Development of non-thermal atmospheric plasma torch utilizing high voltage power supply

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Abstract: In this paper, we report the successful development of non-thermal atmospheric plasma torch employing high voltage power supply. Usually atmospheric plasma is generated at high temperature (>1000 °C) and it is quite a challenge to generate cold plasma (<150 °C). The plasma torch in this assembly uses helium gas. The length of helium plasma glow discharge in this research is studied and optimized, with flow rate varied from 2 to 7 liters per mins, at varied applied voltage of 1.20 to 2.00 kV. The generated cold helium plasma has tunable length of around 5 to 35 mm, as cold as 26 °C. The plasma setup in this study is projected to be suitable for future applications in several fields such as industrial wastewater processing, as well as food processing, or agricultural field.

Keywords : Cold plasma, glow discharge, atmospheric plasma helium

1. Introduction

It is generally known that plasma is the fourth state of material [1], having high energy content but in neutral state of equal amount of positive and negative charge. This nature of plasma is highly useful in the modification of the several micrometers of the surface of materials, without changing the bulk properties of the materials [2]. It is also developed to produce plasma polymer, in which polymers are generated via high energy polymerization, resulting in unconventional network of pinhole-free and densely packed structure imbued with various functional groups on the surface of the modified materials [2, 3].

Plasma founds vast implementation in medical applications, such as in the medical field for the investigation of effect of nitrogen-based surface functional groups to the growth of mammalian cells [3-6], immunosensing [7], biomedical coating or pharmaceutical materials [8-10], hemocompatible coating for surgical materials [11], or for materials science and environmental engineering, such as for gas sensor [12], glucose sensor [13], electronic materials [14], wettability of functionality gradient [5, 15, 16], degradation of dyes [17, 18], etc. Due to its nature of high energy, the plasma generated in atmospheric pressure is usually similar to that of corona or plasma of the sun, which is > 1000 °C [1, 2]. This kind of plasma is obviously too hot for the purpose in the medical, food or agriculture field. Therefore, in order to generate less hot plasma, or cold plasma, then vacuum condition is commonly chosen [2]. However, it is quite expensive and requires high maintenance of the vacuum pumps. This
Research is carried out with the objective to overcome this kind problem by aiming to assemble non-thermal cold atmospheric plasma system, by using unconventional power supply, which is high voltage power supply.

2. Experimental
The cold plasma torch in this study is based on the previous study [19], but with the form of a cylindrical torch. It uses high voltage power supply, coupled with 555 circuit timer with ignition coil. Figure 1 describes the schematic diagram of the fabricated cold plasma torch. It contains stainless steel pipe (inside diameter of 3 mm, and outside diameter of 6 mm), connected with high voltage power supply. The pipe is jacketed with silicon hose with outside diameter of 12 mm. About 10 mm after the end of the silicon hose (as the plasma outlet), a copper coating is wrapped around the silicon hose and connected to the grounded power supply. Helium gas (PT. Tira Austenite, Jakarta, Indonesia) is flowed from one stainless steel pipe to another end while being charged by the high voltage power supply to produce cold plasma.

![Schematic diagram of the cold atmospheric plasma torch in this research](image)

The electrical characteristic of the generated cold helium plasma is diagnosed by using Hantek DSO5072P oscilloscope, with probe PD-28 (attenuation ratio of 1000:1) [19] The temperature of the helium cold plasma generated in this study is measured by using two methods, which are firstly by direct measurement of the plasma discharge by using infrared thermometer (IRTEK Dual Beam Infrared Thermometer IR150, Bhinneka, Indonesia) for 120 seconds, until the obtained value is constant. The second method is by shooting the plasma discharge to a good conductive material (e.g. copper plate) and measured the temperature of the copper plate by using infrared thermometer for 120 seconds. Furthermore, in order to know the effect of applied voltage and gas flow rate to the length of the produced cold plasma, we varied the voltage from 1.20 to 2.00 kV, and helium flow rate from 2 to 7 liters per mins.

3. Results and Discussion
In this research, a prototype of non-thermal atmospheric plasma torch, or cold plasma torch, for various emerging applications is assembled. This plasma assembly is specifically built in the form of cylindrical torch in order to be able to treat samples with various shapes, such as fruits, vegetables, mammalian skin, etc. The resulted plasma torch (helium gas flow rate of 3 liters per mins, at applied voltage of 1.18 kV) is demonstrated in Figure 2.
Figure 2. Plasma torch in action at ambient condition (helium 3 liters per mins, applied voltage 1.18 kV).

