Investigation on Characteristics of Atmospheric Pressure Helium Plasma Jet by Using different Pyrex Tubes Thickness

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Abstract

Characteristics of atmospheric pressure plasma jet (APPJs) is significant for use in different application such as medical, biomedical, agriculture, and industry. In this work, Pyrex tubes of different thicknesses (1, 0.5, 0.2, 0.1) mm were used in glow discharge to generate the helium plasma jet, effect of tube thickness on the properties of the generated plasma was investigated. The temperature of the generated plasma was measured for all tubes of different thicknesses. The length of the plasma jet was calculated for a range of applied voltage (8-14) kV at a helium gas flow rate (4 SLM). Also, the plasma temperature and the length of the flame were estimated for different gas flow rates (1-6) SLM where the applied voltage between the two electrodes of the system was 8 kV. The results show that the optimization characteristic obtained at 1mm thickness, the plasma temperature was confined between (24-26) ºC and the length of the plasma plume was 6cm These results were suitable to use in medical and biomedical applications.

Keywords: *atmospheric pressure helium plasma jet, plasma temperature, plasma plume, gas flow rate, applied voltage.*

1. Introduction

Many studies have been done so far on gas atmospheric pressure plasma jets (APPJs). Its plasma has many advantages such as the effects of low temperature, low electric field, and chemical reactions of energetic radicals have different applications and become widely used in many applications such as sterilization, surface applications such as coating, cleaning, polymerization, oxidation, and medical treatments [1-3]. Many researchers introduced different types of plasma devices based on the applied voltage and method of plasma generation such as dielectric barrier plasma pens, double electrode or high-frequency RF column plasma jetting, and pulsed DC power supplies [4–5]. The non-equilibrium nature of plasma makes it different from thermal plasma and more complex in terms of the physics and chemistry involved, and its non-thermal nature (the temperature of heavy particles remains close to room temperature) makes it suitable for biomedical applications such as wound healing, tissue sterilization, blood coagulation, electro surgery, etc., as they avoid thermal effect or damage to living cells [6–8]. The advantage of generating cold plasma is that it does not require costly and complex operating methods. Plasma parameters such as plasma temperature, electron temperature (Te), electron density (ne), reactive species, plume length, etc. need to be investigated to understand how to use them in biological and industrial applications [9–12]. Many experimental studies have been carried out to perform plasma diagnostics and guidance using various methods such as electro diagnostics, optical emission spectra (OES), temporal analysis, etc. [13-16]. The operating parameters such as applied voltage and gas flow rate affected by fluctuations in plasma are investigated [17–20]. In atmospheric pressure plasma, the measured plasma temperatures were found to be in the range of (26°C – 40°C) [21]. The temperature ranges are suitable for biological applications (killing bacteria and fungi) and industrial applications, as they kill foreign bodies (bacteria and viruses) and will not harm living cells [22]. One of the critical parameters that need to be understood is the plume dynamics in the ambient air in the plasma jet [23-25].

In this work, a simple system is constructed to generate a helium plasma jet at atmospheric pressure, Pyrex tube thickness used in the glow discharge is a very sensitive parameter to form atmospheric pressure plasma. For this purpose, different tube thicknesses (1, 0.5, 0.2, 0.1)mm are employed to show the effect of tube thickness on the properties of the generated plasma. The temperature of the generated plasma is measured for all tubes. Also, the length of the plasma jet is calculated for a range of applied voltage between the two electrodes of (8-14) kV at a gas flow rate (of 4 SLM). The effect of the helium gas flow rate (1-6) SLM on the plasma temperature and the length of the flame is estimated when the applied voltage is 8 kV. A simple UTS electronic thermocouple sensor is used to estimate the plasma temperature along the column in the range of (26 -46) °C, which is desirable for many biological applications.

2. Materials and Methods

A schematic view of the experimental setup is illustrated in Fig.1.A high sinusoidal AC voltage (1 -20) kV is applied to produce a helium plasma A Pyrex tubes with an inner diameter of 2 mm and different thicknesses are used. Two electrodes made of aluminum with 1 mm thickness are arranged in a multi-domain configuration. Helium (He) gas with a purity of 99.99% is used as the active gas for electrical discharge. An image of the visible plasma plume is shown in Fig. 2. In the present work, the operating conditions, i.e., the applied voltage is 8 kV, and the helium gas flow rate is 4 L/min which are produced by optimized characterization.

