Characterization of an Atmospheric-pressure Cold Plasma Jet

G. M. Elaragi, H. S. Elaraby

***Abstract*— Cold atmospheric pressure plasma jets are playing important role in various plasma applications. Each jet is characterized by providing its operational parameters such as power, type of gas, plasma temperature and density, electrode system and geometrical jet (radius, length). The velocity of the plasma jet has been observed by time of flight (TOF) using optical fiber cable and Photomultiplier tube, the measured average plasma velocity is about 10^6 cm/sec.**

***Index Terms*— jet velocity, plasma, power, temperature**

I. Introduction

Atmospheric Pressure plasma Jets (APPJ) is commonly subdivided into thermal and non-thermal plasmas. Thermal plasmas are in local thermal equilibrium where the heavy particle temperature is close to the temperature of electrons. Inelastic collisions between electrons and heavy particles create plasma reactive species whereas elastic collisions heat up the heavy particles [1]

APPJ can be generated through a number of configurations, generally using mono-atomic and diatomic gases. The APPJ are suitable for industrial and research applications, such as surface modification, biological material sterilization, biomedical applications (dermatological, dental, etc.), ozone formation and treatment of heat-sensitive materials [2]. In general, APPJ is produced between planar or tube-type shape electrodes and the gas flow expulsion the plasma into the ambient air, strongly reducing the gas temperature (much lower than the electron temperature) allowing several other applications [3].

Non-thermal APPJ have been extensively investigated due to their low-temperature properties and controllability of various agents such as radicals, ions, UV and electric fields, making them suitable for a wide range of biomedical applications such as sterilization [4,5].

Non-thermal plasmas, operated at ambient atmospheric pressure and temperature, are very efficient sources for the production of highly reactive neutral particles, for example, reactive oxygen and nitrogen species (RONS) (such as atomic oxygen, atomic nitrogen, hydroxyl radical, superoxide, singlet delta oxygen, and nitrogen oxides), charged particles, UV-radiation, and electromagnetic fields.

An APPJ can provide a local treatment with a relatively high density of charged particles and RONS since the length of the plasma plume (bright region) from the opening of the APPJ can be several centimeters. Even short-lifetime species such as atomic oxygen can therefore be involved in reactions with the target. Furthermore, a very precise treatment is possible and owing to the high gas velocity, penetration of the plasma components into small cavities can be achieved [6]. The application of several APPJ next to each other is also possible to enlarge the treatment area. However, the plasma composition (i.e., plasma chemistry) of the multiple jet arrangement will be influenced by each jet, which hits a nearby-situated plasma stream.

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II. Experimental Set-up

The plasma generator is consisting a negative DC source, Blumlein-type pulse-forming network (E-PFN) and a dynamic spark gap switch. A triggered spark gap switch was used as a closing switch of E-PFN. The APPJ is consists of 4 inductor, each inductor equal 5µH and 5 capacitor each capacitor equal 5nF. A charging resistance value of 100k Ω is chosen in the present case which corresponds to a charging RC time constant of 1.0ms. A schematic of the pulsed atmospheric-pressure plasma jet (APPJ) discharge and of the experimental set-up is shown in Fig. 1. The gas is fed through an annular region between the two metal electrodes 15 cm in length. The inner electrode is 5 mm in diameter and is powered with a pulsed high voltage power supply, while the grounded outer electrode is separated from the inner electrode by a gap of a few millimeters. The APPJ device operates using 5-20 kV power supply with a gap between two electrodes of 2-3 mm under atmospheric pressure [7]. The spark gap between rotating grounded electrode and fixed high voltage electrode is adjusted at required breakdown voltage. Hence the gap gets triggered in each rotation, which gives the repetition frequency of order 25 Hz (pulses/s). As the voltage on the capacitors reached the spark-over voltage of the spark gap electrode, the capacitors discharged, producing a high voltage pulse.

