Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 7, 2021, Pages. 1524 - 1533
Received 05 May 2021; Accepted 01 June 2021.

Comparison of the Characteristics of Atmospheric Pressure Plasma Jets Using Different Applied Voltage and Gas Flow

Ghaith H. Jihad, Kadhim A. Aadim
Department of Physics, College of Science, University of Baghdad, Iraq
E-mail: ghaith.jihad1104@sc.uobaghdad.edu.iq , kadhim_adem@scbaghdad.edu.iq

Abstract
The design of atmospheric plasma jet is basically using the combination of Ar-gas, different Needle diameters size, potential difference and a good dielectric material. In this work, we used Teflon tube as a dielectric material with different needle diameter size to investigate the effect on the plasma discharge. We studied the changes of plasma discharge by observing the discharge lengths ,applied voltage and the spectrum of Ar-gas. We introduced a gas flow rate of 5 L/min and maximum Needle diameter of dielectric material of 2.75 mm. Results showed that the discharge length are capable of reaching 3 cm for large needle while for medium needle the length of plasma jet is 1.75mm and at last for small needle size the plasma jet length is 1 cm and having various excited plasma species shown through optical emission spectrum.

Keywords: Atmospheric plasma jet, L.N. (Large Needle), M.N. (Medium Needle), S.N. (Small Needle), optical emission spectroscopy (OES), reactive species

Introduction
Atmospheric plasma [1] is plasma with a pressure that is close to that of the surrounding atmosphere. Surface modification, bacterial inactivation, food processing, dentistry, and medicinal applications are only few of the uses for atmospheric plasma. There are many distinct types of plasmas that may be created depending on the application. The plasma can be set up in a variety of ways. A combination of noble gases, potential difference, and a suitable dielectric material has recently been created to create an atmospheric plasma jet. Ionized gas is created at atmospheric pressure and room temperature by allowing the gas to flow in a tiny tube with a greater voltage applied to the area [1]. Helium, argon, and nitrogen are some of the most frequent gases utilized in plasma generation. This is because when they are operated in an open way, they do not affect the environment or the human body [1].

In general, free radicals, such as the reactive oxygen species found in plasma, can have a variety of consequences. Reactive species produced by electron impact excitation and dissociation in non-equilibrium plasma discharges at higher pressures play an essential role in germicidal properties [2]. Plasma excitation produces both reactive oxygen species (ROS) and reactive nitrogen species (RNS). The cell structure, including lipids, proteins, and DNA, would be harmed by excessive generation of ROS and RNS [2].

Optical emission spectroscopy may be used to identify the reactive species (OES). The light released by the de-excitation of atoms, molecules, ions, and radicals that were previously excited and generated in the plasma discharge is captured by the OES [3]. A spectrometer is a device that may be used to measure plasma's spectrum. The spectrometer is made up of a monochromatic and many components that divide or separate and transmit a limited piece of the optical signal from a larger range of wavelengths accessible at the input [3].

The fiber optic focuses the light released by the plasma onto the screen. Fibre optics are used to transport radiation or pictures from one component to another [3]. The wavelength value at each peak was used to identify the reactive species. The presence of additional peaks indicates the presence of more reactive species.

The presence of reactive species in the plasma contributes to cell death, therefore an atmospheric plasma jet can be employed in a variety of medicinal applications, such as inactivating cancer cells. The purpose of this article is to investigate the influence of different dielectric material inner diameter sizes on the length of plasma discharge in plasma production. Following that, the plasma discharge composition is investigated utilizing the optimum inner diameter size for plasma setup. Plasma production will be optimized as the length

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of plasma discharge and plasma composition increase. The relationship between plasma discharge length and plasma composition is also investigated.

Methodology

Figure 1 illustrates the work steps for this research.

