Experimental Model to Study the Characteristics of Gliding Arc Plasma Reactor with Argon/Nitrogen

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Abstract—**Gliding arcs have properties of both thermal and non-thermal plasma conditions. Gliding arc discharge plasma in the atmospheric pressure with argon/nitrogen and its characteristics are described. Some experimental results about AC gliding arc plasma generator have been obtained. It seems that the current density strongly depend on the gas, and increased with increasing discharge power and gas flow rate.**

Keywords—AC Gliding arc plasma, Discharge in the atmospheric pressure, Gas flow rate, Experimental model.

I. INTRODUCTION

The gliding arc discharge (GAD) is a simple and inexpensive way to generate non-thermal plasma. It has a dual character of thermal and non-thermal plasma, and can involve relatively high electric powers compared with the corona discharge. They are highly reactive and often have a high selectivity for chemical processes. The main reason why it is used is because it can provide plasma with useful properties both from thermal plasmas (large electron densities, currents, and power) and non-thermal plasmas (low gas temperature).

A gliding arc is usually generated between two diverging electrodes typical in a gas flow [1]. The discharge ignites at the shortest distance between the electrodes (few millimeters). Typical breakdown voltages are a few kilovolts. The formation of hot quasi-thermal plasma corresponds with a decrease in voltage and strong increase in current. Owing to the gas flow (or in absence of the gas flow due to thermal buoyancy) the discharge moves upward and the length of the plasma column increases. This increasing length causes an increase of the heat losses in the column, which exceeds the input energy of the power supply. The quasi-thermal plasma converts into a non-thermal plasma corresponding with a decrease in current and increase in voltage due to the increasing resistivity of the plasma. Eventually, the plasma extinguishes as the power supply cannot maintain such a long plasma column. At this point the recombination of the plasma starts and a re-ignition of the discharge occur at the minimum distance between the electrodes. This causes the self-pulsing nature of the GAD, which is always clearly visible in current–voltage waveforms and typically occurs on $10\ ms$ on the timescales.

GAD has been studied for combustion, gas cleaning, and production of syngas [2], and water treatment [3, 4]. Gliding arcs can also be magnetically stabilized [5]. More details about the physics of gliding discharges can be found in the review papers by [2].

Gliding arc is a new technology of non-thermal plasma. In recent years, a number of researchers are paying increasing attention on this new technology for environmental protection. It was demonstrated that gliding arc plasma efficiently destructed volatile organic compounds (VOCs) (higher than 90%), NO_x, SO_x [6]. The research given by [7-8] indicated that phenol in solution can be degraded by gas-liquid gliding arc discharge. This kind of source of high energy electrons without heating the plasma gas in the whole volume of plasma reactor chamber is essential for typical plasma chemistry applications.

II. EXPERIMENTAL SETUP

The gliding arc experiment consists of two identical electrodes made of copper each with length $44\ mm$, width $26\ mm$, thickness $15\ mm$ and arc angle 120^o. The gap between two electrodes a few millimeters, connected to AC power supply through step up transformer. The gas was injected from narrow tube located from narrow gap between two electrodes. The two electrodes and the gas pipe were located inside glass bottle.

Figure 1, indicates the electrical scheme of gliding arc discharge.

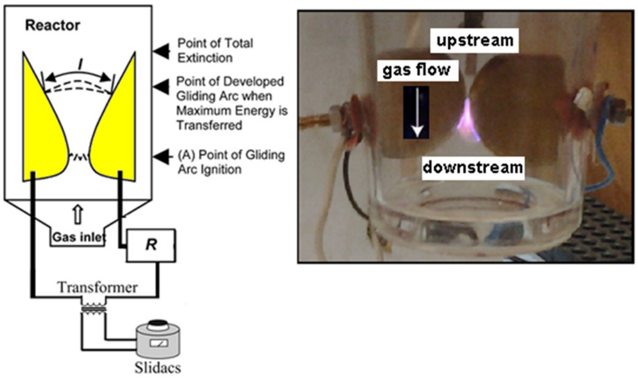

Fig. 1 A schematic diagram of gliding arc and the electric scheme. Photo image of GAD.

