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# Plasma diagnostic of gliding arc discharge at atmospheric pressure

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**Abstract**
A gliding arc discharge (GAD) with a water spray system was constructed. A non-thermal plasma, generated between two V shaped electrodes in an ambient argon driven by 100 Hz AC voltage, was investigated using optical emission spectroscopy (OES) with different gas flow rates (0.5, 1, 1.5, 2 , 2.5 , 3 1/min). Boltzmann plot method was used to calculate electron temperature ($T_e$) and electron density ($n_e$). The electrodes design was spectrally recognized and its $T_e$ value was about 0.588-0.863 eV, while the $n_e$ value of $6.875\times10^{17}$-$10.938\times10^{17}$ $cm^{-3}$. The results of the plasma diagnostics generated by gliding arc showed that increasing gas flow rates was associated with decreased electron temperature ($T_e$), Debye length, and Debye Number, along with decreased electron density ($n_e$) and plasma frequency.

**Keywords:** Gliding arc discharge, Plasma diagnostics, Optical emission spectroscopy, electron density, electron temperature.

# تشخيص بلازما قوس التفريغ ألانزلاقي بالضغط الجوي الاعتيادي

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**الخلاصة**
تم بناء منظومة قوس التفريغ ألانزلاقي مع منظومة لترذيذ الماء . تم تشخيص البلازما الغير الحرارية التي تولدت بين القطبين على شكل حرف Vفي وسط من الاركون بتردد100هرتز وفولتية متناوبة باستخدام تحليل الانبعاث الضوئي لمعدل تدفق الغاز ( 0.5 , 0.1 , 1.5, 0.2, 2,5 ,0.3) لتر/دقيقة. باستخدام طريقة رسم بولتزمان تم حساب درجة حرارة الالكترونات. تم التعرف على درجة حرارة وكثافة الإلكترون لأقطاب المصممة طيفياً،و قيمتها تبلغ(0,588 −0,863) إلكترون فولت, ($6,875\times10^{17}$ − $10^{17}\times 10,938$)سم$^{-3}$ , تم عرض نتائج تشخيص البلازما الناتجة عن قوس التفريغ الانزلاقي لقيم مختلفة من معدل تدفق غازوأظهرت ان درجة حرارة الالكترون وطول ديباي ,عددالجسميات في كرة ديباي تقل مع زيادة معدل تدفق. بينما كثافة الالكترون وتردد البلازما يزداد مع زيادة معدل تدفق الغاز.

## 1. Introduction

Gliding arc discharge is a quasi periodic electrical discharge. This type of plasma is used for numerous applications in chemistry and environment protection [1-3]. Gliding discharge is extensively used in several plasma processing techniques such as the surface modification of different materials, water treatment, and air treatment [4]. This discharge system consists of two V shaped electrodes, with a gas flowing between them at atmospheric pressure. It fabricates a comparatively cold non-equilibrium plasma with a complex time-space arrangement, counting quasi-equilibrium (hot) and non-equilibrium (cold) periods. Also, a quick Equilibrium to Non- Equilibrium change between them.

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During this process, ionization instability creates suitable conditions for the presence of some cold plasma and, at the same moment, the length explosion (arc) happens [5]. The spark of discharge begins at 1 to 2 mm distance between the electrodes. Over a period of time that does not exceed microseconds, the resistance between the poles becomes very low, causing the breakdown of the voltages. The tiny plasma filament is dragged up by the gas flow and the arc line length increases with the voltage.The current is stable in this phase but the voltages are increased until the arc length reaches the critical value and then the resistance of plasma becomes equivalent to the exterior resistance. At the same time, the total of voltage and electric field come close to their greatest values. As the arc length becomes greater than the critical value, the heat of arc decreases. The electric power is fixed, so that it cannot keep the arc in a thermodynamic semi-equilibrium state. The high temperature of the electrons maintains the plasma conductivity as well as the gradual ionization. After that, the gliding arc continues its growth but in a non-equilibrium state. The quantity of heat lost in a non-equilibrium system is less than that lost in an equilibrium system [6, 7]. Therefore the lengths of discharge grow to be higher than the critical value when the arc breaks down and a new discharge begins [8]. The goal of this research is to have optimum control on plasma parameters. The results contribute to a preferable understanding of mechanisms taking place in the gliding arc discharge and provide efficient control on the electron plasma parameters.