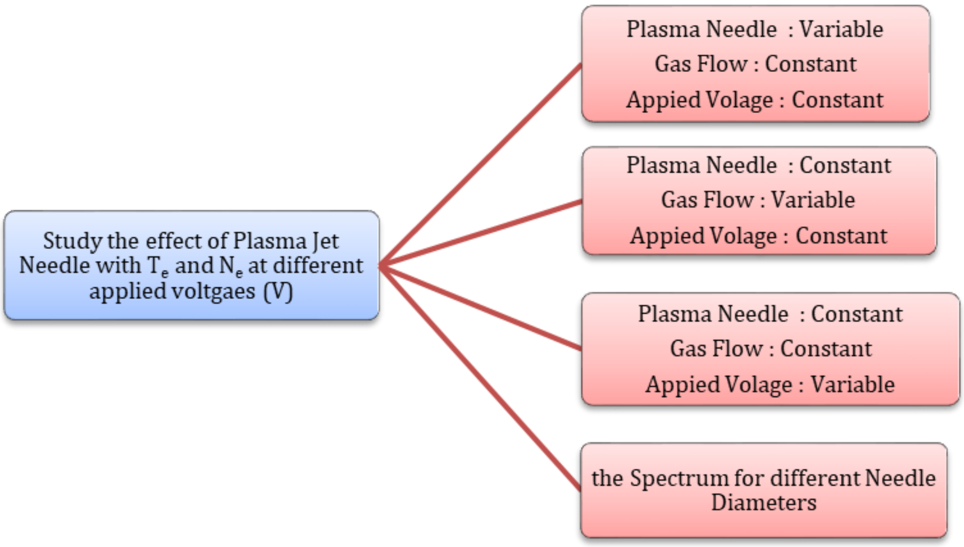

Figure 1: Diagram of the experimental frame work of the plasma jet

Atmospheric plasma jet set up

A dielectric material is one of the requirements to set up the atmospheric plasma jet. Choosing different Needle size of dielectric material gives different effect on the plasma discharge. It will change the length of the plasma discharge. This experiment used a Teflon tube as the dielectric material. Three different diameters of Needle tubes which are 0.75, 1.75 and 2.75 mm shown in **Figure 2** will be used to compare the length of plasma discharge. The diameters of Needle will be measured the size of Needles using VERNIER CALIPERS shown in Figure 3. Plasma parameters such as Ar-gas used and different of flow rate of gases used will also be varied to get an optimize plasma generation.

(a) **(b)** **(c)**

Figure 2 Example of different Needle diameter size, a) Small Needle (S.N.) with diameter =0.75mm, b) Medium Needle (M.N.) with diameter =1.75mm, c) Large Needle (L.N.) with diameter =2.75mm

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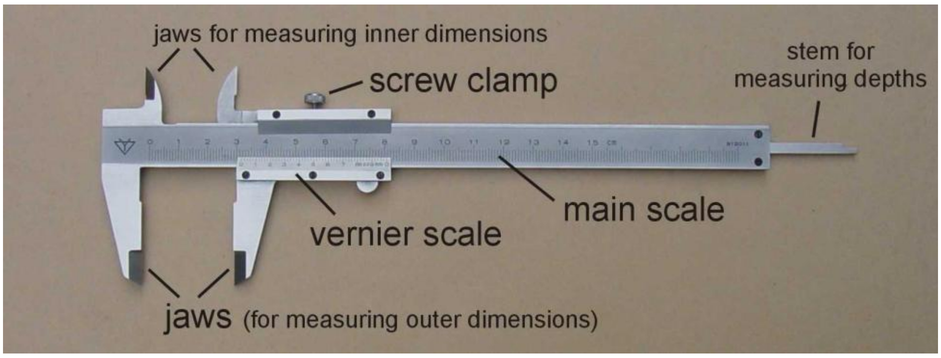

Figure 3 Dimensional Measurement using Vernier Calipers

Measurements length of plasma discharge

The length of plasma discharge was measured starting from the mouth jet to the last tip of plasma discharge. The last tip of plasma discharge was recorded until it reached at the maximum time used which is 1 min. The reading was repeated for 5 times to show its consistency. The measurement length of plasma discharge is shown in the **Figure 4**.

