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Electron Temperature and Density Measurement of Plasma Jet in Atmospheric Pressure

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Abstract: **The optical description of the system was done by recording emission spectrum for wavelengths emitted from plasma in spectral range (160-960) nm, then analyzing this spectrum. Finally the thermal characteristics were done by measuring the temperature of flowing gas at various flow rates for deferent distances from the ending of needle which generates electric discharge. Also, a study of effect of flowing gas along plasma discharging was done and the temperature of electron for plasma was estimated spectrally about 0.61 eV and the density of electrons was about 4.38x10^{15} cm^{-3}.**

Keywords: **Plasma diagnostic, Langmuir probe, spectroscopy, atmospheric pressure.**

1. INTRODUCTION

Micro hollow cathode discharge (MHCD) is a promising technique used for generating atmospheric-pressure glow plasma [1, 2]. Furthermore, micro hollow cathode sustained (MCS) [3], glow discharge, in which the MHCD becomes the electron source and the electrode for the third-electrode discharge [4], is used for expanding plasma volume along approximately one direction.

For a three-dimensional expansion of the plasma volume, parallel operations of the MCS discharge are required [5, 6]. We propose a method using a cylindrical parallel MCS discharge plasma, in which several MHCD electrodes are placed on a cylindrical tube and the third electrode is a line electrode at its center, for carrying out parallel operations of the MCS discharge [7].

In the plasma process such as gas treatment, thin film deposition and etching, it is important to know the plasma parameter of its temperature and density so that we understand the mechanism of the process and control those [8]. In this study, we measured the electron temperature and the density of the MHCD plasma, MCS discharge plasma, and the cylindrical MCS discharge plasma by using a Langmuir probe method and spectroscopy [9].

2. EXPERIMENTAL

a- Optical Emission Spectroscopy (OES):

OES has been used to detect plasma jet composition by observing electronically the excited species and their intensities in the discharges generated by argon plasma jet. The spectra were collected in the range (160 – 1010 nm) directly from the plasma jet, using a device (Surwit) model (S3000-UV-NIR), as shown in figure (1).

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Fig. (1): Image (OES)

b- Electron temperature measurement:

Optical emission spectroscopy measurements are performed to obtain the electron temperature and electron number density of argon plasma jet. Emission spectrum ranging from (300-810 nm) is recorded in axial and radial directions by using ocean spectrometer (S3000-UV-NIR).

The electron temperature is determined from the slope of Boltzmann's plot that uses the intensity of several spectral lines versus their corresponding excitation energies **[9]**.

C- Electron density measurement:

The electrons in the plasma jet are quickly influenced by the external electric-field due to their small masses. In addition, they cannot transfer a large part of their kinetic energy to the heavy particles and hence, they possess higher average kinetic energy when compared with the heavy particles. Electron-impact dissociation, excitation and ionization account for the preliminary reactions in the hierarchy of chemical kinetics. Subsequently, the other chemical processes between heavy particles are initiated. Since electron collisions play an important role in the plasma-chemical kinetics, it becomes necessary to determine the electron density in the active plasma volume **[10]**.

3. RESULTS AND DISCUSSION

a- Optical Emission Spectroscopy (OES):

The electron temperature is determined from the slope of Boltzmann's plot that uses the intensity of several spectral lines versus their corresponding excitation energies as shown in Figure (2). The electron number density is determined from the Stark broadening of well-isolated Ar-I (696.54 nm). It is observed that electron temperature and electron number density is higher when optical emission is recorded in axial direction in comparison with radial direction **[11]**.