Figure 1. Photograph of APPJ plasma jet system (1. Earth wire, 2. Helium gas,3. Power supply, 4. Pyrex tube, 5. Electrodes, 6. OES sensor, 7. High voltage prob, 8. Helium flow meter. 9. OES device, 10. Oxygen flow meter, 11. Oscilloscope, 12. Laptop)

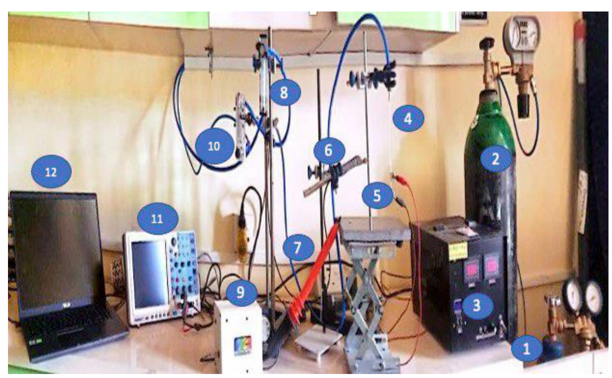


Figure 2. image of plasma plume

Pyrex tubes of different thicknesses (1, 0.5, 0.2, 0.1) mm are employed to satisfy the effects of tube thickness on the electrical characteristic of generated plasma such as plume length and plasma temperature.

Plasma temperature and plasma plume length play a major role in various cold plasma applications, a simple electronic thermo-sensor of the type UTS is used to estimate the temperature of the plasma. The electrical discharge of atmospheric pressure plasma jet is mainly dependent on the applied voltage and gas flow rate, therefore studying the effect of these parameters on the electrical properties of generated plasma must need attention. A range of applied voltage between the two electrodes of (8-14) kV at a gas flow rate (4 SLM) is investigated, also the effect of the helium gas flow rate (1-6) SLM on the plasma temperature and the length of the flame is estimated when the applied voltage is 8 kV.

Results and Discussion

Different Pyrex tubes were used to generate atmospheric pressure plasma jet to show the effects of tube thickness on plasma temperature and plasma plume length as shown in Table 1.

Table 1. plasma temperature and plasma plume length at different Pyrex tube thicknesses in case of 8kV applied voltage and 4SLM gas flow rate, The distance between the electrodes was (1cm)

No. of tube	Tube length cm	Inner diameter mm	Thickness mm	flame length cm	Temperature °C
1	17	2	0.5	8.5	32
2	21	2	0.2	6.5	35
3	21	2	0.1	7	40
4	16	2	1	6	26

Table 1. shows the plasma plume length randomly variation due to the thickness of the Pyrex tube because the drift velocity of ions is unstable in different thicknesses. The maximum jet length of 8.5cm has been observed at 0.5 mm thickness and the plasma temperature is 32 °C, the suitable results for use in biomedical and medical applications are obtained at 1 mm thickness because of plasma temperature is 26 °C. Figure 3 presented a plasma plume of different Pyrex tube thicknesses when the applied voltage is 8kV and the gas flow rate is 4 SLM, the plasma temperature strongly depends on the thickness of the Pyrex tube. tube with 1mm thickness has a low temperature of 26 °C than other tubes which is close to room temperature because of collisions between electrons and ions,

Fig.3 plasma plume length at different Pyrex tube thickness

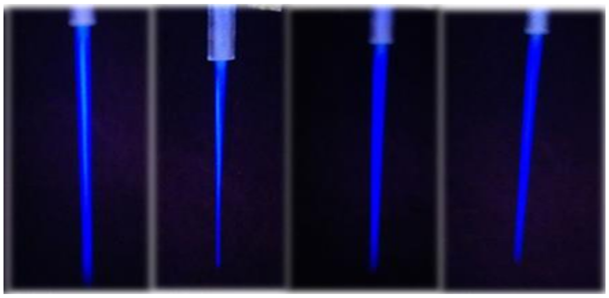


Fig.4 explains the behavior of plasma temperature with time, more than one minute the increase in the plasma temperature becomes constant and can be recorded the temperature of the plasma.Fig.5 shows the plasma is generated at a range (1-2.5)cm distance between the electrodes but the plume length of the plasma jet decreases as the distance increase in constant applied voltage (8 kV)and helium flow rate 4 SLM, this behavior occurs due the voltage drop.