From the plasma torch in action as illustrated Figure 2, it could be observed that the type of the helium cold plasma generated from our setup is the glow discharge type, as shown by the purple luminous glow. This glow discharge plasma type is very suitable for surface modification of materials (without modifying the bulk properties of the materials).

Figure 3. Typical AC voltage profile of cold atmospheric plasma using high voltage power supply (at helium flow rate of 3 liters per mins).

Electrical diagnosis of the generated cold helium plasma is shown in the diagram of voltage waveform in Figure 3. With helium gas flowrate of 3 liters per mins, the glow discharge plasma can be generated at 1180 V peak-to-peak. The displayed oscillation voltage in Figure 3 (1.18 V) is obtained by using high voltage probe with attenuation of 1000:1, and therefore the actual applied voltage must be multiplied by 1000 from the displayed voltage, which is 1180 V or 1.18 kV. The typical alternating current (AC) at 1.18 kV and frequency of 25 kHz creates sinusoidal wave with period of 40 μs to maintain the generated glow discharge plasma. Further increase of the applied voltage (at constant gas flow rate) is discouraged. Increasing the applied voltage to 1.70 kV changes the regime of the generated plasma from glow discharge to aggressive plasma streamer regime, followed with hot arcing phenomenon (data not shown). Therefore the optimum parameters (helium flow rate 3 liters per mins, 1.18 kV, 25 kHz) will be further used in this study.
Figure 4. Temperature of the cold atmospheric plasma torch, as shown by thermal imaging camera and infrared thermometer.

Temperature is one of important characteristics for the fundamental of the atmospheric cold plasma. Generally, atmospheric plasma is commonly generated as hot thermal plasma (temperature $>1000 \, ^\circ C$). It is quite a challenge for scientists and engineers to generate cold plasma ($<150 \, ^\circ C$) at atmospheric pressure. The result for the temperature measurement of the glow discharge is shown in Figure 4, where it is confirmed that the cold helium plasma of around $26 \, ^\circ C$ is successfully generated under the condition of atmospheric pressure. Therefore, this cold atmospheric helium plasma is promising to be applied for various implementations (such as agriculture, food processing, or medical treatment) that can modify materials without invasive or deteriorating effects imparted to the materials itself.

![Figure 5](image)

Figure 5. The effect of applied voltage to the length of the generated glow discharge plasma (helium flow rate of 4 liters per mins).

The length of the generated plasma is also an important characteristic in this study, in order to identify how far is the range that can be covered by the cold atmospheric plasma torch. It is found that the length of the glow discharge plasma is affected by the applied voltage and also the gas flow rate, as shown in Figure 5, and Figure 6, respectively. The effect of applied voltage to the length of plasma in Figure 5 is observed at constant helium flow rate of 4 liters per mins. It is shown that at 1.20 kV, plasma can be generated as long as 8 mm. If it is less than 1.20 kV, then there will be electrical breakdown and no plasma can be generated. By increasing the applied voltage, longer plasma can be obtained up to 27 mm (at maximum voltage of 1.85 kV). However, when the voltage is increased up to
1.96 kV, no significant increase of the plasma length is acquired. When the voltage is further increased to 2.00 kV, the plasma is getting shorter and accompanied with arcing, which is not the optimum condition sought in this study.

The effect of helium gas flow rate to the length of the generated plasma is illustrated in Figure 6, by using constant applied voltage of 1.65 kV. It is observed that the gas flow rate is positively affecting the length of cold plasma. At helium flow rate of 6 liters per mins, the plasma glow discharge is at the maximum length of 35 mm. Further increasing the flow rate to 7 liters per mins delivers insignificant effect to the length of plasma. Beyond that, the resulted plasma glow discharge will slowly diminishing.

![Graph](image)

**Figure 6. The effect of gas flow rate to the length of the generated glow discharge plasma (applied voltage of 1.65 kV).**

4. **Conclusion**

The research results shown in this investigation concludes that cold atmospheric helium plasma torch is prepared successfully, owing to the use of high voltage power supply. By modulating several parameters (applied voltage, and helium gas flow rate), then the length of the plasma can be tuned in order to fit the requirements demanded by several applications, namely in medical treatments, agricultural processing, and/or material science and engineering. The recommended parameter for applied voltage is 1.20-1.80 kV, with helium flow rate of 2-6 liters per mins, giving the cold glow discharge plasma with temperature of around 26 °C, having the length of 5-35 mm.

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