This paper presents the experimental work that includes construction of gliding plasma system and its operation at atmospheric pressure and a standard frequency of 100Hz. The atmospheric pressure and the gliding plasma parameters were determined by optical emission spectroscopy (OES). The Boltzmann plot method was used

to calculate temperature and the electron density by local thermal equilibrium [9,10]. Optical spectroscopy (OES) has been used for years to determine plasma parameters such as electron temperature, Debye length, Debye Number, electron density and plasma frequency. The electron temperature of plasma was calculated using Boltzmann plot method [11]:

$$\ln\left|\frac{\lambda_{ji} I_{ji}}{hcA_{ji}g_j}\right| = -\frac{1}{KT}\left(E_j\right) + \ln\left|\frac{N}{U(T)}\right| \quad \text{........ (1)}$$

Where $I_{ji}$ is the relative emission line density between energy levels I and j,

$g_j$ is the degeneracy or statistical weight of the upper level emitted from the transition phase, $\lambda_{ji}$ is the wavelength (in nm), $E_j$ is the excitation energy (in eV) for level i

$A_{ji}$ is The possibility of automatic transmission of radiation from the level i to the lower level j, N refers to the densities of the population of the state, K is the Boltzmann constant.

Debye's length ($\lambda_D$) can be calculated by the following formula [12]

$$\lambda_D = \left[\frac{\varepsilon_o K_B T_e}{n_e e^2}\right]^{1/2} \cong 7.43x10^2 \left(\frac{T_e(eV)}{n_e}\right)^{\frac{1}{2}} \ldots \quad \text{.............. (2)}$$

Where

$n_e$ is the electron density, $\varepsilon_0$ is the electric constant

$T_e$ is the plasma temperature

Plasma frequency can be given as in below [12]:

$$\omega_{pe} = \sqrt{\frac{e^2 n_e}{\varepsilon_\circ m_e}} \quad \text{................. (3)}$$

Where $m_e$ is the electron mass

Debye Number ($N_D$) can be given by the following formula [12]:

$$N_D = \frac{4}{3}\pi\lambda_D^3 n_e \quad \text{........................(4)}$$

**2. Experimental part**

The gliding arc discharge consists of four main parts: Power supply, DC/AC converter, coil and two electrodes. Figure-1 shows a schematic diagram of the gliding arc system. The gliding arc was generated using a Dc power supply (12V) connected to the DC/AC converter circuit. DC to AC converter circuit was designed and implemented. The DC/AC converter circuit consists of two major parts; the first part is the pulse generator circuit part while the second part is the high voltage circuit part. The purpose of the DC to AC converter circuit is to convert the 12 volts DC power supply to AC voltage equal to about 220 volts. DC/AC converter circuit is joined to a coil which is used to raise the output voltage from 3000 to 13000 volt. The output of this circuit is attached to two electrodes . The

gliding arc discharge (GAD) reactor consists of two , 1 mm thick, stainless steel diverging electrodes located under a feeding gas nozzle. These electrodes are attached to a ceramic support placed between two thin rectangular glass plates. The discharge is produced by two knife-shaped electrodes, which are 2.5 cm in radius and 1mm in thickness. The maximum gap between the two electrodes is 2cm and the minimum is 2mm. The distance between the connecting points of the electrodes is 1 cm. The AC high voltage circuit provided max~ 13kV at a frequency of 50 Hz.
Optical emission spectroscopy was used to detect gliding discharge plasma by electronically observing the excited species and their intensities in the discharges generated by the gliding arc's discharge plasma. The spectra were recorded by means of an Surwit device (model S3000-UV-NIR) and had a range of 300-900 nm. The optical fiber is collimated and placed at 1 cm away from the discharge electrodes, with a wavelength range of 300–900 nm and at different flow rates of argon gas (0.5, 1, 1.5, 2, 2.5 and 3 1/min).

