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Measurement of Electron temperature (T_e) and Electron density (n_e) Cold Plasma Jets Optical Emission Spectroscopy (OES) Method

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ABSTRACT

The electron density (**n_e**) and temperature (**T_e**) of the cold argon plasma jets are determined at normal atmospheric pressure using the Stark expansion analysis method for two emission lines. This method depends on the Stark expansion for different lines having unlike lines depending on both the electron temperature (**T_e**) and the electron density(**n_e**). So, the expansion processes for comparison between two or even more lines let us determine both the electron temperature and electron density at the same time. In this study, these parameters which include both electron density (**n_e**) also its temperature (**T_e**) were calculated at a constant frequency (75 KHz), a constant gas flow rate (50 l/h), and sinusoidal alternating voltages (12, 16, 20) KV, at different times (10, 20, 30) sec. The results shows that increasing the potential difference leads to a rise in the electron temperature (**T_e**), Also, it was found that the electronic density (**n_e**) increased when the alternating voltage increased and for all times.

Keywords: cold plasma jets, plasma diagnostics, electron density, Optical Emission Spectroscopy.

1. Introduction

Ionized gas is known as plasma. It contains neutral, charged quasi-particles that show collective behavior. When a solid is heated to a sufficient degree, it turns into a liquid, and by continuing to heat the liquid, a gas is formed, by heating the gas continuously to a sufficient degree, the number of particles that are ionized will increase, the ionized gas exhibits a new behavior, so it is called the fourth state of matter [1-11].

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Plasmas are classified depending on the thermodynamic temperature equilibrium of their parts into thermal equilibrium (TP) and non-thermal equilibrium (NTP) plasmas. TP Plasma Electrons are at the same temperature as the rest of the species (ions or atoms, molecules), reaching millions of degrees (10^7-10^9 °C). NTP plasma is weakly ionized gases, and it is called cold plasma because it does not cause thermal damage because it has a low temperature, usually less than (100 °C). The focus of the research will be on one type of plasma used in various fields of life, which is cold plasma. [11-16].

Normal atmospheric pressure plasma jets (NAPPJs) is non-thermal plasma. Because of its flexibility, its ability to generate reactive chemical temperatures, its low-cost operation, and its ability to filter and diffuse within small apertures, it has the unique advantage of producing plasma far from the electrodes in the ambient air environment, so the plasma can be delivered to a target far from the plasma generation area. So, it is attractive for applications in the medical field. Cold plasma can be delivered through a flexible tube at a specific location for the uses of endoscopes in medicine, including pancreatic cancer and colon cancer in addition to rectal cancer treatment, biological treatment, and the treatment of materials and surfaces of various materials (gas, air, water) [11-20].

Optical Emission Spectrometer (OES) represents some of the electromagnetic radiation that includes visible, infrared, and ultraviolet radiation with wavelengths that lie between (130-800) nm OES is one of the simple and uncomplicated methods by which the excited species emitted by radiation are determined. The importance of OES method for the determination of plasma parameters, including electron density (**n_e**), electric field strength (E), and gas temperature (T_g). Characterized by OES as an invasive measurement process, OES uses radiation to assess the properties of plasma without contact. Using the spectral emission ratio containing two different spectral intensities, we obtain the electron excitation temperature that matches the electron temperature, [15, 21-25]. and the following formula is used to calculate the electron temperature [26]

$$T_e = \frac{-(Ek-Ei)}{k} \ln\left(\frac{Ak\, gk\, Ii\, \lambda i}{Ai\, gi\, Ik\, \lambda k}\right)^{-1} \quad (1)$$