Fig.4 Helium plasma temperature as a function of time

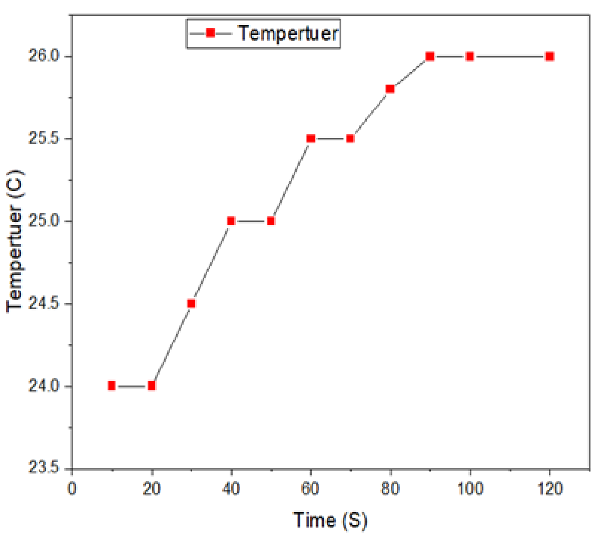


Fig.5 Dependence of plasma plume length on the distance between electrodes

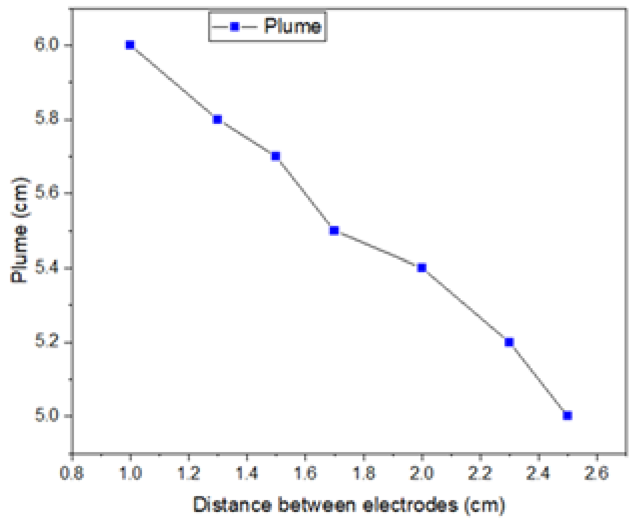


Fig.6 illustrated the effect of gas flow rate on plasma temperature at range (8-14)kV of applied voltage, when the electrical voltage applied in the discharge Pyrex tube is high, the kinetic energy of electrons increased and the plasma temperature increased at a low gas flow rate (1 SLM). But at high concentrations of helium plasma, the electrons have little time to exchange energy with their surroundings and the plasma temperature becomes low (see fig.6) at a gas flow rate(3-6)SLM.

The influence of the helium flow rate on the plasma plume length illustrated in Fig.7 at range (8-14)kV applied voltage on the electrodes, the plume length increased at(2-3) SLM gas flow rate but at (4-6) SLM gas flow rate, the behaviors of plume length like randomly because of the electric discharge non-uniform which affects negatively on plume length.

Fig. 6 effect of gas flow rate on plasma temperature

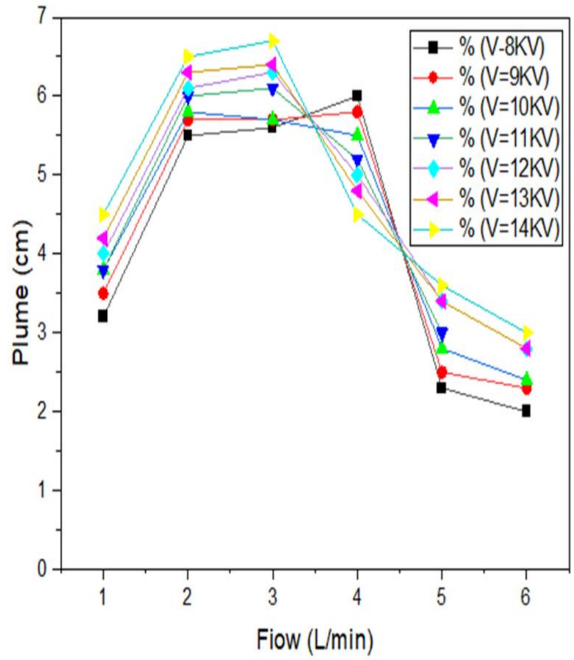
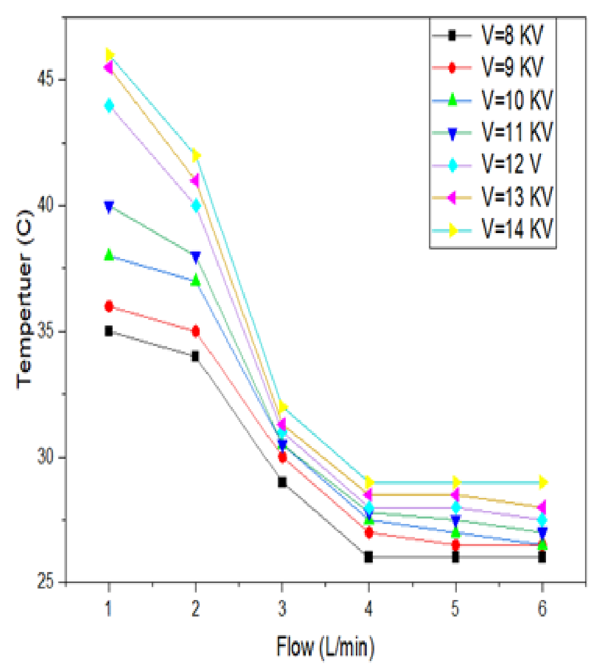