The gases used for the experiment were argon and nitrogen. However, the atmosphere gases were mixed these gases since the electric discharge domain is not sealed. Gas flow rate was controlled from 5 $SCHF$ to 50 $SCHF$ by the pressure regulator, where, $SCHF$ is the standard cubic feet per hour. Discharge

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voltage was controlled by the voltage slide regulator and increased by using the high voltage transformer (30: 1), and then high voltage was applied to the electrodes. Therefore, the frequency of electric discharge is 50 Hz. Discharge current was measured using the clamp current probe.

III. EXPERIMENTAL RESULTS

The current flowing through the gas was measured by using A Rogowiski coil and for measurement of the voltage in the GAD; a resistive voltage divider was used. The discharge current increased with increasing gas flow rate, as shown in Fig 2. This may be due to promotion of gas ionization by the gas flow rate increasing. In this experiment, high electric power was supplied to the 1 mm gap electrode. Therefore, ionization is promoted with increase in gas flow and electron density increased (argon gas) and then discharge current may increases. Nitrogen gas has high internal energy over argon due to the dissociation reaction in the N_2 prior to ionization [9].

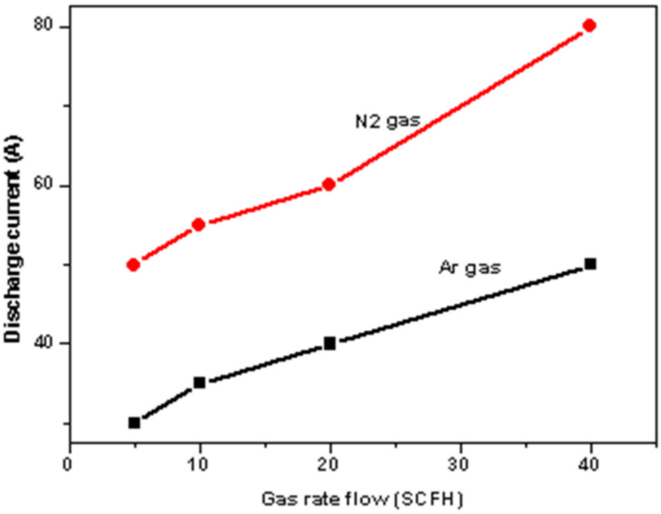

Fig. 2 Discharge current for different gases and flow rates.

The process of plasma formation of a two-atom gas differs from the process of plasma formation of a one-atom gas. The difference consists in the fact that the ionization of two-atom gas start after dissociation of its molecules. Nitrogen dissociates at a temperature of about 8500^oK [10]. Differing enthalpy and plasma temperatures are other important distinctions between the one-atom (argon) and two atom (nitrogen) gases.

Nitrogen at 8000^oK has an enthalpy five times higher than argon [11], since the energy gained by the one-atom gases in the plasma column is given by the specific heat and ionization energy, while in two-atom gases, in addition, the great volume of energy is obtained from the dissociation of molecules into atoms.

In nitrogen [11]:-

$$N_2 \leftrightarrow 2N \text{ (9.764 eV)}$$

$$N \leftrightarrow N^+ + e \text{ (14.54 eV)}$$

$$N^+ \leftrightarrow N^{++} + e \text{ (29.6 eV)}$$

In argon [12]:-

$$Ar \leftrightarrow Ar^+ + e \text{ (15.76 eV)}$$

$$Ar^+ \leftrightarrow Ar^{++} + e \text{ (27.64 eV)}$$

The picture and oscillograms of discharge current of gliding arc discharge for different discharge voltage at 20 $SCHF$ in nitrogen gas flow rate is shown in Fig. 3. As the result, it seems that two discharge domains exist in the upstream and downstream sides along with a gas flow. In the upper-stream side, emission intensity was strong and it increased with increasing discharge voltage. In addition, electric discharge area is small and it was increased with increasing the discharge voltage. On the other hand, emission intensity is weak and electric discharge area is large in the downstream side.