Where is E energy level, (k,i) the lowest and highest energy level, respectively, K the Boltzmann constant, A the transition probability, g the statistical weight, and λ the wavelength, {E_k, E_i,A_i, A_k, g_i, g_k} values can be obtained by (Atomic Spectroscopic Database) NIST [27]. A stark broadening analysis of the two lines of the emission spectrum results in the electron density. The principle of the above method is that for different lines, the Stark expansion depends on temperature and electron density in different ways. By comparing two or more-line extension lines, we can diagnose the temperature and electron density simultaneously [28]. The electron density(n_e) is obtained using the following relation [29]

$$n_e = \exp^{(44.2476+1.20\ln\Delta\lambda\, ½-0.6\ln Te)} \quad 2)$$

Where ne represents the electron number density measured in cm^{-3}, $\Delta\lambda_{1/2}$ represents the full line width at the intensity mid-maximum (FWHM) for any spectral line, and T_e represents the electron temperature in K.

2- Experimental Setups

The cold plasma jet system, which was used to obtain cold plasma jets at normal conditions of pressure and temperature, was manufactured locally and contains a large sinusoidal voltage source higher than (40 KV) also the highest frequency up to (80 KHz), where both can be controlled, and a cathode electrode Made of tungsten with a length of (6 cm). It is dipped in a cylindrical piece of Teflon, and at the other end, a glass tube with a length (10 cm) and a diameter (1 cm) is fixed. The other electrode is a circular ring surrounding the glass tube from the outside and a far way of (2 cm) from its end. From the side, the plastic gas tube enters the Teflon, and from there to the glass tube, the argon gas bottle, and the needle valve. Where the work was done in the laboratory of the University of Al-Qadisiyah, College of Education, Department of Physics, the plasma laboratory for postgraduate studies, as in Figure (1).

Figure (1) The locally manufactured cold plasma jetting system

3- Result and Discussion

The temperature of the electrons was determined visually using the ratio technique between the intensities of two different spectral lines from relation (2), and the two spectrum lines are Ar I (311.9, 766.4)nm from Figure (2), at a constant flow rate of gas (50L/h) and frequency Constant (75KHz), with different voltages (12, 20,16) KV and times (10,20,30) sec, and using the values of equation (1) the temperature of the electrons and the parameters (A, E and g) were calculated from a database Atomic Spectra Web site (NIST) [27].

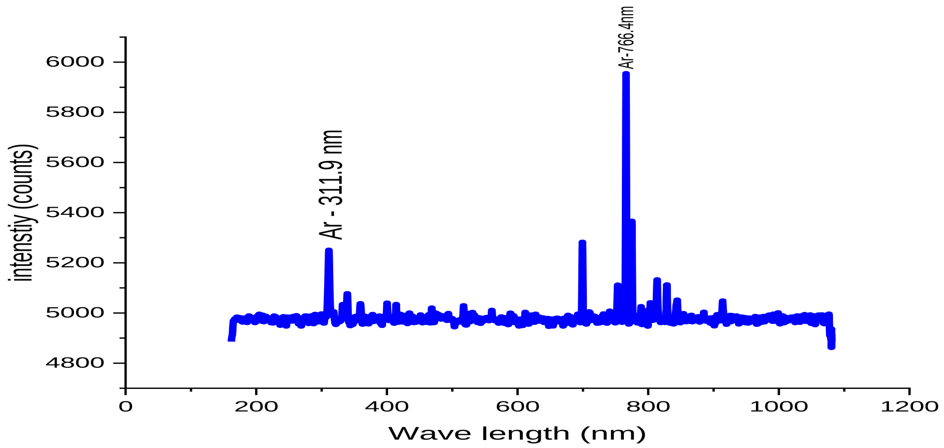

Figure (2), the two lines of Ar I (311.9, 766.4) nm represent the spectrum used to calculate the temperature of the electrons.

3-1 Electrons temperature

From shape (3) notice, the emission spectrum of cold plasma jets at a constant flow rate of the used gas (50 l/h) and a constant frequency (75 KHz) and a different voltage ranging between (12,16, 20) KV and for different periods of time (10, 20, 30) sec. which represents the three intensity curves. When the voltage difference increases, the peak values increase to fixed values for both the gas flow rate and the frequency. It appears that the intensity of the spectrum line varies from one line to another, and it also shows an increasing number of peaks, at all times. The explanation for this is that when the applied voltage increases, ionization increases, and thus the number of peaks increases.

