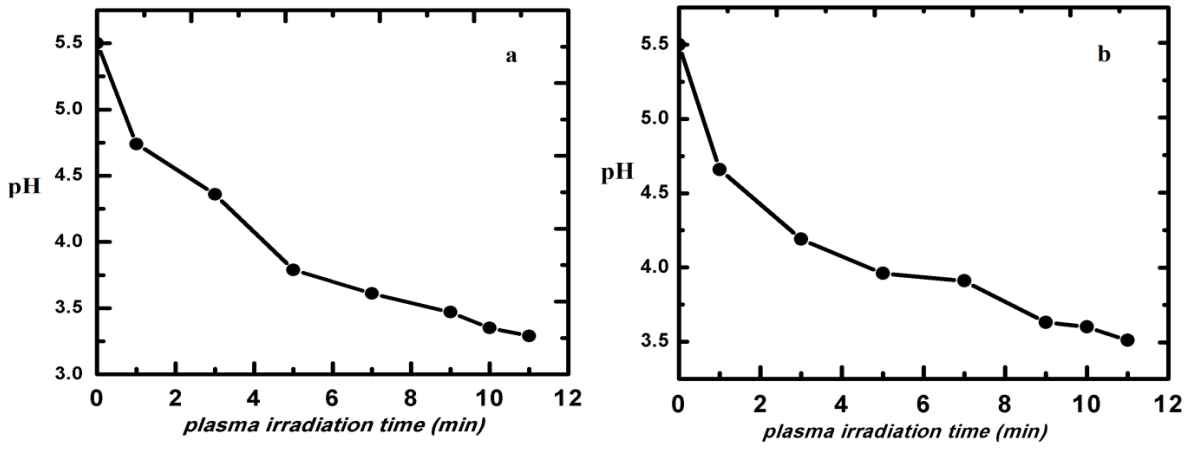

Figure 1: pH of distilled water sample plotted against plasma jet irradiation time for (a) argon and (b) nitrogen gas source.

The pH of the distilled water sample is 5.5 before irradiation. It gradually decreases over irradiation time and gets to 3.3 and 3.5 for argon and nitrogen gas source, respectively after 11 minutes of irradiation. As it can be seen in Fig. 1, absorbance at 200 nm increases which is supposed to be the result of an increase in H^+ due to concentration of NO_3^- in distilled water. This is in good agreement with the results of Fig. 4 which shows the decrease of pH with an increase in irradiation time. This result indicates that the concentration of hydrogen ions (H^+) in the distilled water samples increases as a result of plasma jet irradiation.

Therefore, the ions that generate in these samples as a result of plasma jet irradiation are H^+ or another substance that accompanies the generation of H^+.

In other studies, it was reported that ozone (O_3) and nitrogen oxide (NO_3) were generated during a discharge in air because of the interaction between electrons and the nitrogen (N_2) and oxygen (O_2) molecules in air [25, 26] and that NO_3 reacted with water (H_2O) molecules to generate nitric acid (HNO_3) in water [23]. In the present work, HNO_3 is ionized into H^+ and NO_3^- in water. Because a similar reaction occurred during the irradiation of the distilled water sample with the plasma jet in our experiment, it is considered that H^+ and NO_3^- exist in these samples but with more intensity for nitrogen gas source. Therefore, NO_3^- was the cause of the absorbance spectral peak near 200 nm.

Conclusion

Comparing the properties of distilled water irradiated with plasma jet, it is concluded that the type of gas source has an important effect on optical and electrical properties of the samples. When a plasma jet is directly irradiated into distilled water at different time intervals, an absorbance spectral peak is observed at approximately 200 nm and the peak intensity increases with increasing irradiation time for both types of gas. However, samples which are irradiated with nitrogen source enjoy more absorbance intensity. On the other hand, the electrical conductivity of the distilled water samples increases over irradiation time with a fluctuation with nitrogen source. This result indicates that the concentration of some type of ion that conducted electricity in the distilled water sample increased with increasing irradiation time. According to pH measurement, we hypothesize that NO_3^- is responsible for the absorbance spectral peak near 200 nm at plasma jet irradiation. The amount of NO_3^- compound, which is generated during plasma jet irradiation with nitrogen as the gas source is more than argon source. The main result is a decrease in pH in nitrogen source more than that of argon source with an increase in H^+ as a result of NO_3^-. The greater pH in nitrogen gas compare to argon gas is the main result of the study.

ACKNOWLEDGEMENTS

We thank Ms. Negin Beryani Nezafat for her help in writing this paper.

References

[1] I.E. Kieft, J.J.B.N. van Berkel, E.R Kieft,. E. Stoffels, “Radicals of Plasma Needle Detected with Fluorescent Probe,” In d’Agostino, R. Favia, P., Oehr, C., Wertheimer, M.R. (eds.) Plasma Processes and Polymers, Wiley-VCH ,2005, pp. 259-308.

[2] S. Nijdam, E. van Veldhuizen, P. Bruggeman, U. Ebert, “An Introduction to Nonequilibrium Plasmas at Atmospheric Pressure,” In Parvulescu, V.I., Magureanu, M., Lukes, P. (eds.) Plasma Chemistry and Catalysis in Gases and Liquids, Wiley-VCH ,2012, pp. 1-44.