Figure 4 Plasma Jet Length Measurement (Handmade)

Table 1 shows the length of plasma jet for different Needle Diameter at different gas flows:-

Argon Gas Flow (L/min)	Plasma Jet Length (cm) L.N.	Plasma Jet Length (cm) M.N.	Plasma Jet Length (cm) S.N.
5	3	1.75	1
4	2.6	1.6	0.9
3	2	1.5	0.6
2	1.6	1.3	0.5
1	1.4	1.1	0.3

The variation of plasma jet length with different gas flow is shown in the **Figure 5**.

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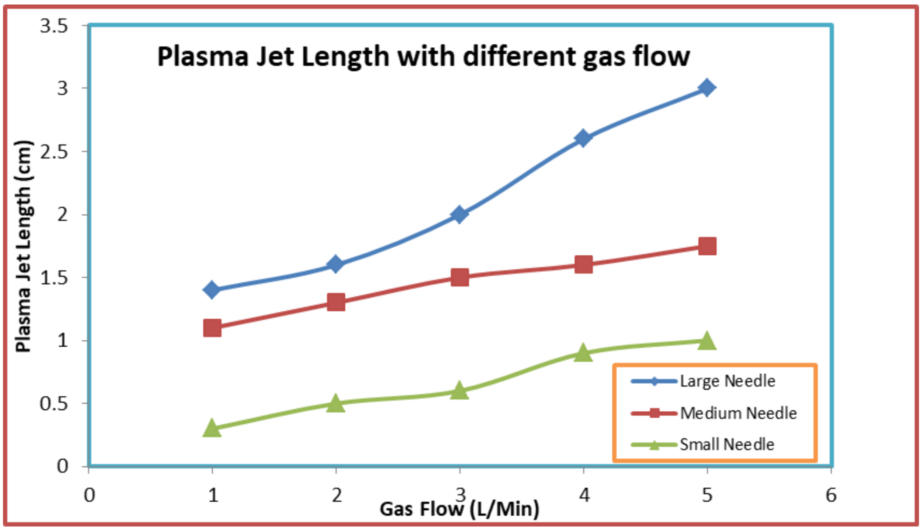
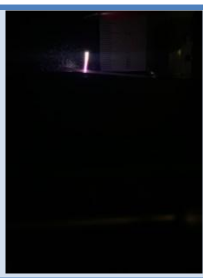
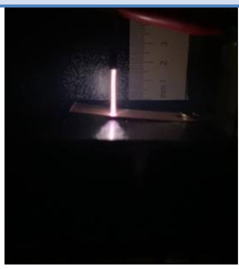
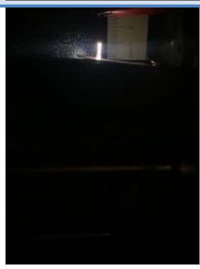
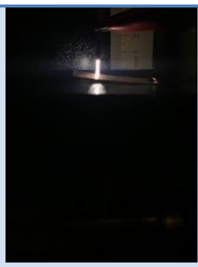
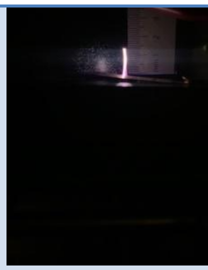


Figure 5 Plasma Jet Length V.S. different gas flows

The following figure 6 represent the plasma jet length images during measuring for different Needle gas at different gas flow with time during the time 1 min.

Gas Flow (L/Min)	Large Needle 2.75 cm	Medium Needle 1.75 cm	Small Needle 0.75 cm
1			
2			
3			

