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Research Article

Electrodes Configuration Effect on Some Properties of Low Temperature Plasma Jet (LTPJ)

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Abstract

In this work the development of a non-equilibrium atmospheric pressure plasma torch by use of two electrodes configuration, the linear-field configuration and cross–filed configuration. Where the experimental set up is based on very simple and low cost electric components, and generates an electrical field sufficiently high at the electrodes to ionize various gases, which flow at atmospheric pressure. The working gas (Ar) was supplied to flow through the torch with adjustable flow rate by flow meter regulator. In all cases of configuration the high voltage power supply generates high voltage of sinusoidal shape of 7.5 kV peak to peak and frequency of 28 kHz. The optical characterization was made by taking the spectrum of discharge by optical emission spectrometer. The electron temperature for the two electrodes configuration was identified spectrally, and its value is about 1.75eV. Also the effects of the gas flow rate on working gas temperature have been studied.

Keywords: *Plasma torch, non-thermal plasma jet, electron temperatures measurement*

Introduction

The LTPJ is a type of non-thermal atmospheric glow discharge, it has a single electrode configuration and is operate by different noble gas He-Ar, important properties of this type of plasma are that it operate at near room temperature, the plasma does not cause any thermal damage to any articles it comes in contact with. This characteristic was open up the possibility to use this plasma for treatment of the heat sensitive materials. Atmospheric pressure discharge plasma is of great interest because of their low costs and simplified operation (X. Li and P. Jia, 2010). It has been studied for decades to treat the surface of plastic films, metal foils, paper board, glass sheet and so on, However, due to the relative high breakdown voltage of working gases at atmospheric pressure a high voltage of sinusoidal shape of 7.5 kV peak to peak and frequency of 28 kHz was used.

LTPJs are easy to construct, and as a result different jet configurations. One common electrodes configuration that often employs a powered electrode wrapped around dielectric tube through which the feed gas flows axially, as the gas flow and the electric field are parallel, this type of LTPJ jets is referred to as the linear-field configurations, and this can be achieved by two electrodes configuration as shown Fig.1 a and b. Very different is another common type of LTPJ jet employs a coaxial electrode structure with the electric field being largely in the radial direction and the feed gas flowing in the axial direction. It is referred to here as cross-field configurations as its electric field and its gas flow are perpendicular to each other as shown in Fig.1 c

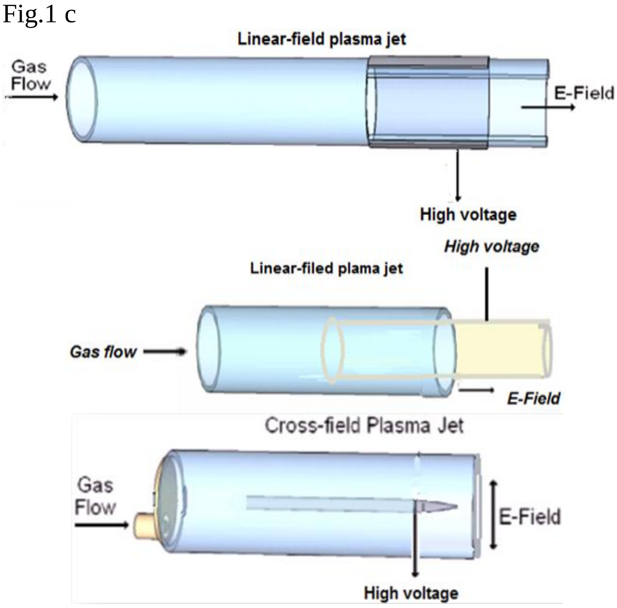

Fig.1: Schematic diagram for electrode configuration a and b linear field configuration c cross field, configuration