[3] P. Attri, B. Arora, E.H. Choi, “Utility of plasma, “a new road from physics to chemistry,” RSC Adv, vol. 3(31), 2013, pp. 12540-12567.

[4] V. Nehra A. Kumar, H. Dwivedi, “Atmospheric non-thermal plasma sources,” Int. J. Eng, vol. 2(1), 2008, pp. 53-68.

[5] C. Tendero, C. Tixier, P. Tristant, J. Desmaison, P. Leprince, "Atmospheric pressure plasmas," A review. Spectrochim. Acta B, vol. 61(1), 2006, pp. 2-30.

[6] A. Schutze, J.Y. Jeong, S.E. Babayan, J. Park, G.S. Selwyn, R.F. Hicks, "The atmospheric-pressure plasma jet, "a review and comparison to other plasma sources," IEEE Trans. Plasma Sci, vol. 26(6), 1998, pp. 1685-1694.

[7] M. Laroussi, T. Akan, "Arc-Free Atmospheric Pressure Cold Plasma Jets A Review," Plasma Process. Polym, vol. 4(9), 2007, pp. 777-788.

[8] Z. Matinzadeh, F. Shahgoli, H. Abbasi, M. Ghoranneviss, M.K. Salem, "Degradation of bromophenol blue molecule during argon plasma jet irradiation," J. Theor. Appl. Phys, vol. 11(2), 2017, 97-102.

[9] M. Teschke, J. Kedzierski, E.G. Finantu-Dinu, D. Korzec, J. Engemann, "High-speed photographs of a dielectric barrier atmospheric pressure plasma jet," IEEE Trans. Plasma Sci, vol. 33, 2005, pp. 310-311.

[10] R. Dorai, M.K. Kushner, "A model for plasma modification of polypropylene using atmospheric pressure discharges," J. Phys. D, vol. 36, 2003, pp. 666-685.

[11] P. Chu, "Plasma-treated biomaterials. Plasma Science," IEEE Trans. Plasma Sci. 35, 2007, pp. 181-187.

[12] H. Abbasi, M.A. Bani, M. Nazeri, S.A. Mireei, "Application of Fluorescence Spectroscopy in the Freshness Control of Lettuce Leaf after Irradiation of Cold Atmospheric Pressure Plasma," In Proc. 2nd Conf. on Plasma Engineering and Physics, 2014, pp. 1-4.

[13] K. Ostrikov, "Ostrikov, K. (2005). Colloquium, "Reactive plasmas as a versatile nanofabrication tool," Rev. Mod. Phys, vol. 77, 2005, pp. 489-511.

[14] I. Levchenko, K. Ostrikov, E. Tam, "Uniformity of postprocessing of dense nanotube arrays by neutral and ion fluxes," Appl. Phys. Lett, vol. 89, 2006, pp. 2231081-2231084.

[15] R. Vidmar, "On the use of atmospheric pressure plasmas as electromagnetic reflectors and absorbers," IEEE Trans. Plasma Sci, vol. 18, 1990, pp. 733-741.

[16] M. Laroussi, "Interaction of microwaves with atmospheric pressure plasmas," Int. J. Infrared Millim. Waves, vol. 16, 1995, pp. 2069-2083.

[17] S. Ikawa, K. Kitano, S. Hamaguchi, "Effects of pH on Bacterial Inactivation in Aqueous Solutions due to Low-Temperature Atmospheric Pressure Plasma Application," Plasma Process. Polym, vol. 7, 2010, pp. 33-42.

[18] G. Konesky, "Dwell time considerations for large area cold Plasma decontamination," Proc. SPIE, vol. 7304, 2009, pp. 73040N.

[19] H. Abbasi, M. Nazeri, S. Mirpour, N.J. Farahani, "Measuring electron density, electric field and temperature of a micro-discharge air plasma jet using optical emission spectroscopy," In 2nd International Conference on Knowledge-Based Engineering and Innovation (KBEI), IEEE, 2015, pp. 1139-1141.

[20] M. Sato, "Environmental and biotechnological applications of high-voltage pulsed discharges in water," Plasma Sources Sci. Technol, vol. 17(2), 2008, pp. 59-62.

[21] B. Locke, M. Sato, P. Sunka, M. Hoffmann, J.-S. Chang,, "Electrohydraulic discharge and nonthermal plasma for water treatment," Ind. Eng. Chem. Res, vol. 45(3), 2006, pp. 882-905.

[22] P. Bruggeman, C. Leys, "Non-thermal plasmas in and in contact with liquids," J. Phys. D, vol. 42(5), 2009, pp. 1-28.

[23] S.K. Dhali, I. Sardja, "Dielectric-barrier discharge for processing of SO2/NOx," J. Appl. Phys, Vol. 69, 1991, pp. 6319-6324.

[24] I.H. Hutchinson, "Principles of Plasma Diagnostics," Cambridge University Press (2002)

[25] D. Braun, U. Kuchler, G. Pietsch, "Behaviour of NOx in air-fed ozonizers," Pure Appl. Chem, vol. 60, 1988, pp. 741-746.

[26] S. Mukkavilli, C.K. Lee, K. Varghese, L.L. Tavlarides, "Modeling of the electrostatic corona discharge reactor," IEEE Trans. Plasma Sci, vol. 16, 1988, pp. 652-660.