21. Study of an Atmospheric Pressure Plasma Jet of Argon Generated by Column Dielectric Barrier Discharge

by Muhlisin Zaenul

Study of an atmospheric pressure plasma jet of Argon generated by column dielectric barrier discharge

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Abstract. An atmospheric of argon plasma jet was generated by using column dielectric barrier discharge has been investigated. In this study, argon gas was passed through the capillary column by regulating the flow rate of gas. This atmospheric pressure plasma jet (APPJ) was generated by a sinusoidal AC high voltage in the range of 0.4 kV to 10 kV and at frequencies of 15 kHz and 26 kHz. APPJ has been produced with flow rate of argon gas from 1 litter/min - 10 litters/min. The electric current has been taken with variation of voltage and each interval argon gas flow rate of 1 litter/min. The results show that electric current increase linearly and then it trends to saturation condition by the increasing of applied voltage. We found also that the length of the plasma jet increase by augmenting of applied voltage both for frequencies of 15 kHz and 26 kHz. Furthermore, our results show that length of plasma jet optimum for flow rate of argon gas of 2 litters/minute. In addition, we obtained that the larger applied voltage, the greater the temperature of the plasma jet.

1. Introduction

In the last decades, cold atmospheric pressure plasma jets (APPJ) have attracted much attention due to their versatility, low-cost operation and also ability to produce reactive chemistry at room temperature [1]. Many applications have been developed and studied using the discharge plasma based on different geometries using various materials for electrodes. This great flexibility in producing plasma causes the diversity of the use of plasma in a wide range of applications in industrial, energy, biomedical, analytical and quality of life [1,2,3]. Plasma Jet is the result of ionized gas flow from plasma discharge column [1,2]. Plasma jet shaped like flares. The phenomenon of atmospheric pressure plasma jet (APPJ) can date back to 1960s when it was first generated as a local thermodynamic equilibrium plasma jet. Cold plasma jet in atmospheric pressure can be applied to material processing and biomedical applications such as disinfectant and decontamination [4] and for medicine such as wound healing [2,5,6]. In the atmospheric pressure plasma jet has various dimensions of coverage, ranging from the micrometre scale suitable for local treatment and accurate, up to large scale suitable for large scale sample treatment. So many different configurations and applications of non-thermal plasma [7]. Plasma jet can be generated with a length up to several centimetres and can be touched by hands. Argon plasma jet in atmospheric pressure at room temperature can be produced from a stainless steel electrode in dielectric barrier discharge system [7]. Dielectric barrier discharge is also called as a silent discharge plasma, the discharge can be used to produce non-equilibrium atmospheric pressure plasma. Discharge between the electrodes, one or both are coated by dielectric layer [8]. In the produce plasma jet, argon gas was flowed in the reactor plasma reactor. Argon gas was included in the group of noble gases which are unreactive element [9,10]. Noble gas is added so that the process of ionization, excitation and dissociation in the plasma takes place optimally. Working gas is used in the range of atmospheric pressure, or a device to generate plasma in the open air [3]. Therefore, the need for research to determine the characteristics of the plasma jet using dielectric barrier discharge column by the addition of argon gas. In this paper, we presented our results on characteristic of APPJ argon gas such as, I-V characteristic, length and temperature of jet influence of argon gas flow rate and influence of applied voltage.

2. Research Methods.

This research was conducted by characterizing of argon plasma jet using a dielectric barrier discharge column at atmospheric pressure. This atmospheric pressure plasma jet (APPJ) was generated by AC high voltage. A sinusoidal voltage at 15 kHz and 26 kHz are applied for the excitation and sustaining of the discharges. AC high voltage source connected with a resistor of 100 kΩ and HV probe, of the resistor is then connected to the upper electrode.