The Optical emission spectra have been used to detect plasma composition by observing the electronically excited species and their intensities in the discharges generated by Ar plasma torch, The spectrum of light emitted by plasma jet in air is dominated by emission lines originating from electronic exited states of the N_2 molecule and the N_2^+ ion (T. P. Kasih, 2007 and, Qais Thanon Najim Algwari, 2012). A group of N_2 emissions in

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the form of second positive system (SPS) and first negative system (FNS) The electron temperature can be estimated by using the line intensity ratio method. To apply this method, four suitable lines (two for SPS and two for FNS) are chosen with the Eq.(1) (R. B. Tyata et.al, 2009).

$$\frac{R_1}{R_2}=\frac{I_1/I_2}{I_3/I_4}=\left(\frac{A_{pq}}{A_{xy}}\right)\left(\frac{g_p}{g_x}\right)\left(\frac{\lambda_{xy}}{\lambda_{pq}}\right)\left(\frac{A_{uv}}{A_{rs}}\right)\left(\frac{g_u}{g_r}\right)\left(\frac{\lambda_{rs}}{\lambda_{uv}}\right)\exp\left[-\frac{E_p-E_x-E_r+E_u}{kT_e}\right] \quad (1)$$

where R is the ratio of intensity of two lines, I is the intensity of the spectral line, Aij is the transition probability of transition i $\rightarrow$ j , gi is the statistical weight of the upper level, λ i is the wavelength of line radiation, Ei is the energy of the upper level, k is Boltzmann constant and Te is electron temperature. The value of λ and I are obtained from the observation, and the values of Aij, gi, and Ei are obtained from NIST atomic Spectra Database. Considering two SPS lines with wavelengths 381.02nm and 426.98 nm and two FNS lines with wavelengths 392.12 nm and 409.6 nm we obtain plot between R_1/R_2 and T_e with different values of T_e. This graph is used to determine the electron temperature using the value of R_1/R_2 obtained from the observation (R. B. Tyata et.al, 2009, R. Bhaityata et al, 2013).

A_{pq}= ASPS (381.02 nm) = 8.95 x 10^5 s^{-1}, g_p= 4, E_p= 13.92 eV
A_{rs}= ASPS(426.98 nm) = 2.26 x 10^6 s^{-1}, g_r= 4, E_r= 14.92 eV
A_{xy}= AFNS (392.12 nm) = 7.99x 10^6 s^{-1}, g_x= 5, E_x= 28.34 eV
A_{uv}= AFNS (409.6 nm) = 8.05 x 104 s^{-1}, g_u= 4, E_u= 15.03 eV

(2)

Using above data we get

$$R_1/R_2 = 8.95 \times 10^{-5} \exp\left[\frac{14.31}{kTe}\right] \quad (3)$$

Experimental Work

Optical Emission Spectroscopy (OES)

The spectra were collected in the range 200-600 nm directly from the plasma jet which directed parallel to monchromator inlet slit 10cm away from the slit as shown in Fig.2 for the two electrode configuration

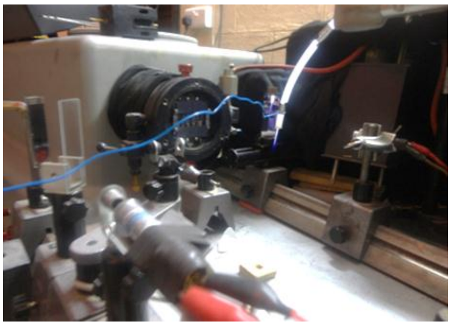


Fig.2: Measuring the spectra by monchromator with photomultiplier

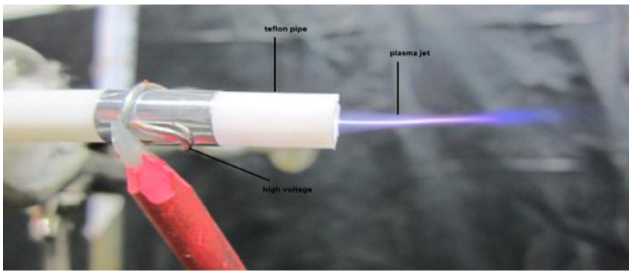
OES has been used to detect plasma composition by observing electronically the excited species and their intensities in the discharges generated by Ar LTPJ torch.