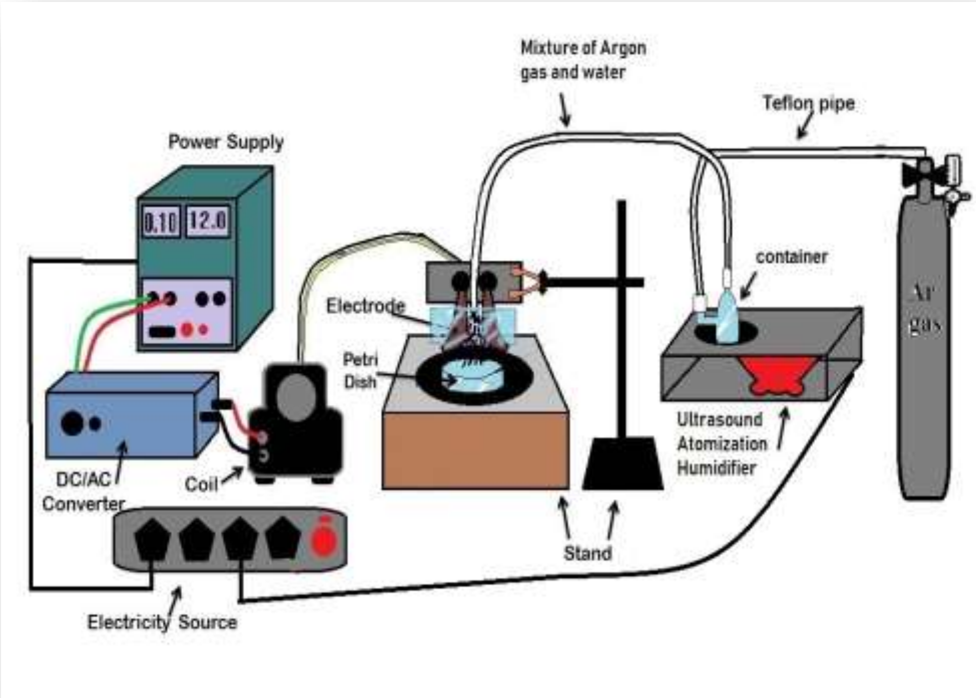


**Figure** 1-Schematic illustration of the expermantial set-up for the gliding arc discharge .

## 3. Results and discussion

Spectroscopy is a good instrument to calculate the temperature and density of gliding arc argon plasma in a wavelength range of 300–900 nm. The spectrum shows numerous peaks, most of which belong to ArI which corresponds to NIST data [13]. Figure-2 shows the intensity distribution of gliding arc's discharge plasma spectrum obtained by optical emission spectroscopy. The maximum peak of ArI is located at 772.4207 nm for different values of gas flow rate. The electron temperature was calculated using the Boltzmann plot of discharge lines.