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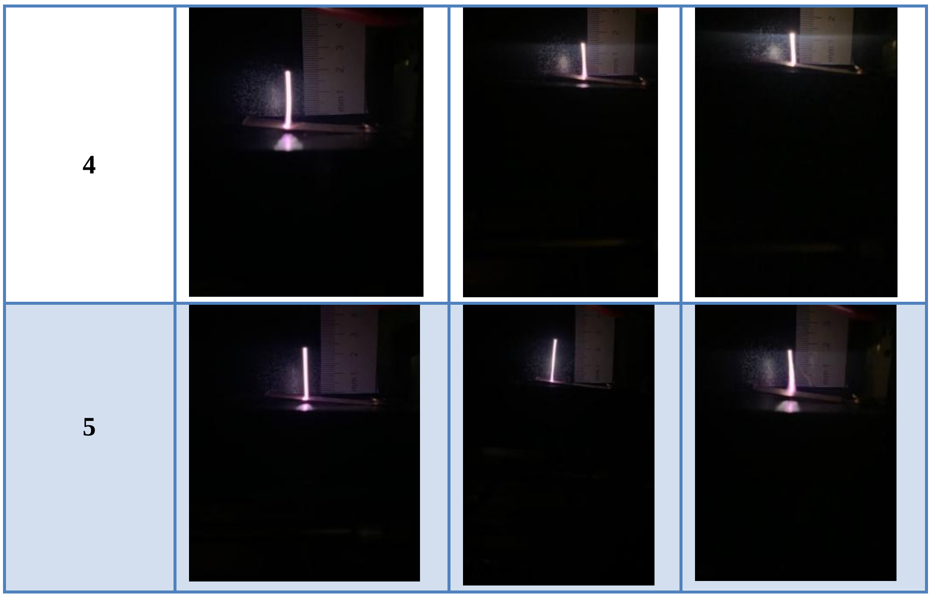

Figure 6 Images for different Needles Diameters

Gas Flow (L/Min)	Applied Voltage (V) L.N.	Applied Voltage (V) M.N.	Applied Voltage (V) S.N.
1	830	650	530
2	910	700	570
3	1100	740	610
4	1240	780	660
5	1360	800	700

Measurements the effect of the Diameters of plasma Needle with Applied Voltage

We shows that when we change the gas flows with Different Needle Diameter the output Voltage will change and can be measured using the High Probe Voltage , the Table 2 represent the measuring of Applied Voltage with different Gas flows at different Needle .

Table 2 shows the Applied Voltage for different Needle Diameter at different gas flows:-

The variation of Applied Voltage with different gas flow is shown in the **Figure 7**.

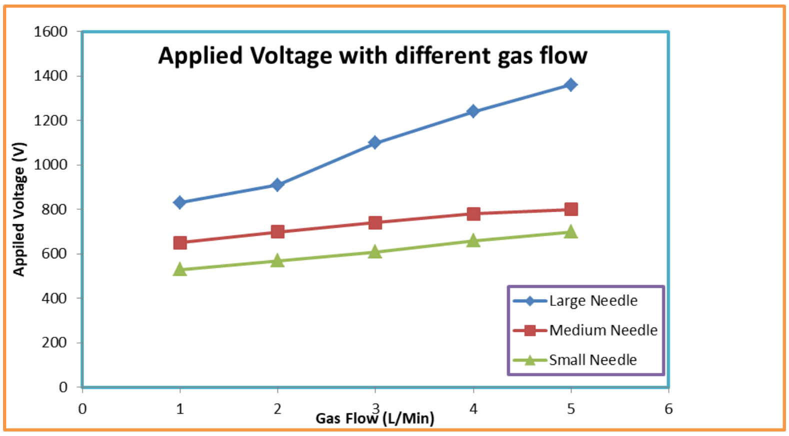

Figure 7 Applied Voltage V.S. different gas flows

Table 1 and 2 shows the measurement of the plasma jet length and applied voltage at different gas flows using the different Needle diameter tube, Ar-gas used and flow rate of gas used. The flow rate of gas used

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which are 1 to 5 L/min was chosen based on the minimum and maximum suitable flow rate gas for plasma generation using atmospheric plasma jet.

Atmospheric plasma was produced by combining the high voltage and a gas flowing into Needle tube. Generating atmospheric plasma is different for each gas. The length of plasma discharge was varied for every Needle diameter size tube used. Regardless the Ar-gas used large diameter (L.N.), 2.75 mm, the maximum length of plasma discharge is 3 cm for flow rate 5 L/min and 1.4 cm for flow rate 1 L/min.