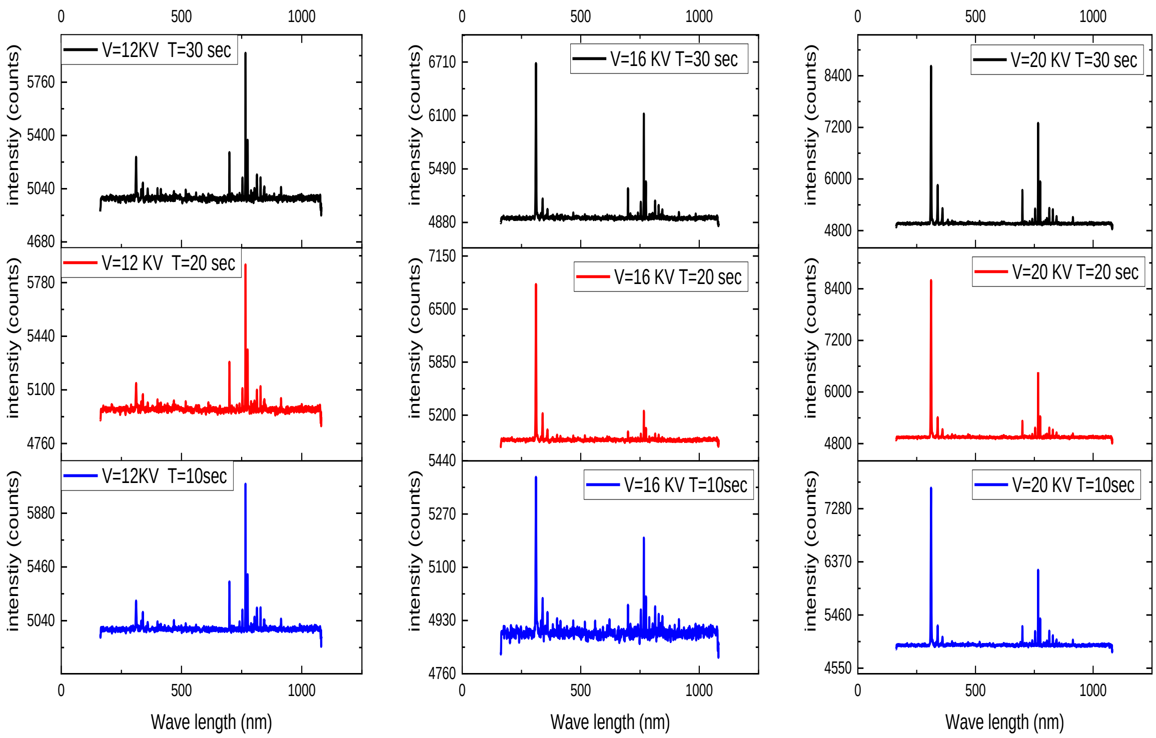

Figure (3) depicts the emission spectrum of NAPPJs.

The emission spectrum of NAPPJs, for a constant gas flow rate (50 l/ h) and frequency (75 KHz), with a different alternating sinusoidal voltage of (12,16,20) KV and different times (10, 20,30) sec. Figure (4) shows the temperature of an electron (Te) on the vertical axis as a result of changing the voltage once and changing the time again on the horizontal axis at a constant frequency and flow rate of gas. When the voltage applied increases, we observe an increase in the electron temperature (Te), because an increase in ionization degree is caused by an increase in voltage, degree in addition to the electron energy. there is a difference occurs in both processes of ionic excitation and atomic excitation If the energy levels increase, different spectral lines will be produced, and this result agrees with the result of the source [30].