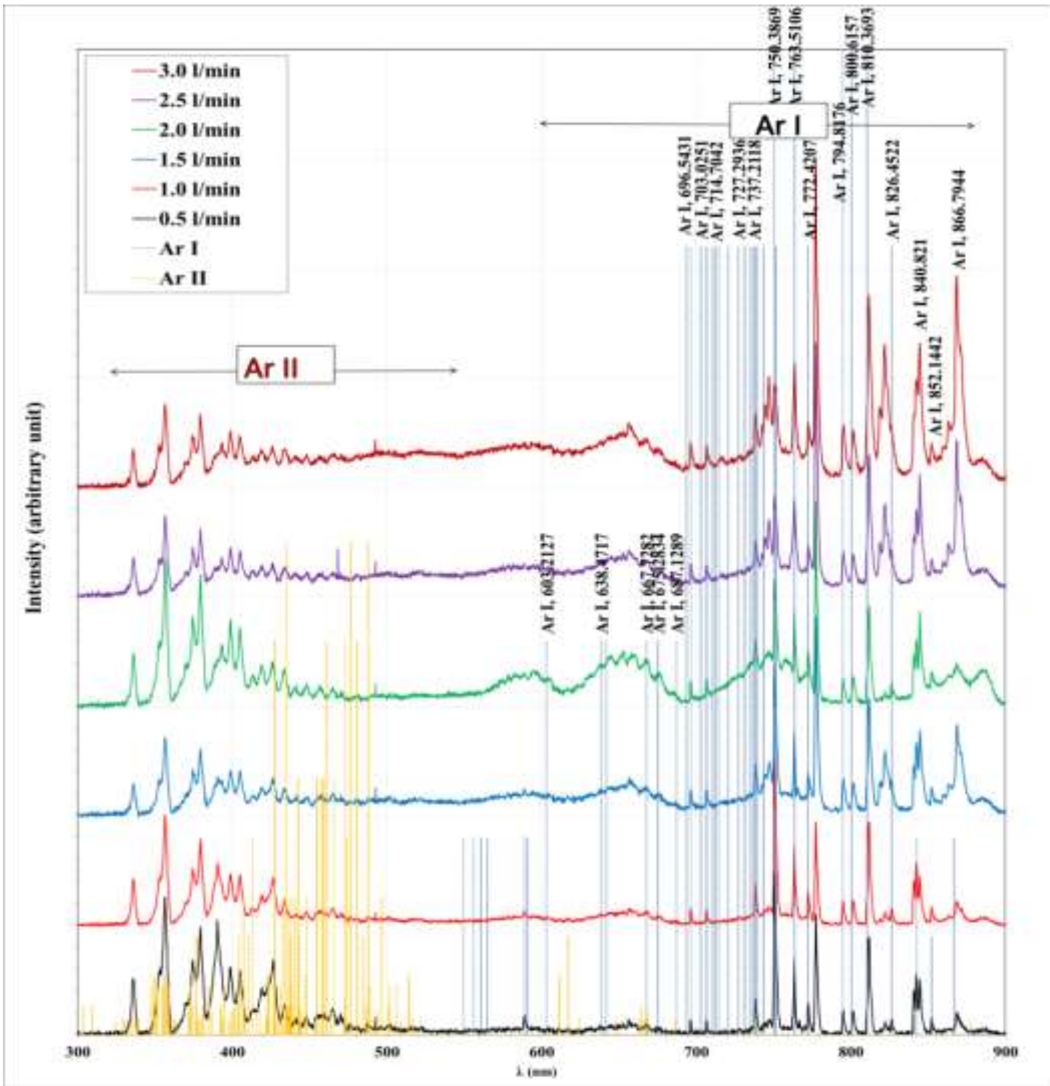


**Figure 2-**Optical emission spectra for different values of gas flow (0.5, 1, 1.5, 2, 2.5, 3) 1/min.

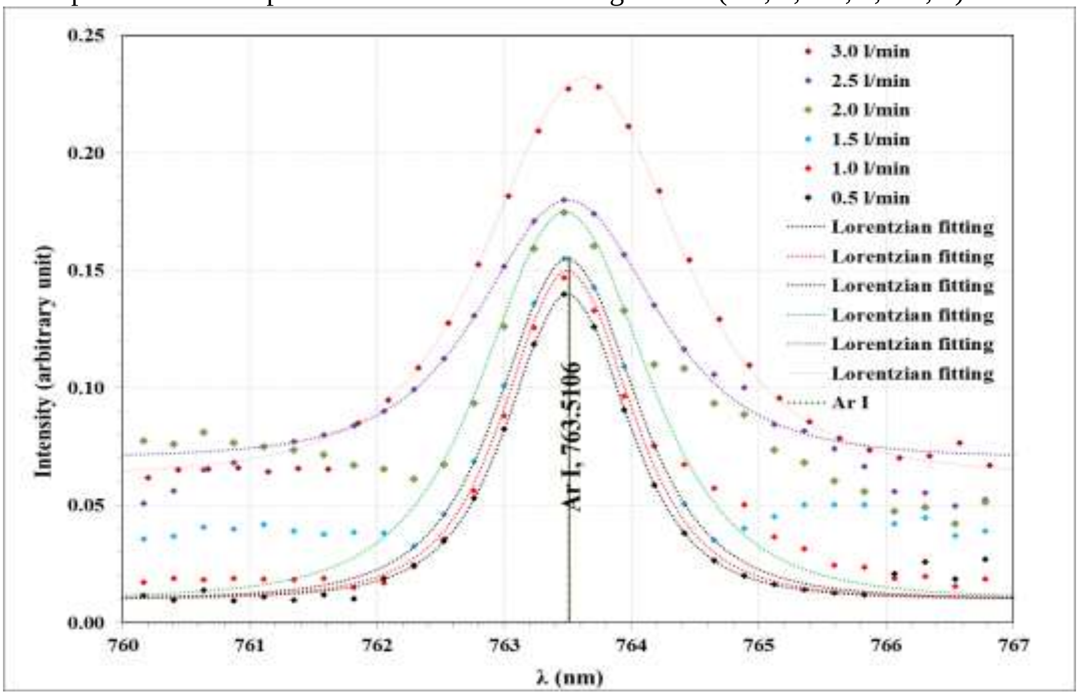


**Figure 3-**Variation of intensity with wavelength at highest peak for different values of gas flow rate.

The 763.5106 nm line peak profile of ArI is shown in Figure-3, where full width at half maximum was found by the Gaussian fitting to estimate electron density for different flow rates of argon gas via Stark effect, depending on the standard values of broadening for this line. It can be observed from the figure that the peak half width increases with rising of gas flow rate. Similarly, the intensity of the peak increases with increasing of gas flow rate, because of rising of ArI species emission in argon plasma ,which refers to an increase in electron density.