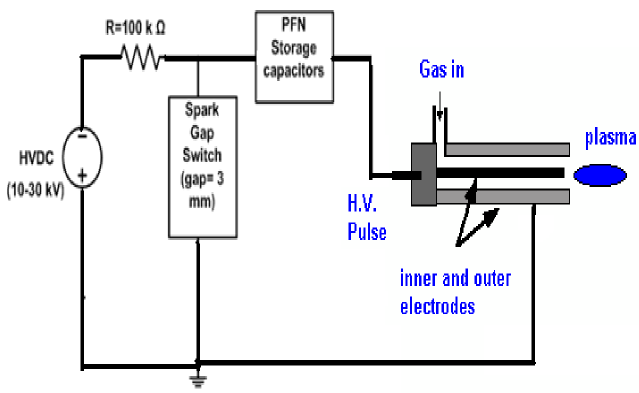

Figure (1): A schematic of the APPJ discharge

III. Results and Discussion

A Lecroy 200 MS/s 4-channel digital storage oscilloscope model (9304c) was used to recorded voltage and current waveforms, via a high voltage probe and a pulse current transformer, respectively. A typical oscillograph of discharge current and voltage pulse using was shown in Figure 2. A capacitor bank (25 nF) charged at 6 kV giving peak discharge current of about 188 A and 184 A for nitrogen and argon plasma jet respectively. The total inductance of the circuit and plasma about 16 μH.

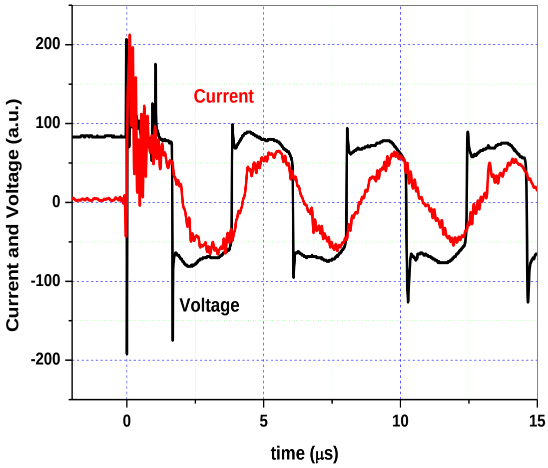

Figure (2): Current-voltage characteristics of pulsed plasma jet

Plasma jet Velocity Measurements

Figure (3) show velocity of plasma by using of photomultiplier (IP28 PCA).

Were v=8kv , From this figure there is two signal at different distance and different time. One signal at d=21cm , t=80 μsec And the other at d=1cm , t=60 μsec The different distance between two signal Δd=20cm ,The different time between two signal $\Delta t=20 \mu sec$

$V=\frac{\Delta d}{\Delta t}$ Were(v) is velocity of plasma $V=\frac{20}{20\times10^{-6}}$; $V \approx 10^6 cm/sec$

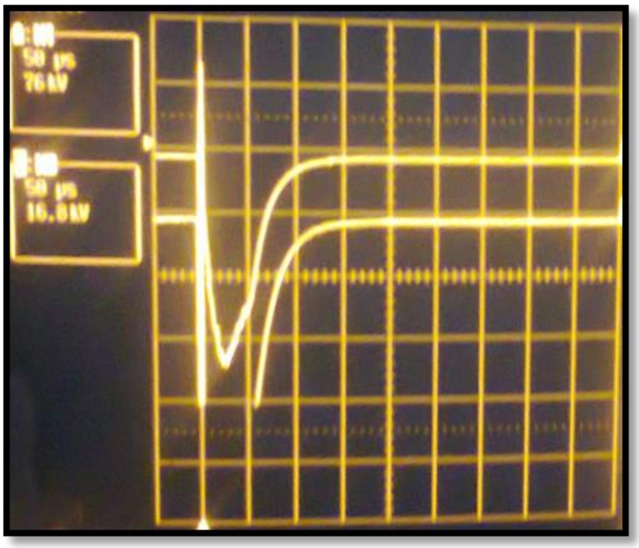

Figure (3): velocity of plasma by using of photomultiplier (IP28 PCA)

The plasma velocity is measured via a fiber cable that is interfaced to the PMT system. The signals are taken and measured at two locations 1 cm, 21 cm from the plasma source. The change in the velocity of each signal is due to the kinetic energy of particles entering and leaving the plasma source. The average velocity of the plasma jet was about 10^6 cm/sec.

Table 1 indicate the molecules bond type and related dissociation and ionization energies The ionization energy required for molecular gas (nitrogen) and inert gas (argon) are nearest from each other with values of 14.54 and 15.76 electron volt respectively [10].