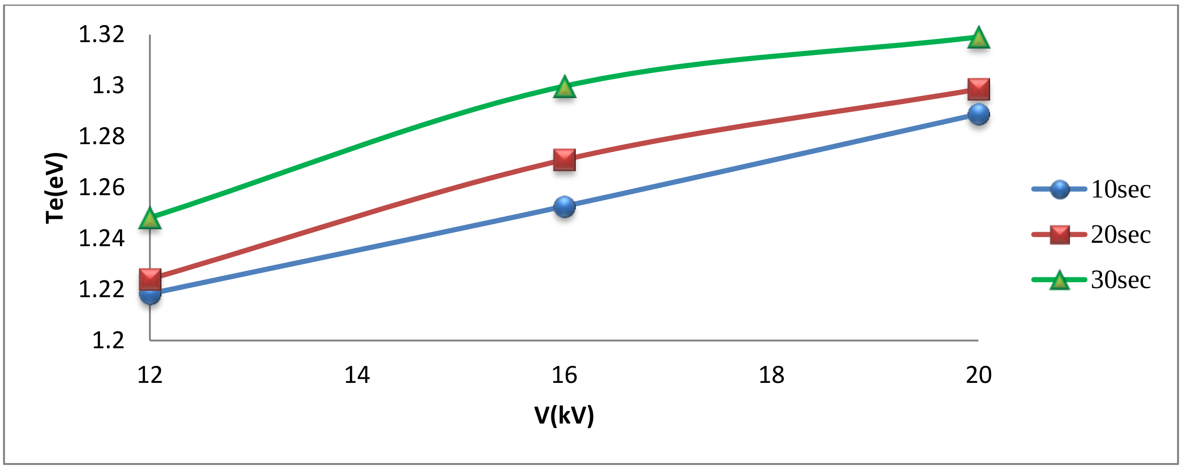

Figure (4) Temperature electron is shown on the vertical axis and voltage on the horizontal axis for a fixed gas rate (50 l/ h) and frequency (75 KHz), with a different alternating sinusoidal voltage of (12,16,20) KV and different times (10, 20,30) sec.

3-2 Electron Density Calculation

Using the FWHM approach, electron density was determined using relation (2) at a gas flow rate (50l/h) and frequency (75KHz) constant, when voltage was applied {(12,16, 20) KV}, and different times (10, 20, 30) sec. The FWHM was calculated using the analysis of the origin data and the temperatures' respective values were derived from the ratio of the two spectral lines' intensities, (FWHM) for the spectral line (Ar I – 311.9 nm) as shown in Figure (5).