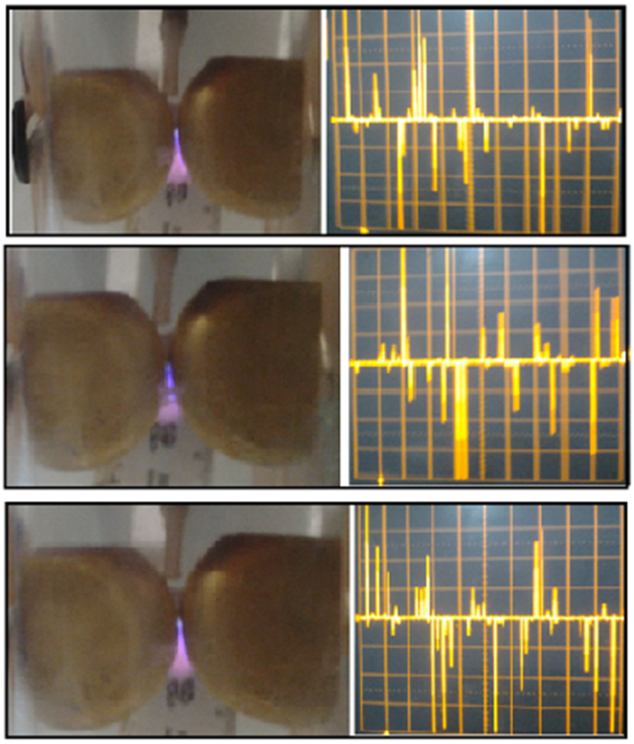

Fig. 3 The picture and oscillograms of discharge current (5 ms per division) of GAD for different discharge voltage at 20 $SCHF$ in nitrogen gas flow.

Figure 4 shows the photograph and oscillograms of discharge current of gliding arc for different nitrogen gas flow rate at 3.3 kV discharge voltage. With increasing the gas flow rate, emission intensity increased in the upper-stream side. On the other hand, electric discharge area increased with increasing gas flow rate in the downstream side. These results suggest that the upstream area is a positive column of the main arc discharge which can be controlled by discharge voltage, and downstream domain is a plasma jet plume which exists across between electrodes that depend on the gas flow.

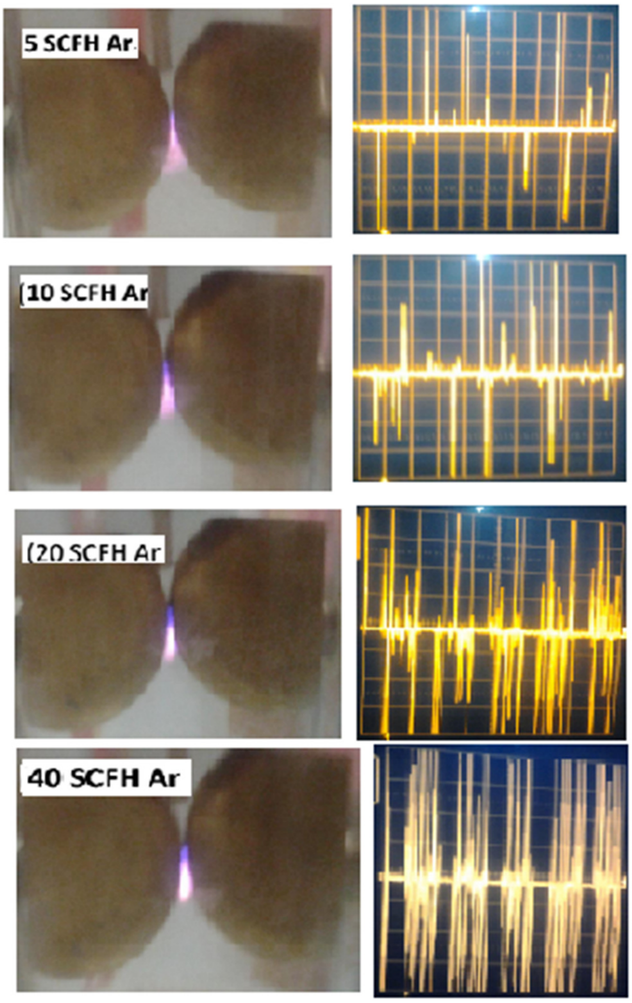

Fig. 4 The photograph and oscillograms of discharge current (5 ms per division) of gliding arc for different argon gas flow rate at 2.7 kV discharge voltage.