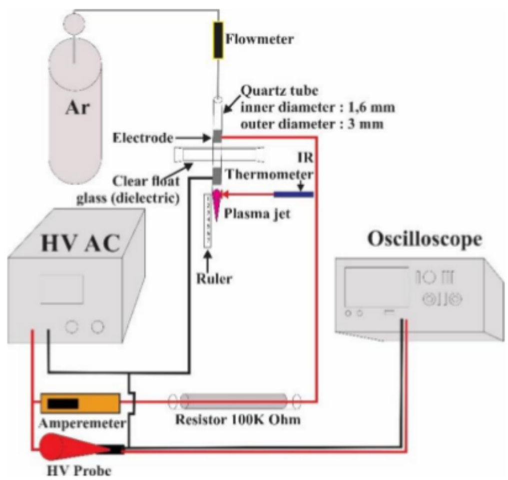

Figure 1. Schematic of research equipment set-up

Output of AC high voltage source was connected to the bottom electrode and the HV probe. HV probe connected to an oscilloscope (GW, GOS 563, 50 MHz). Argon plasma jet was generated by using capillary column as tube of jet. Capillary column made of quartz glass with an inner diameter of 1.6 mm and an outer diameter of 3 mm with a length of 100 mm. At the center of the length capillary column, we added a clear glass with a length of 100 mm, width of 74 mm and a thickness of 3 mm. The clear glass serves as a dielectric barrier (dielectric barrier discharge) to separate the two electrodes. The electrodes used in this study is made of a thin layer of aluminium (aluminium foil) encircling the quartz capillary column. We used two type of reactor. Reactor "A" with the top electrode length of 20 mm and 30 mm of lower electrode, the distance between the electrodes of 10 mm and the spacing between lower electrode to the tip of the capillary column is 5 mm and HV-AC with frequency at 26 kHZ. Other, reactor B with the top electrode length of 30 mm and 20 mm of lower electrode, the distance between the

electrodes of 10 mm and the spacing between lower electrode to the tip of the capillary column is 5 mm, and HV-AC with frequency at 15 kHZ.
Argon gas as the working gas (Ar, 99.95%) is inserted into the capillary column by regulating the gas flow rate in the range of 1-10 L/min with intervals of 1 L/min. Voltage and electronic signals are generated can be observed using an oscilloscope. Electrical current was measured using ammeters (Kyoritsu, AC/DC digital Clamp meter). Gas flow rate was measured using a flow meter (Koploc Kojima Model RK 1600 R). The jet length is measured using a ruler, long jet results are documented using a digital camera. The temperature of plasma jet was measured by IR thermometer (Krisbow, KW06-280). The research equipment scheme can be seen in figure 1. The signal frequency was fixed at 26.0 kHz and 15 kHz the voltage amplitude was varied in the range of 0.4 - 10.0 kVpp. The exit of the DBD reactor, located on its bottoms side, is connected to a commercial flexible plastic tube (3.2 mm outer diameter, 2 mm inner diameter), which guides the plasma species downstream. At certain conditions (especially if a conductive object is closed to the tube end) a plasma jet can be extracted from the plastic tube.

3. Results and Discussion

Characteristics of Electrical Current (I) - Applied Voltage (V)

In this study, we carried out experiment of variation in voltage from 0.4 kV to 10 kV. Average of electrical current as function of voltage for argon gas flow rate of 1-10 liters/min, can be seen in graph shown in Figure 2.