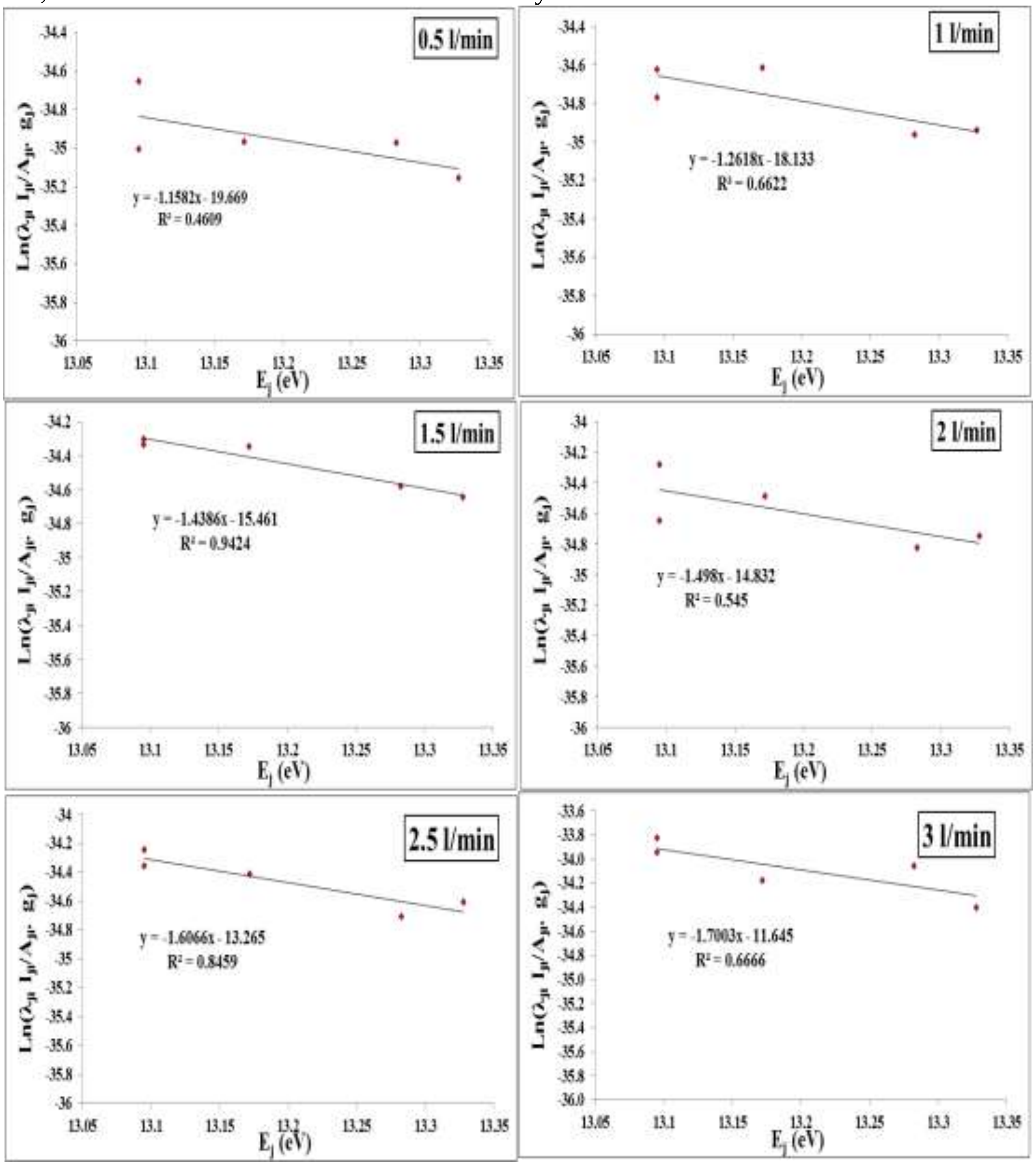


**Figure 4-**Boltzmann plot for different values of gas flow rate.

Figure-4 demonstrates the $\mathrm{Ln}\left(\frac{I_{ji}\lambda_{ji}}{A_{ji}\,g_j}\right)$ as a function of ($E_j$). The electron temperature (Te) Which is associated with the slope of the fitting ($slope = m = -\frac{1}{KT}$). Also the electron density ($n_e$) was calculated using stark broadening which has the following formula [12].

$$n_e = \left[\frac{\Delta\lambda}{2\omega_s}\right] N_r \quad \ldots\ldots\ldots\ldots\ldots(5)$$

Where $\Delta\lambda$ is the FWHM of the line, $\omega_s$ is the Stark broadening parameter that can be found in the standard tables, $N_r$ is the reference electron density. $R^2$ is a statistical coefficient indicating the quality of linearity and takes a value between 0 and 1.