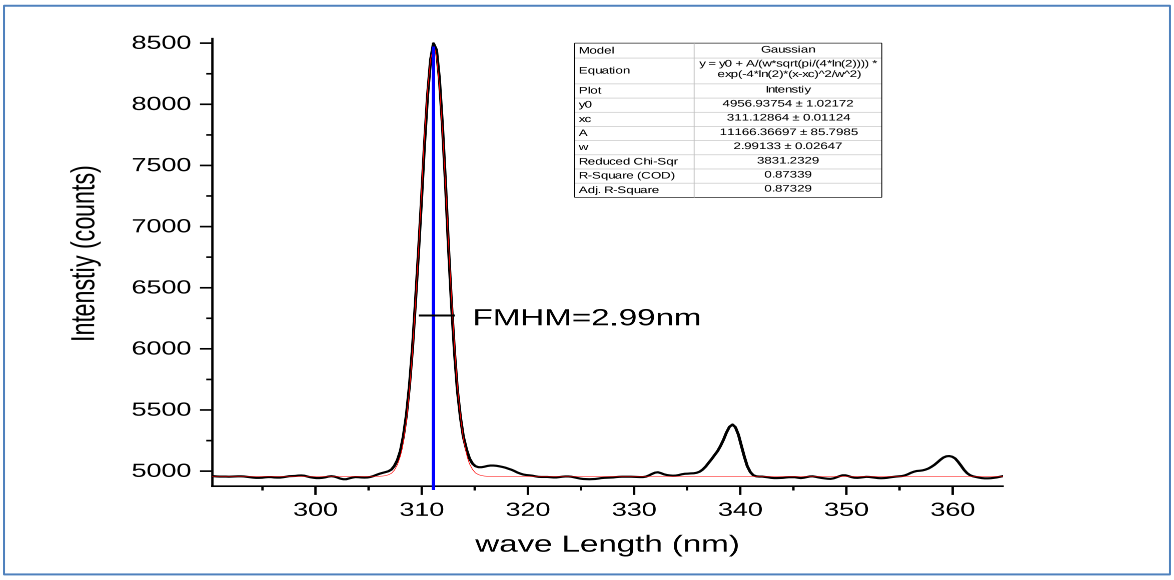

Figure (5) Ar I - 311.9, the spectrum line that was used to calculate the FWHM

The electron density is depicted in Figure (6), on the vertical axis as a function of changing the voltage once and changing the time again with a fixed frequency and flow rate of gas. It was noticed that the density of electrons increased with the voltage applied, and This happens because an increase in the applied voltage and electric field strength causes the electrons to heat up and accelerate. this leads to a collision of active electrons (high energy) with molecules and atoms, and this result is in agreement with [31], also agreement [3, 32-34]

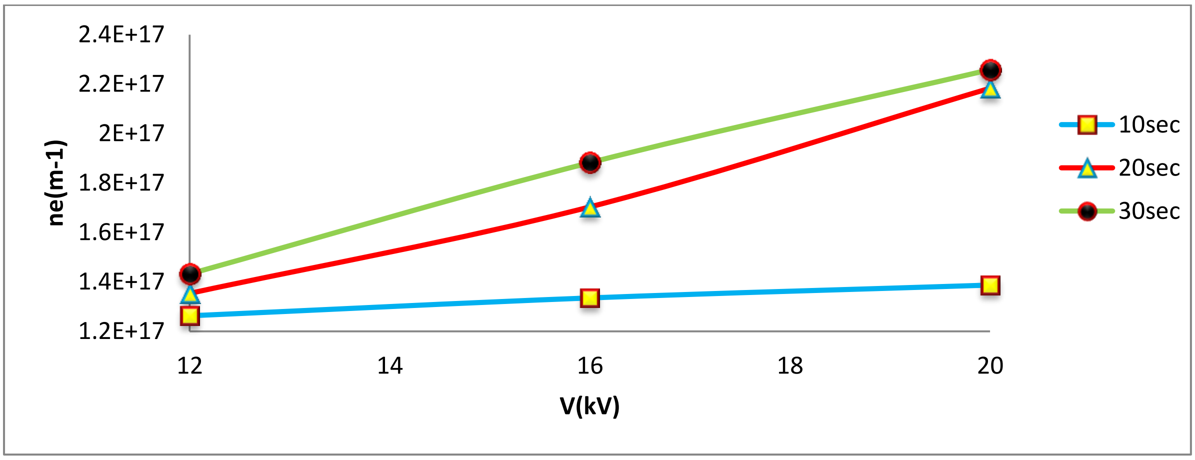

Figure (6) show the density electrons as a component of applied voltage for a consistent gas stream rate (50 l/ h) and frequency (75 KHz), with a different alternating sinusoidal voltage of (12,16,20) KV and different times (10, 20,30) sec**.**

The effects of a different alternating sinusoidal voltage on cold plasma jet features are in the following Table 1.

Table 1: Plasma parameters at not similar alternating sinusoidal voltage.

t(sec)	**sinusoidal voltage** (k**V**)	**electron temperature** **T_e**(eV)	**electron density** **n_e*10^{17}(cm^{-3})**
10	**12**	1.218	1.262
	16	1.252	1.334

	20	1.288	1.386
20	**12**	1.224	1.353
	16	1.270	1.702
	20	1.298	2.182
30	**12**	1.248	1.431
	16	1.299	1.881
	20	1.319	2.257

4- Conclusion

When studying the plasma parameters (electron density and temperature) using OES for cold plasma jets at normal atmospheric pressure and both electron density and temperature were calculated, the following can be concluded:

1. Operational status is the basis on which spectrum lines are emitted from the jet plasma.
2. Because of the increased electric field, increasing the applied voltage causes the electron temperature to rise.
3. The electron density increases when the applied voltage is raised.
4. The intensity increases with increasing voltage.