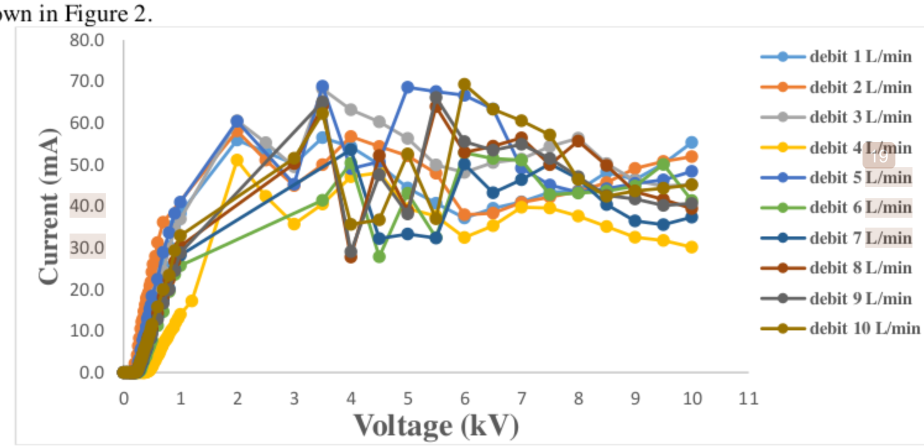

Figure 2. Characteristic of electric current - applied voltage, with power frequency of 26 kHz

Figure 2 shows that there are two areas of current as a function of voltage. The first regions (with applied voltage of 0.4 kV – 2 kV) indicates that the discharge current rises linearly with increasing voltage. In this area can be approached as if the laws apply ohm (called "ohmic" region). After this region, we found that electric current tends to volatile saturate with high range diversity (from 28 mA to 68 mA). Characteristic of I-V in the figure 2, has been taken from reactor A plasma jet with frequency of power supply at 26 kHz. Electric current will increase along with the increase in voltage up to 1 kV, then there will be saturation current at a voltage of 1 kV to 10 kV. The peak of maximum current occurs at a voltage of 3.5- 4 kV and the maximum current of 68.9 mA current occurs in argon gas flow rate of 5 L/min. Generally, the characteristic of electric current as function of applied voltage on argon plasma jet using a dielectric barrier discharge column at atmospheric pressure, after the electric current start to appear, the electric current will increase proportional to the voltage, this region is categorized as ohmic region. Ohmic region is the enactment area of law Ohm.

The total current in the plasma jet is a combination of capacitive currents to currents. High-energy electrons striking atoms or molecules will transform kinetic energy to produce ionization energy of excited species. The absorption of collision energy by electrons resulting in the displacement of electrons of lower energy levels to higher energy levels. Excitation will take place temporary and the electrons will return to its original energy level accompanied by emission of photons. Interactions that occur repeatedly and continuously, which results generated currents going up and down.

Characteristic of Jet Length as Function of Voltage (V)

Based on the results, the plasma jet can be seen inside and outside the capillary column. The plasma jet emerging and the voltage is increased, the plasma jet will be pushed out through the end of capillary column. Length of the plasma jet was measured from the end of the capillary column to the end of the plasma jet. Plasma jet length will increase with the increase of applied voltage and reaches the maximum length in highest voltage. The measurement results can be seen in the Figure 3.

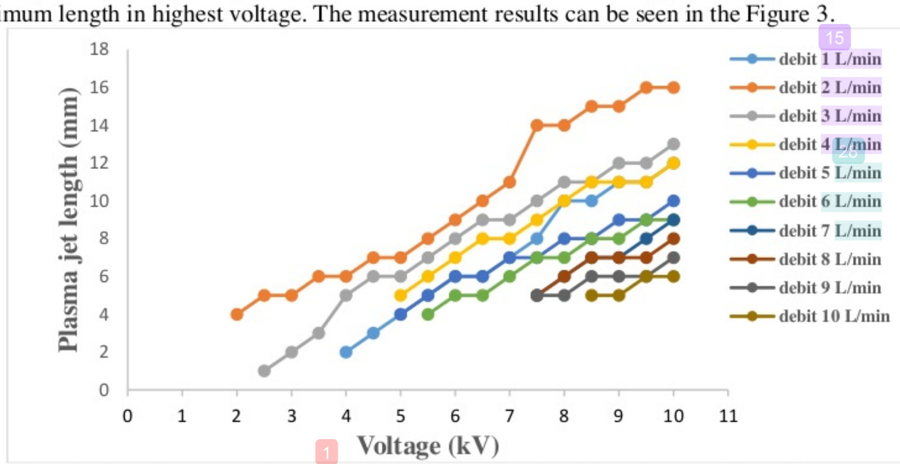

Figure 3. The characteristic of jet length as function of voltage for several gas flow rate and frequency of power supply at 26 kHz.