Electron Temperature Measurement

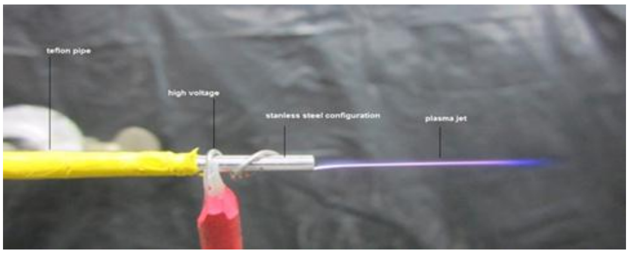
Electron temperature measurement was cared by the line intensity ratio method as mentioned in Eq.(3) for the three electrode configuration.

LTPJ torch construction

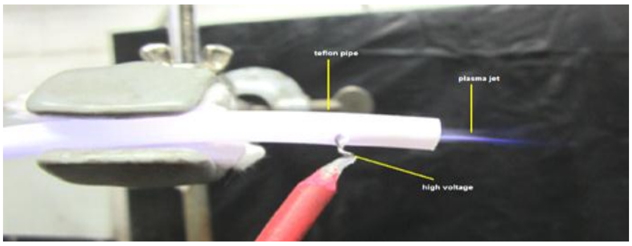
In this work two type of LTPJ torch were developed and constructed as shown in Fig. 3 a, b and c The first plasma jet torch has linear-field configuration, Fig.3 a, and b



a



b



c

Fig.3: LTPJ torch with different electrode configuration a, b linear and c cross field configuration

Linear-field configuration a it consists of teflon tube with an inner diameter of 4.5mm and outer diameter 6.5mm and Aluminum foil, 10mm wide, is placed around the Teflon pipe, 10mm away from its end. The Aluminum foil is connected to high voltage power supply.

Linear-field configuration b it consists of stainless steel tube 100mm long with inner diameter 2.14mm and outer diameter 2.98 mm inserted inside the Teflon pipe the stainless steel connected to the high voltage power supply. And the tolerance between teflon pipe and stainless steel tube filed with teflon tape.

The second LTPJ torch has cross-field configuration, as shown in Fig.3c, it is consists of teflon pipe with an inner diameter of 4.5mm and outer diameter 6.5mm. stainless steel wire 15 mm long and 1mm diameter placed in the center of the teflon pipe, where the wire end does not come out of the end of the teflon pipe. This wire connecting to high voltage power supply. In the all cases configuration the high voltage power supply generates high voltage of sinusoidal shape of 7.5 kV peak to peak and frequency of 28 kHz.

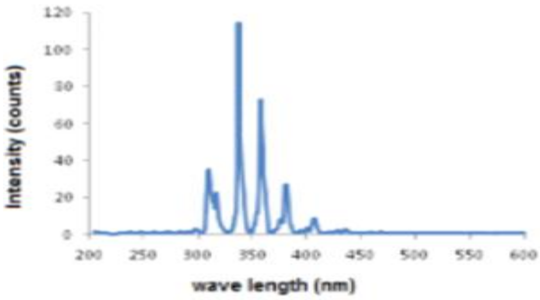
Axial gas temperature

The gas temperature of the working gas of the plasma jet was measured by an infrared thermometer when the plasma jet touching the piece of silicon wafer. For the two electrode configuration while the Ar gas was flowing at different flow rate through the electrode.