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References

[1] R. J. Goldstone and P. H. Rutherford, "Introduction to Plasma Physics", 1995.

[2] J. A. Bettencourt, "Fundamentals of Plasma Physics", Third Edition, 2004.

[3] Jassim, M. K. (2019). Investigation in the Effect of Applied Voltage and Working Pressure on Some Plasma Parameters in the Positive Column of Dc Glow Discharge. *Ibn AL-Haitham Journal For Pure and Applied Sciences*, *32*(2), 9-20.

[4] F. E Chen "Introduction to Plasma Physics and Controlled Fusion", Second Edition, 1974.

[5] Adhikari, B. R., & Khanal, R. (2013). Introduction to the plasma state of matter. *Himalayan Physics*,

[6] H. J. De Blank, "Plasma Physics Lecture Notes", Lecture notes, Utrecht University, 2008.

[7] Miyamoto, K. (2011). *Fundamentals of plasma physics and controlled fusion* (No. NIFS-PROC--88). National Inst. for Fusion Science.

[8] Jabur, Y. K., Hammed, M. G., & Khalaf, M. K. (2021). DC glow discharge plasma characteristics in Ar/O2 gas mixture. *Iraqi Journal of Science*, 475-482.

[9] Chen, Z., Attri, P., & Wang, Q. (Eds.). (2022). *Advances in Plasma Diagnostics and Applications*. MDPI Books.

[10] Sakudo, A., Yagyu, Y., & Onodera, T. (2019). Disinfection and sterilization using plasma technology: Fundamentals and future perspectives for biological applications. *International journal of molecular sciences*, *20*(20), 5216.

[11] Zhou, R., Zhou, R., Wang, P., Xian, Y., Mai-Prochnow, A., Lu, X., ... & Bazaka, K. (2020). Plasma-activated water: Generation, origin of reactive species and biological applications. *Journal of Physics D: Applied Physics*, *53*(30), 303001.

[12] Pereira, S., Pinto, E., Ribeiro, P. A., & Sério, S. (2019). Study of a Cold Atmospheric Pressure Plasma jet device for indirect treatment of Squamous Cell Carcinoma. *Clinical Plasma Medicine*, *13*, 9-14.

[13] M. Suresh, V. T. Hemalatha, N. Mani Sundar, and A. Nisha, "Applications of Cold Atmospheric Pressure Plasma in Dentistry- A Review", Journal of Pharmaceutical Research International, 2022.

[14] Leti, L. I., Gerber, I. C., Mihaila, I., Galan, P. M., Strajeru, S., Petrescu, D. E., ... & Gorgan, D. L. (2022). The modulatory effects of non-thermal plasma on seed's morphology, germination and genetics—A review. *Plants*, *11*(16), 2181.

[15] Laroussi, M. (2021). Cold gas plasma sources and the science behind their applications in biology and medicine. *arXiv preprint arXiv:2106.01366*.

[16] Nishime, T. M. C., Borges, A. C., Koga-Ito, C. Y., Machida, M., Hein, L. R. O., & Kostov, K. G. (2017). Non-thermal atmospheric pressure plasma jet applied to inactivation of different microorganisms. *Surface and Coatings Technology*, *312*, 19-24.

[17] Laroussi, M., Lu, X., & Keidar, M. (2017). Perspective: The physics, diagnostics, and applications of atmospheric pressure low temperature plasma sources used in plasma medicine. *Journal of Applied Physics*, *122*(2).