In general, the characteristic of electric current as function of voltage in argon plasma jet using dielectric barrier discharge in atmospheric pressure, jet length will increase by the increase of voltage. It is occurring due to the role of electrons in plasma jet generation, when the voltage increased, electric field will increase and there are more electron striking the argon gas atoms, so that the plasma jet will become longer due to the encouragement plasma species of argon gas comes out of the capillary column. Photographs of plasma jet on argon gas flow rate of 2 litters/min can be seen in Figure 4.

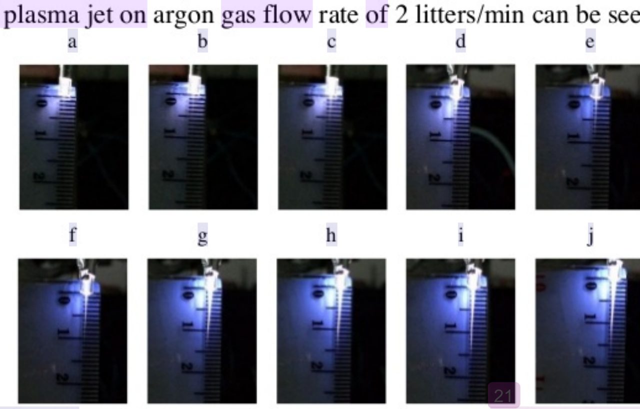

Figure 4. Photographs of plasma jet on Argon gas flow rate of 2 L/min

This flow rate generates the optimum length of plasma (see also Figure 6). This photographs indicates the ten length of the plasma jets. Each length is a length of a jet for a certain value of voltage. So the letter "a" to "j" marking the change in length from the lowest voltage to largest.

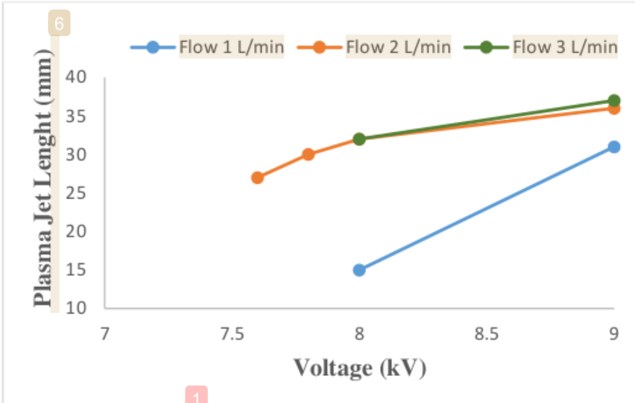

Figure 5. The characteristic of jet length as function of voltage for several flow rate and frequency of power supply at 15 kHz.

Characteristic of Jet Length as Function of Argon Gas Flow Rate (L/minutes)
In this study, the characteristic of jet length as function of Argon gas flow rate (L/min) for voltages variation of 4-10 kV, can be seen in figure 4. This treatment is to determine the length of the plasma jet is based on the increase in argon gas flow rate at a certain voltage.
By depicting the relation between jet length as function of Argon gas flow rate in voltage variation of 4-10 kV obtain the same pattern. The jet length will increase begin the Argon gas flow rate of 1-2 L/min. When the Argon gas flow rate more than 2 L/min, jet length will decrease gradually and when the voltage increase will increase the jet length. At a voltage of 10 kV obtained the longest plasma jets for all Argon gas flow rate. At Argon gas flow rate of 2 L/min obtained the longest plasma jets for all voltages, with a length of 16 mm.