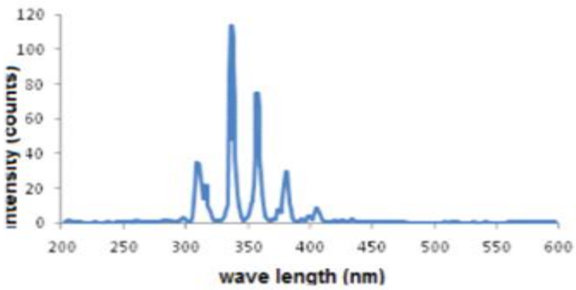
Results and Discussions

Optical Emission Spectra (OES)

OES has been used to detect plasma composition by observing the electronically excited species and their intensities in the discharges generated by Ar plasma torch the emission spectrum of the atmospheric pressure Ar plasma jet in linear-filed electrode configuration and cross-filed electrode configuration at different gas flow rate are shown in Fig.4,5 and 6

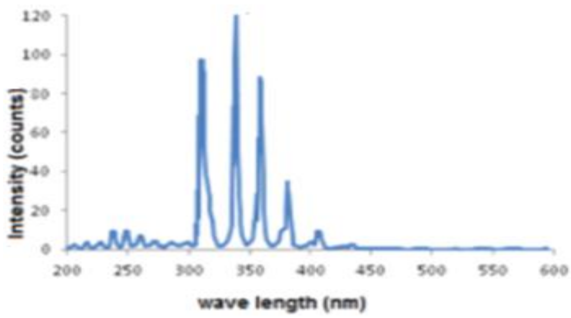


(a)

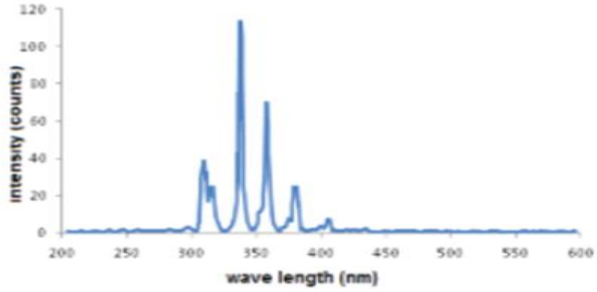


(b)

Fig. 4: Emission spectrum of the atmospheric pressure Ar plasma jet in linear-filed electrode configuration-a-, figure a- for gas flow 3 L /min, figure b- for gas flow 4 L /min

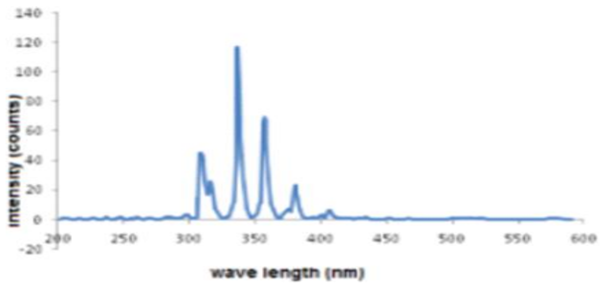


(a)

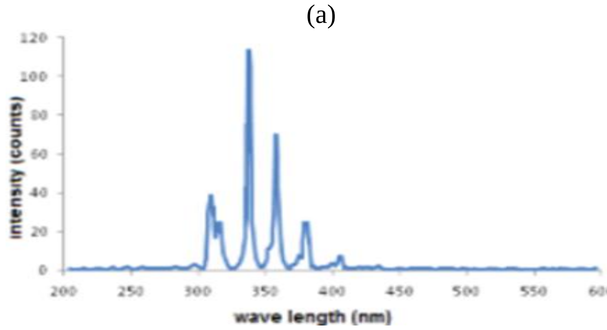


(b)

Fig. 5: Emission spectrum of the atmospheric pressure Ar plasma jet in linear-filed electrode configuration –b- figure a for gas flow 1 L /min, figure b-for gas flow 2 L /min



(a)



(b)

Fig. 6: Emission spectrum of the atmospheric pressure Ar plasma jet in cross-filed electrode configuration figure a- for gas flow 3 L /min, figure b- for gas flow 4 L /min

From these Figs. can be seen that the spectrum of two electrode configuration linear filed a, b and cross filed, have the same peak position and belong to the same excited species and different by its intensity. This is expected because the two electrode plasma jet configuration working by Ar gas, and injected to the atmosphere which contain the same components.