Also, Fig. 5 shows the photograph and oscillograms of discharge current of gliding arc for different argon gas flow rate at 2.7 kV discharge voltage.

The electron temperature T_e can be roughly calculated using Einstein's equation of electrons in argon and nitrogen [13].

$$\frac{k_B\,T_e}{e}=\frac{D_e}{\mu_e}$$

where, μ_e , k_B, and D_e are the electron mobility, Boltzmann constant, electron diffusion constant, which is expressed as a function of E/N. The electric field E is estimated to be $2.7\,kV/cm$, for the gap of $1\,mm$, showing $E/N = 1.1\times 10^{-15}\,V.cm^2$ for $N = 2.5\times 10^{19}/cm^3$. The ratio of the diffusion coefficient to the electron mobility is calculated to be $D_e/\mu_e = 1.74\,V$ for $E/N = 3.91\times 10^{-16}\,V.cm^2$ in argon [10]. Thus the electron temperature for argon plasma is estimated to be about $1.9\,eV$ and for nitrogen plasma approximately $0.7\,eV$.

The averaged electron density, n_e, can also be estimated [10] from the equation;

$$n_e=\frac{J}{eE\mu_e}$$

This equation contains the electrical parameters of the discharge, the electric field E, the current density J, and the electron charge e. Consider that for argon plasma at one atmosphere, the electron mobility μ_e has a value of $434.2\,cm^2/Vs$ for $\mu_e P = 0.33\times 10^6\,cm^2Torr/Vs$, where, P is the pressure[10]. The current density J is about $50\,A/cm^2$ at flow rate $5\,SCFH$ between the two electrodes. Eventually, the peak electron densities for argon and nitrogen at the same rate of flow, $40\,SCFH$, are estimated to be $9.7\times 10^{13}/cm^3$ and $8.49\times 10^{13}/cm^3$ respectively. Figure 6, shows an electron density of argon and nitrogen plasmas in GAD at different gases flow rate.

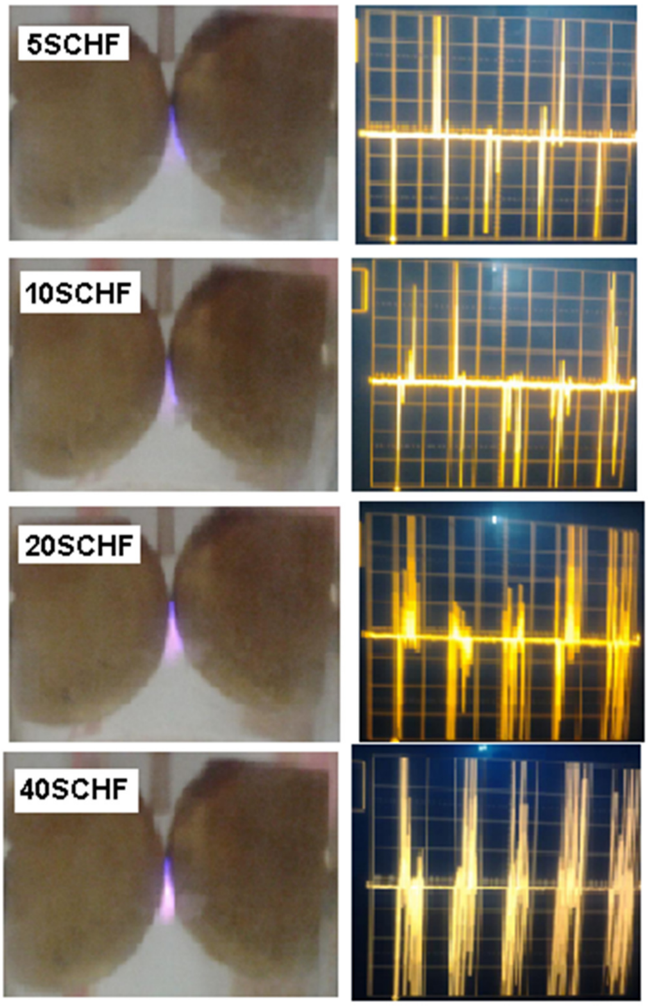

Fig. 5 The photograph and oscillograms of discharge current (5 ms per division) of gliding arc for different argon gas flow rate at 2.7 kV discharge voltage.