Table 1 molecules bond type and related dissociation and ionization energies [9]

Gas	Bond type	Dissociation energy(eV)	Ionization energy(eV)
N_2	Triple	9.8	14.54
Ar	Van der waals	Weak values	15.76

Electron density (n_e)

The averaged electron density(n_e) can be calculated from the following equation, [8],

$$n_e=J/(e\,E\,\mu_e) \quad (1)$$

The above equation can be rewritten as follows

$$n_e = J/(\mu_e p \times (E/P) \times e) \quad (2)$$

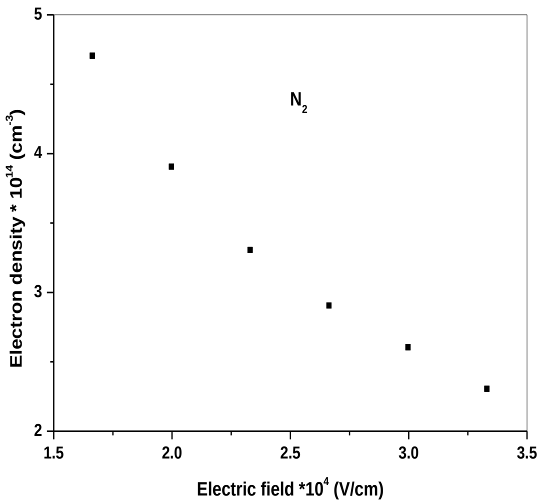

Figure (4): Electron density of molecular gas (nitrogen) as a function of E-field.

The nitrogen has an electronegative characteristics gas, therefore the electron density number becomes smaller and decreasing electron density leads to increasing resistivity, see table 3 for a comparison between (Ar) and (N_2) gases.

Figure (4) and figure (7) indicates the electron density of molecular gas (nitrogen) and inert gas (argon) as a function of electric field between two electrodes. The electron density decreased with increasing electric field for two gases.

In the interval between two collisions, an electron is accelerated along the line of force of the electric field E. A collision changes the direction of motion sharply and in a random way, after which the electron is again accelerated, etc. Encounters of charged particles are rare in a weakly ionized gas; electrons mostly collide with neutral molecules. The systematic motion along the direction of the external force amid the random motion background is known as drift. A consistent approach to calculating the drift velocity is based on analyzing the kinetic equation for the electron velocity distribution function. This approach shows how to average a formula of type (3) correctly. It is found that the assumption of the independence of the effective collision frequency on velocity.

$$v_d = -eE/m\nu_m \;;$$

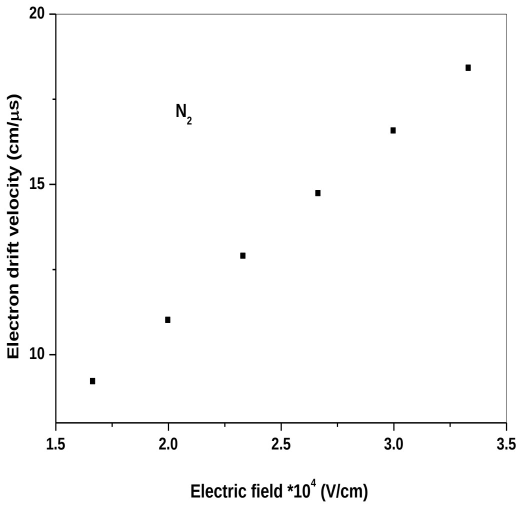

Figure (5): Drift velocity of molecular gas (nitrogen) as a function of E-field.

Figure (5) and figure (8) shows the electron drift velocity of molecular gas (nitrogen) and inert gas (argon) as a function of electric field between two electrodes. The electron drift velocity increased with increasing electric field for two gases. The mobility of massive ions is hundreds of times less than for light electrons. The contribution of ions to electric current is thus small, except in those rare cases when the ion densities n_+, n_- exceed by an appropriate number of times the electron density (n_e). The current density j and conductivity σ in plasma with $n_e \approx n_+$ are

$$j = -en_e v_d = en_e \mu_e E = \sigma E \,,$$

$$\sigma = e\mu_e n_e = \frac{e^2 n_e}{m\nu_m} = 2.82 \cdot 10^{-4} \frac{n_e[\mathrm{cm}^{-3}]}{\nu_m[\mathrm{s}^{-1}]} \mathrm{Ohm}^{-1}\,\mathrm{cm}^{-1}$$

Figure (6) and figure (9) indicates the conductivity of molecular gas (nitrogen) and inert gas (argon) as a function of electric field between two electrodes. The conductivity of plasma jet decrease with increasing electric field for both gases.