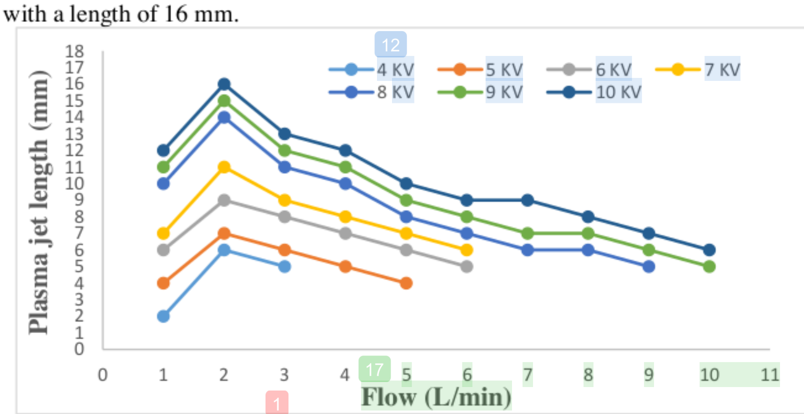

Figure 6. The characteristic of jet length as function of flow rate, for freq. of power 26 kHz.

The typical shape of plasma jet length as a function of argon gas flow rate, the minimum voltage for generating plasma jets is 4 kV at the same argon gas flow rate, the jet length will increase along with the increase of applied voltage and the maximum length of the jet is in voltage of 10 kV at the same Argon gas flow rate. While the minimum jet length of 2 mm occurs at voltage of 4 kV with Argon gas flow rate of 1 L/min, and the maximum jet length of 17 mm occurs at a voltage of 10 kV at Argon gas flow rate of 2 L/min.
Based on observations in this study, it was found that the difference does not only happen on the length of the jet but there are also differences in the plasma jet forms in terms of the diameter of the jet. At

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lower Argon gas flow rate is obtaining the smaller diameter plasma jet and at the higher gas flow rate is obtaining the larger diameter plasma jet. It occurs due to the higher gas flow rates resulting the higher pressure of gas thereby increasing the ability to push the plasma jet out of the capillary column so that the diameter will be larger and due to the magnitude of this pressure results in reduced length of the plasma jet.

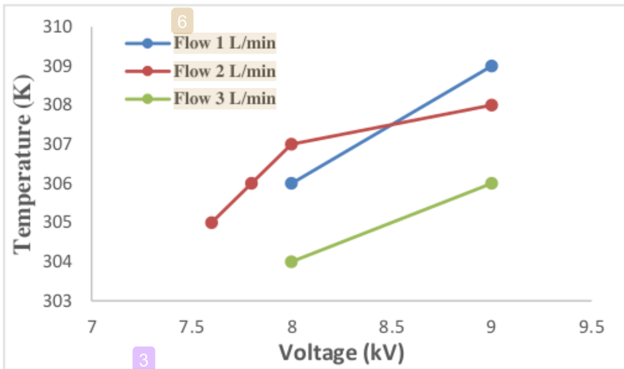

Figure 7. The temperature of plasma jet as function of applied voltage, with frequency of 15 kHz

Figure 7 shows the temperature of the plasma jet as a function of voltage for AC power supply frequency of 15 kHz. In this picture, it can be seen that at a lower voltage the biggest plasma jet temperature of 307 K for an operating voltage of 8 kV. Temperature in figure 7 are closed with rotational temperatures that where found by Hong et al [8]. Overall Figure 7 shows that the larger applied voltage, the greater the temperature of the plasma jet

4. Conclusions

On the characteristics of the current (I) - voltage (V) is obtained that the electric current will increase with increasing of voltage named as "ohmic" region for beginning of discharge. After the plasma jet appears the current tends to volatile saturate. The length of plasma jet increases with increasing applied voltage both for frequencies of voltage signal at 26 kHz and 15 kHz. The influence of argon gas flow rate to plasma jet length has been obtained the optimum value of flow rate at 2 litters/minute. We have found that the temperature of the plasma jet is getting higher with the growing power voltage.

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