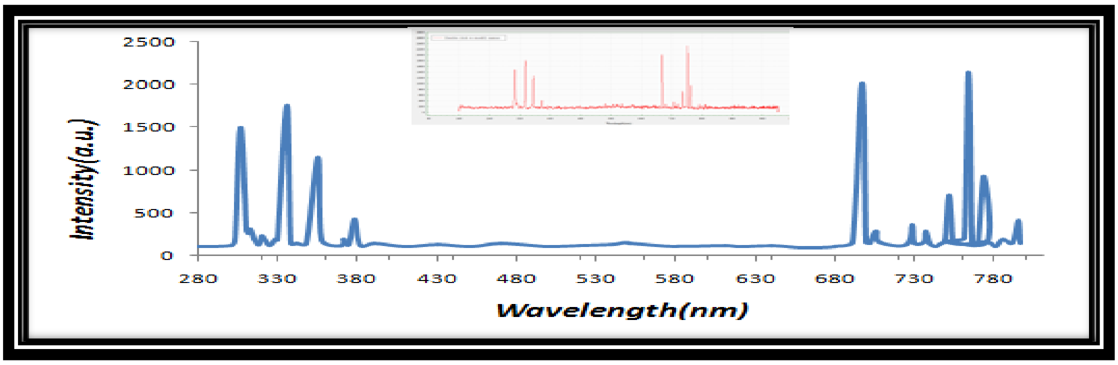

Fig.(2): Spectra of argon plasma jet operated in open air.

The prominent spectral lines in the spectrum are identified and labeled using NIST data as shown in table (1).

Table (1): Spectroscopic parameters of the argon line [12].

Ion	*Observed Wavelength Air(nm)*	A_{ki} (s^{-1})	E_k (eV)	g_k
Ar I	696.5431	6.39e+06	13.32785646	3
Ar I	706.7218	3.80e+06	13.30222689	5
Ar I	763.5106	2.45e+07	13.17177713	5
Ar I	772.3761	5.18e+06	13.15314330	3

The electron temperature was measured by using spectroscopy. We selected four spectrums (wavelengths: 696.54nm, 706.72nm, 763.51nm, and 772.37 nm), these spectrums were clearly distinguished. We calculated the electron temperature to be 0.61 eV by using the Boltzmann plot method.

The equation used for the calculation was as follows **[11]**:

$$\ln\frac{I\lambda}{Ag} = \frac{-E}{KT} + \ln C$$

The electron density was measured by using spectroscopy. We selected one spectrum (wavelengths: 696.54nm), We calculated the electron number density to be 4.38×10^{15} cm^{-3} by using the Stark broadening method.

The equation used for the calculation was as follows **[13]**:

$$\ln n_e = 1.20\ln[\Delta\lambda_{1/2}] + 44.2476 - 0.60\ln[T_e]$$

This fact may be ascribed to energy loss of electromagnetic wave as it propagates along the plasma jet column, which makes the plasma parameters to vary continuously along the discharge region **[13]**.

b- Study the influence of argon gas flow rate on the electron temperature at different Voltage:

Figure (3) represents the variation of electron temperature T_e (eV) of argon plasma with gas flow rate (l/min) for different values of voltages (800, 1200 and 1600) Volt.

From this figure, the plasma jet electron temperature increases with increasing of the gas flow rate for each value of voltage, also the plasma jet electron temperature increases with increasing of the voltage for each value of gas flow rate.

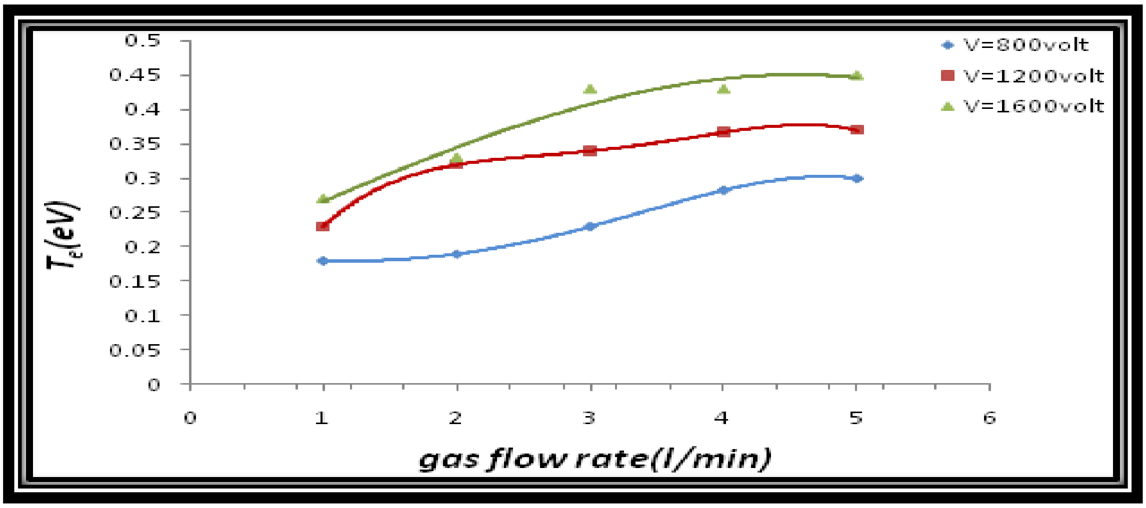

Fig.(3): the relationship between the electron temperature as a function of gas flow rate.