Electron temperature measurement

Electron temperature was determined using the spectrum line intensity ratio R_1/ R_2 all spectrums show the same peak position, these spectrums show no difference except the intensity. This behavior expected because the spectrum represent the finger print for the chemical plasma composition, from Fig.4, 5 and 6 the ratio R_1 / R_2 was determined where:

$$R_1 / R_2 = I_1/ I_2 \Big/ I_3/I_4 \tag{4}$$

where I_1, I_2, I_3 and I_4 are line intensity for the wave lengths 381 nm, 427 nm, 392 nm and 409 nm respectively The electron temperature T_e can be determine from Eq.(3) and Eq.(4). Table (1) shows the measured electron temperature for the different electrode configuration at different Ar gas flow rate. The average temperature for the different electrode configuration (cross-filed and linear-filed a and b) is about 20532 K, this temperature is about 68 time higher than gas temperature this electron temperature is comparable to that calculated and measured by the others (J. L. Delattre, 2008).

Table 1 LTPJ electron temperature for the two electrode configuration at different gas flow rate

Electrode configuration	Flow L/min	(eV)Temperature	(K)Temperature	(cm)Plasma jet length
Linear-a	3	1.77	20532	3.5
Linear-a	4	1.76	20416	3.7
Linear-b	1	1.76	20416	3.5
Linear-b	2	1.85	21460	5.3
Cross	3	1.739	20172	2.4
Cross	4	1.74	20184	2.2

Plasma Working Gas Temperature

Gas temperature is an important parameter in plasma processing application so the gas temperature of the non-equilibrium atmospheric pressure plasma jet was carried out by infrared thermometer, by using a slab of silicon wafer placed at various distance from the torch exit, and where the plasma jet hit the slab directly. The gas temperature for various Ar gas flow rate for linear filed electrode configuration -a- shown in Fig.7 and for linear filed electrode configuration -b- shown in Fig.8. And for cross–filed electrode configuration is shown in Fig.9.

Its appear from Figs. 7, 8 and 9 that the temperature increase with the time and reached saturation around 2.5 min for all flow. Also from these figures the gas temperature for linear field configuration lower than that for the cross field configuration and the gas temperature for linear field configuration b lower than that for a. This result was expected because the plasma jet diameter for linear field electrode configuration is larger than that for cross field electrode configuration. Also from Figs 7, 8 and 9 it appeared that the disturbing temperature rise and full down at gas flow rate large than 3L /min, this is because of the gas flow disturbance.

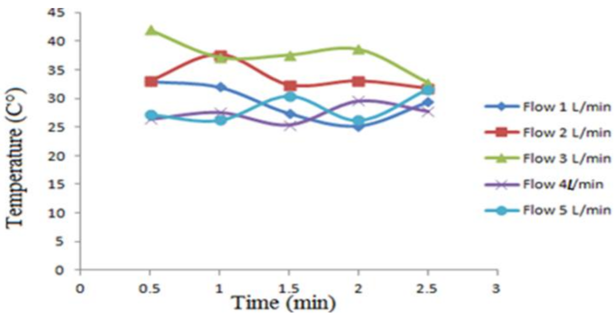


Fig.7: Temperature increment profile of Ar plasma jet by time for linear filed configuration-a- for gas flow rate (1, 2, 3, 4, and 5) L /min at 1 cm distance