[18] Jihad, G. H., & Aadim, K. A. (2022). Determination of Electrons Temperature and Density For Ag, Zn, and Cu metals using Plasma jet System at atmospheric pressure. *Iraqi Journal of Science*, 2039-2047.

[19] Nastuta, A. V., & Gerling, T. (2022). Cold atmospheric pressure plasma jet operated in Ar and He: From basic plasma properties to vacuum ultraviolet, electric field and safety thresholds measurements in plasma medicine. *Applied Sciences*, *12*(2), 644.

[20] L. Wu, W. Zhang, Z. Liu, J. Yu, J. Tao, Y. Yang, and K. Huang, "Discharge properties of a coaxial plasma jet at different microwave frequencies", Phys. Plasmas, 2020.

[21] A. H. Mohamed, A. H. Basher, J. Q. M. Almarashi and S. A. Ouf," Susceptibility of Staphylococcus epidermidis to Argon Cold Plasma Jet by Oxygen Admixture", Appl. Sci.2021

[22] R. Thirumdas, A. Kothakota, U. Annapure, K Siliverud, R. Blundell, R. Gatt, V. P.

[23] D. M. Devia, L. V. Rodriguez-Restrepo and E. Restrepo-Parra," Methods Employed in Valdramidis ,"Plasma activated water (PAW): Chemistry, physico-chemical properties, applications in food and agriculture", Trends in Food Science & Technology, 2018. Optical Emission Spectroscopy Analysis: a Review", Ing. Cienc. 2015.

[24] Ayat J. Mohamed, Mohammed K. Khalaf, Awatif sabir Jasim," The Study of the Characteristics of a Microwave Plasma Jet Operated with Ar at Atmospheric pressure", Tikrit Journal of Pure Science Vol. 27 (4) 2022.

[25] B. Denis, S. Steves, E. Semmler, N. Bibinov, W. Novak, and P. Awakowicz, "Plasma Sterilization of Pharmaceutical Products: From Basics to Production", Plasma Processes and Polymers, 2012.

[26] N. Zhang, F. Sun, L. Zhu, M.P. Planche,H. Liao, C. Dong,and C. Coddet,. "Electron temperature and density of the plasma measured by optical emission spectroscopy in VLPPS conditions", Journal of Thermal Spray Technology, 20(6), 1321-1327.(2011).

[27] https://physics.nist.gov/PhysRefData/ASD/ lines_form.html.

[28] Q. Zhou, Ch. Cheng, Y. Meng," Electron Density and Temperature Measurement by Stark Broadeningin a Cold Argon Arc-Plasma Jet at Atmospheric Pressure " Plasma Science and Technology, (2009).

[29] X. Tu, B. G. Ch´eron, J. H. Yan, K. F. Cen," Electrical and spectroscopic diagnostic of an atmospheric double arc argon plasma jet", Plasma Sources Science and Technology, 2007.

[30] Roy, N. & Talukder, M. R," Electrical and Spectroscopic Diagnostics of Atmospheric Pressure DBD Plasma Jet", Journal of Bangladesh Academy of Sciences, 2016.

[31] Hashim, I. H., Aadim, K. A. & Ali, M. R," Effect of gas flow rate on plasma temperature and electron density of atmospheric argon plasma jet", Iraqi Journal of Physics, 2017.

[32] H. Horita, D. Kuwahara, H. Akatsuka, and S. Shinohara," Estimating electron Temperature and density using improved collisional-radiative model in high- density RF argon plasma", AIP Advances, 2021.

[33] M. Qian, Ch. Ren, D. Wang, J. Zhang, and G. Wei, "Stark broadening measurement of the electron density in an atmospheric pressure argon plasma jet with double- power electrodes, J. Appl. Phys. 107, 063303 (2010).

[34] Shrestha, A. K., Shrestha, R., Baniya, H. B., Tyata, R. B., Subedi, D. P., & Wong, C. S. (2014). Influence of discharge voltage and pressure on the plasma parameters in a low pressure DC glow discharge. *relation*, *2*, 1.