Fig. 7 effect of gas flow rate on plasma plume length



Dependence of Plasma temperature on the distance between the electrodes in the plasma system illustrated in Fig.8, the reduction of plasma temperature is clear when the distance between the electrodes increased at a constant applied voltage of 8 kV, at 1 cm the plasma temperature is 26℃, this value decrease slightly when the distance increased until reaches more than 2.5cm the plasma not generated.

In Fig.9 the plasma temperatures become higher. When the discharge voltage was increased, when the voltage reaches 14 kV, the plasma temperature is up to 45℃, and the electric discharge may be unstable and cause sparking, a higher voltage also damaged the glass capillary tube and caused the discharge to become unstable.

Fig.8 Influence of distance between electrodes on plasma temperature

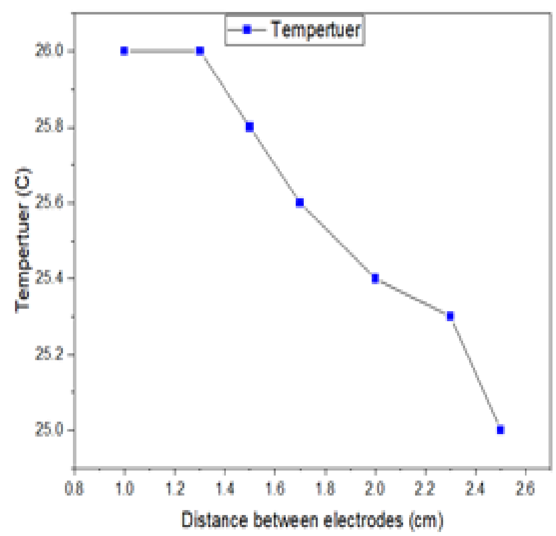
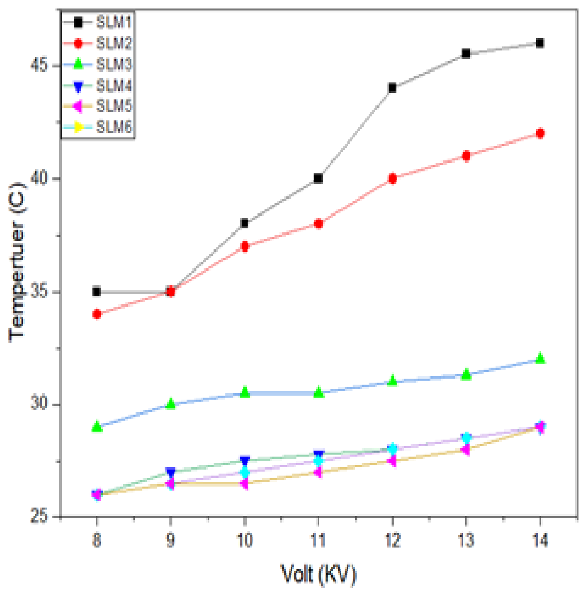


Fig.9 Influence of applied voltage on plasma temperature



Conclusion

Plasma parameters such as plasma temperature and plasma plume length are played a major role in using of cold plasma in biomedical and medical applications, Studying the effect of Pyrex tube thickness on these parameters are used as a guide in the construction of plasma system, 1 mm tube thickness is an optimized value by obtained plasma with room temperature and plume length 6cm. Applied voltage and gas flow rate are principal parameters in determining the uniform electrical discharge of the system. The plasma temperature reaches 45℃ at an applied voltage of 14 kV, a higher voltage also damaged the glass capillary tube and caused the discharge to become unstable.

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