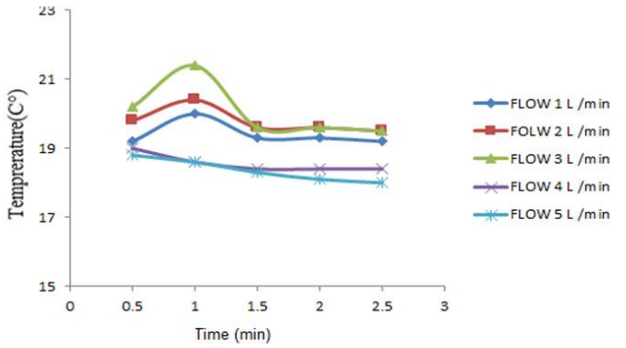


Fig 8: Temperature increment profile of Ar plasma jet by time for linear filed configuration-b- at 1 cm distance

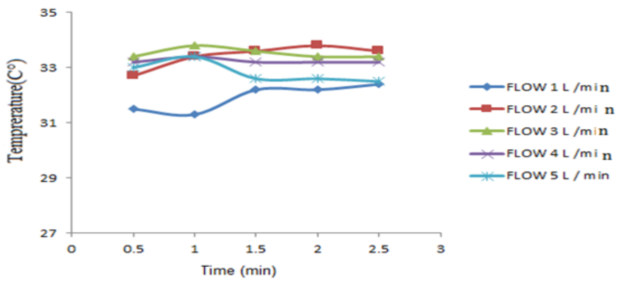


Fig.9: Temperature increment profile of Ar plasma jet by time for cross filed configuration for gas flow rate (1, 2, 3, 4, and5) L /min at 1 cm distance

Plasma gas working temperature for the two electrodes configuration was low and comparable to room temperature. That's where the methods used to generate the non-thermal atmospheric plasma jet with low gas temperature using the following principles i) Transient plasmas**:** if the plasma duration is shorter than 10^{-6}–10^{-5} s, gas heating is limited. In the present work plasma jet duration is about 16 µs. So the gas temperature is low. ii) Micro-plasmas Small-sized atmospheric plasmas are usually non-thermal.

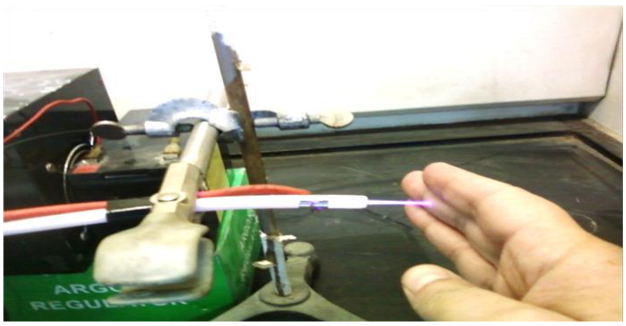


Fig.10: Ar plasma jet in contact with human skin

This is simply a consequence of their low volume to surface ratio. Energy transfer from electrons to gas atoms/molecules occurs in the volume, and the resulting heat is lost by conduction through the plasma boundary surface (S. B. O. Craciunescu, 2011 and R. E. J Sladek, 2006). iii) Dielectric barrier discharges (DBD) In this process the glow discharge does not transit into an arc.

The DBDs have a large surface-to-volume ratio. This promotes heat diffusion losses and maintains low gas temperature. The DBD plasma operated by alternating voltage with frequency 28 kHz and its length scales (plasma jet diameter) is about 1 mm so this plasma has low gas temperature because the electrodes are large. This promotes heat diffusion losses and maintains a low gas temperature. Verification of low temperature of the plasma jet was also performed by simply touching it by the hand, as showed in Fig.10. The Ar plasma jet can strike the human skin without causing harm effect.

Conclusions

The jet temperature of the LTPJ was found to be closer to room temperature than any other plasma jet. For the two electrodes configuration the plasma jet temperature disturbed (rise up and full down) for all gas flow rate larger than 3L /min, this is due to the flow of gas transition from laminar flow into turbulent flow. The average electron temperature for the different electrode configuration (cross-filed and linear-filed a and b) is about 20532 K, this temperature is about 68 time higher than gas temperature.

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