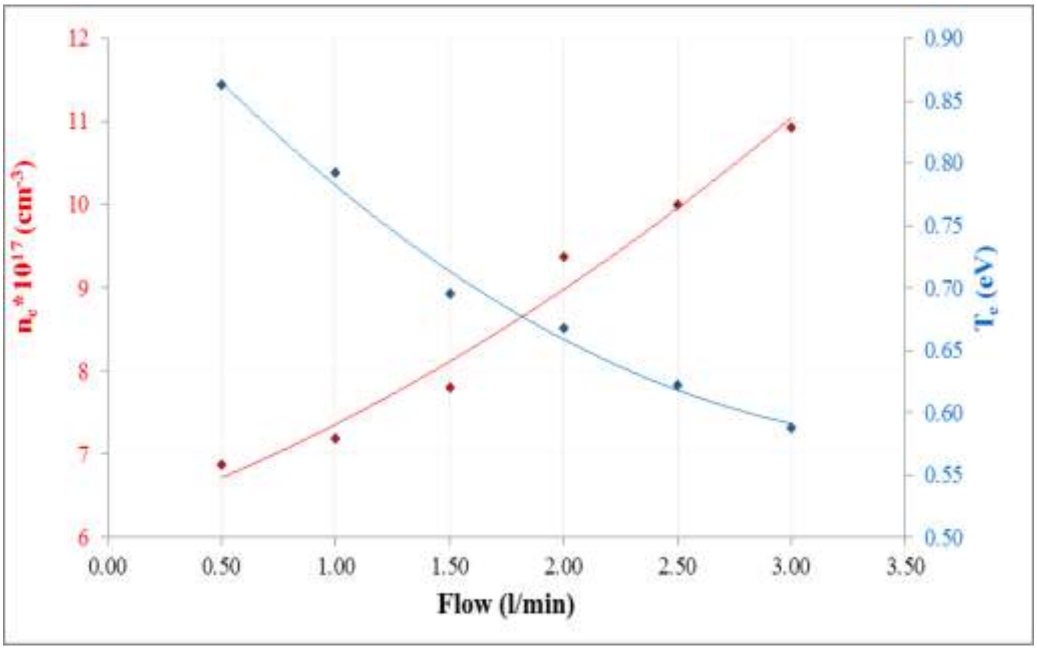


**Figure 5-**Variation of electron temperature and electron density as a function of gas flow rate

The electron temperature ($T_e$) and electron density ($n_e$) of argon plasma is measured against different gas flow rates, as shown in Figure-5. From the figure, we observe that the density of the electrons increases with the increase of the flow rate of the argon gas, while the temperature of the electrons decreases with the increase of the gas flow rate. The reason for the decrease in the temperature of the electrons is the increasing of the number of the collisions which leads to the transfer of energy from the electrons to the molecules and, thus, increases the temperature of the gas. Also, the excitation and ionization of atomic and ionic species in the plasma occurs by the influence of the electrons. If the gas flow rate increases, the high-energy tail of the electron energy distribution's function is reduced to the lower energies. Hence, the ionization, which is produced by the effects of the energetic electrons with gas atoms (direct ionization), is reduced with increasing of electron density, while the flow rate increases due to the gradual ionization. These results agree with data from other investigations [14]. The effects of gas flow rate on plasma characteristics are summarized in Table-1.

**Table 1-**Plasma parameters at different gas flow rates.

| Flow (l/min) | $T_e$ (eV) | $n_e$*$10^{17}$ ($cm^{-3}$) | $f_p$(Hz) *$10^{12}$ | $\lambda_D$ *$10^{-6}$(cm) | $N_d$ |
|---|---|---|---|---|---|
| **0.50** | 0.863 | 6.875 | 7.446 | 0.833 | 1.66 |
| **1.00** | 0.793 | 7.188 | 7.613 | 0.780 | 1.43 |
| **1.50** | 0.695 | 7.813 | 7.937 | 0.701 | 1.13 |
| **2.00** | 0.668 | 9.375 | 8.695 | 0.627 | 0.97 |
| **2.50** | 0.622 | 10.000 | 8.980 | 0.586 | 0.84 |
| **3.00** | 0.588 | 10.938 | 9.392 | 0.545 | 0.74 |

## 4. Conclusions

The plasma produced by the gliding arc system was experimentally investigated. Plasma analysis was performed via Optical Emission spectroscopy (OES). The Plasma parameters were estimated in terms of their dependence on gas flow rate. The results indicated that the electron temperature, Debye length , and Debye Number decreased with the increase of gas flow rate, implying that the increase in gas flow rate cools down the plasma. Also, there were increases in electron density and plasma frequency of gliding plasma with increasing of gas flow rate.

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