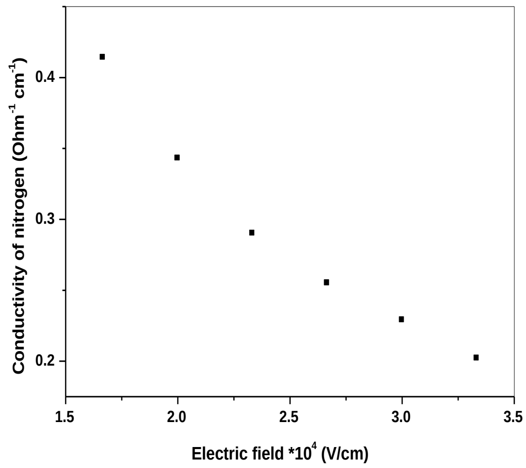

Figure (6): Conductivity of molecular gas (nitrogen) as a function of E-field.

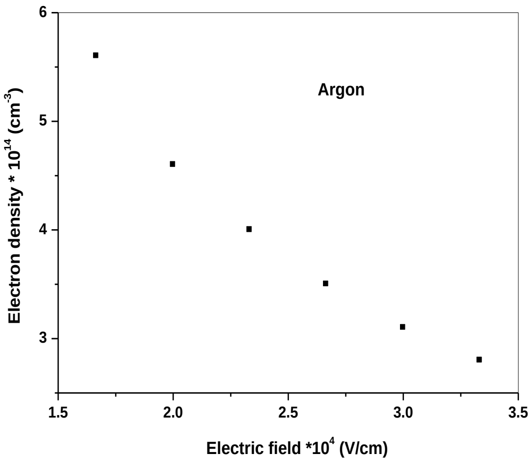

Figure (7): Electron density of inert gas (argon) as a function of E-field.

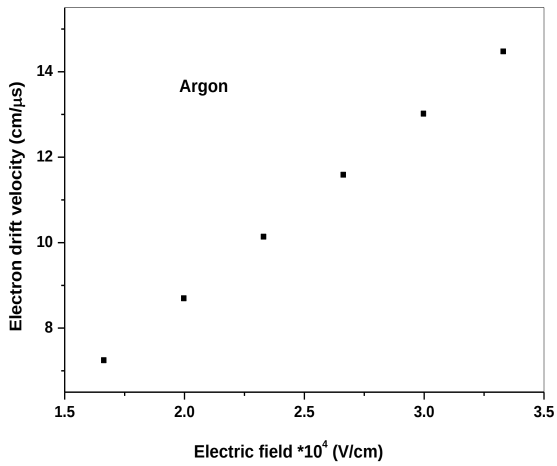

Figure (8): Drift velocity of inert gas (argon) as a function of E-field.

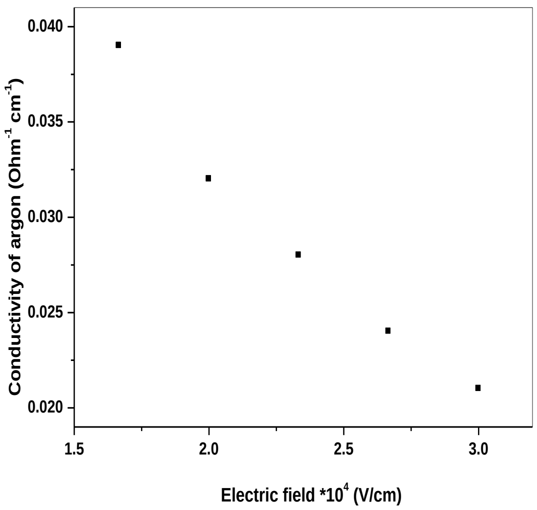

Figure (9): Conductivity of inert gas (argon) as a function of E-field.

IV. CONCLUSION

The measurements of plasma light at very near from the nozzle shows that the pulse width is about 40 µs for N_2 plasma and 48 µs for argon plasma, but the tail is longer (several hundred microseconds). The average velocity of the plasma jet was about 10^6 cm/sec. The conductivity of plasma jet decrease with increasing electric field for both gases (argon and nitrogen).

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