The discharge current increased with increasing gas flow rate (Ar and N_2). This may be due to promotion of gas ionization by the gas flow rate increasing. In GAD, high electric power density was applied to the gap electrode. Therefore, ionization is promoted with the increase in a gas flow and electron density increased, and then discharge current may increases.

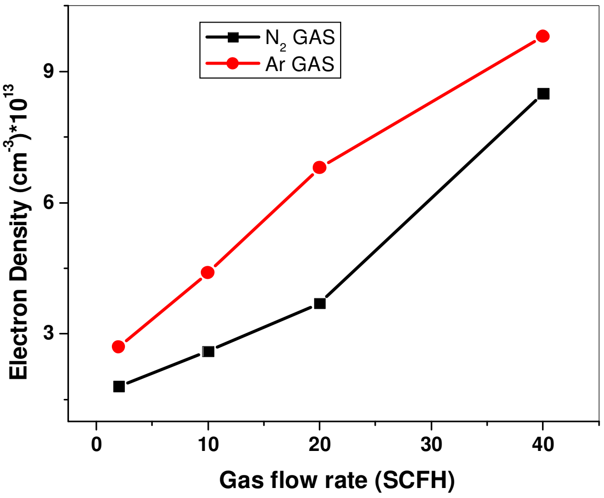

Fig. 6 Electron density as a function of argon and nitrogen gases flow rate.

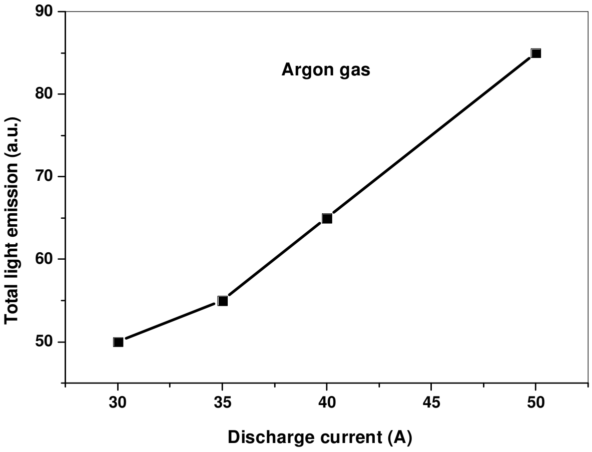

Fig. 7 Light emission of argon as a function of discharge current.

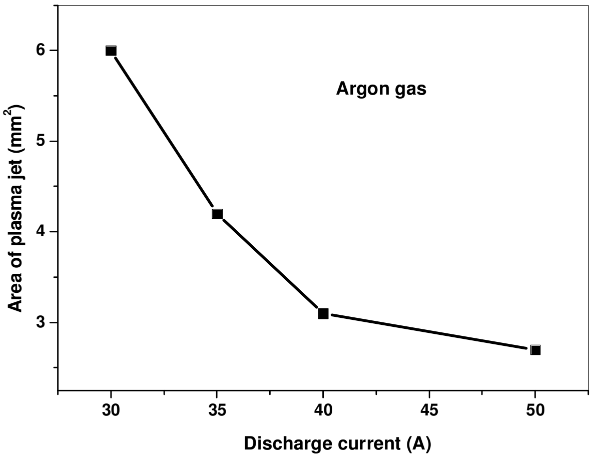

Fig. 8 Dependence of the plasma jet plume of argon gas on discharge current.

Figure 7 shows the total emission of light of argon gas as a function of discharge current. With increasing the discharge current, emission intensity of light increased in the downstream side. In addition, plasma jet plume area is large and it was decreased with increasing the discharge current in the downstream side as shown in Fig. 8.

IV. CONCLUSION

One can see that, at gas flow rate greater than 10 SCFH, an electron density of argon plasma (mono-atomic gas) greater than nitrogen plasma (diatomic gas) because of the presence of negative ions in nitrogen plasma, the number of electrons is smaller in this case, which leads to the increase in discharge voltage of nitrogen in comparison with the argon plasma. Because of nitrogen an electronegative gas, the electron density number becomes smaller, decreasing electron density leads to increasing resistivity.

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