C- Study the influence of argon gas flow rate on the electron density:

Figure (4) shows the variation of argon plasma jet electron density with gas flow rate. When the argon gas flow rate increases from 1 to 3 l/min the plasma jet electron density is increasing from 7.5×10^{15} to 9.5×10^{15} cm^{-3}, where the flow rate increases the average of atomic ionization is increasing therefore, the plasma jet electron density is increasing.

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At gas flow rate higher than 3 l/min the applied power can not ionized the mount of gas flow rate therefore, the plasma jet electron density is decreasing.

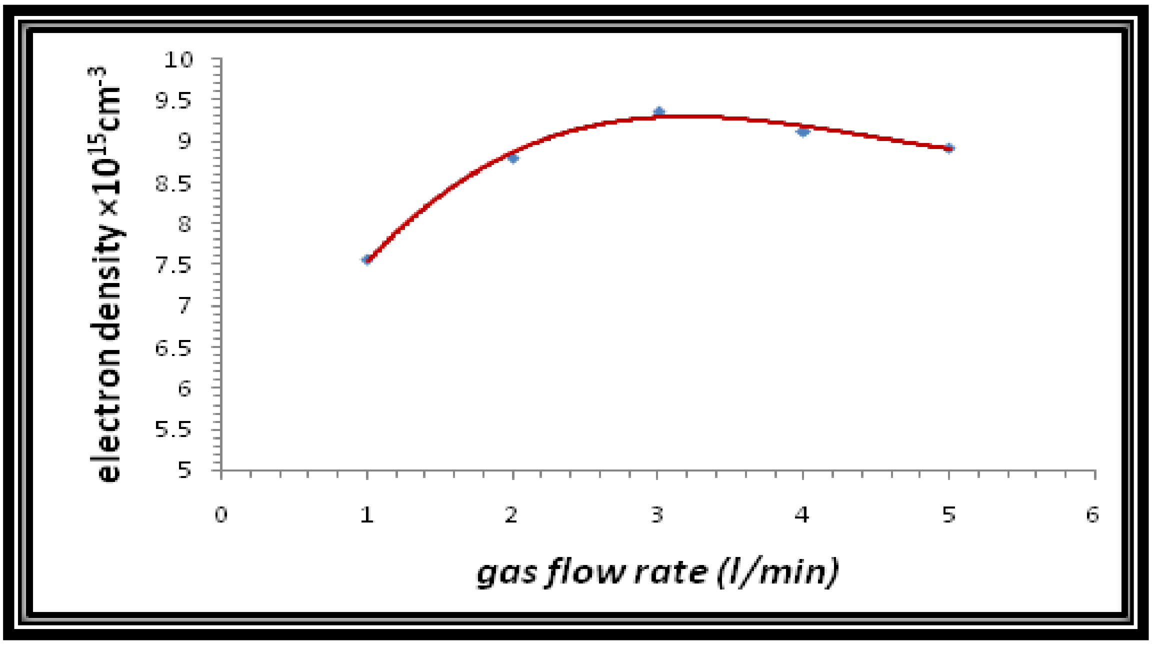

Fig. (4): the relationship between the electron density as a function of gas flow rate.

From figures (3) & (4) can be concluded that the optimize condition of system with a gas flow rate about 3 (l/min). Also, the plasma jet have a best length at this gas flow rate. Thus 3 (l/min) gas flow rate can be used in medical application such as treatment and killing of bacteria.

4. CONCLUSIONS

Using of optical emission spectroscopy showed that the plasma electron temperature and electron density have a maximum values in axial direction of plasma jet comparison with radial direction.

The electron temperature and the electron number density in 33 kHz plasma jet argon plasma are determined by using the optical emission spectroscopy technique at constant input power and flow rate. Basic motivation of this experiment is to explore the effect of filling pressure on wave propagation together with excitation and ionization process involved in optical emission.

Experimental results indicate that the plasma parameters achieve higher values near the axis compared to end region of the plasma column.

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