For inner diameter size (M.N.) of 1.75 mm, the length of plasma discharge at 5 L/min flow rate of Argon used equal to 1.75 cm while at the gas flow 1 L/min is equal 1.1 cm. For third inner diameter size (S.N.), 0.75 mm, initially the length of plasma jet is 1 cm at flow gas 5 L/min and the length at 1 L/min is equal 0.3 cm. Then, after the discharge stabilizes, the discharge narrows down and increased length. Their length was recorded after plasma discharge achieves its stability.

When Applied voltage measuring using High Voltage Probe the largest inner diameter size (L.N.), has reached the maximum Applied Voltage is 1360 V at 5 L/min of Argon flow rate of gas used. While at 1 L/Min the Voltage equal 830 V and so on for M.N. for gas flow from (5-1)L/min the applied voltage (800-650)V respectively and for the small Needle at gas flows(5-1)L/min the Voltage is (70-530) V .

Optical Emission Spectroscopy (OES)

A SUWRIT-S3000 spectrometer device was used to evaluate the emission characteristics of the atmospheric plasma jet. This device has high resolution, within the range of 200 nm to 1100 nm. This spectrometer was connected to a fiber optic (F600-Y-UV-SR-NIR), to collect the spectrum from the light of the plasma, and then transfer it to the spectrometer. The Spectra (V 3.3) software was used to analyze the spectrum graph [3].

The results, depicting the relative intensity of the emission peaks captured by spectrometer, help to identify the reactive species present in the plasma, based on the wavelength, which is plotted on the x-axis. The fibre optic of the spectrometer was placed near the plasma plume at the static distance, d, as shown in **Figure 8** and the measurements were taken for the working gas during different operation. The distance between the fiber optic and the plasma was 5 mm.

The peaks of the spectral bands represented the reactive species or partial species in the plasma. The particle species in the plasma were identified based on the wavelengths. The National Institute of Standards and Technology (NIST, http://www.nist.gov/pml/data/asd.cfm) can be used as the reference source for identifying atomic species based on their peaks' wavelengths [3].

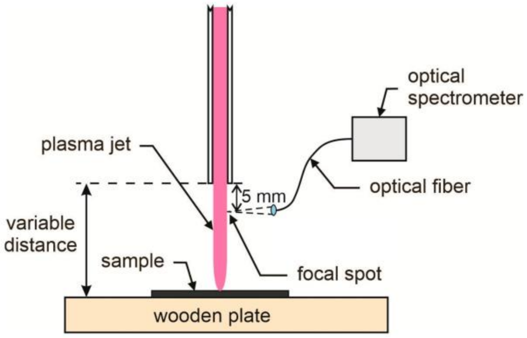

Figure 8 Schematic experimental setup for reactive species measurement by a spectrometer

when we change the gas flows with Different Needle Diameter and different applied Voltage the plsama condition and parameters also change and the Table 3 represent the measuring plasma paramters (T_e ,n_e , f_p , λ_D and N_d).

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Table 3 shows the changing of plsama parameters at constant applied voltages .

Diameters (mm)	Applied Voltage (V)	Gas Flow (L/Min)	T_e (eV)	n_e (cm^{-3})	f_p (Hz)	λ_D (cm)	N_d
Large Needle 2.75mm	1360	4	1.655	1.32E+19	3.3E+13	2.4E-05	8.1E+05
		3	1.521	7.85E+18	2.5E+13	3.0E-05	9.2E+05
		2	1.458	5.97E+18	2.2E+13	3.4E-05	9.9E+05
		1	1.394	4.43E+18	1.9E+13	3.9E-05	1.1E+06
Medium Needle 1.75mm	1360	4	1.473	6.38E+18	2.3E+13	3.3E-05	1.7E+06
		3	1.353	3.61E+18	1.7E+13	4.2E-05	1.5E+06
		2	1.297	2.67E+18	1.5E+13	4.8E-05	1.3E+06
		1	1.174	1.26E+18	1.1E+13	3.7E-05	1.1E+06
Small Needle 0.75mm	1360	4	1.393	4.41E+18	1.9E+13	3.9E-05	1.1E+06
		3	1.281	2.43E+18	1.4E+13	5.0E-05	1.3E+06
		2	1.228	1.78E+18	1.2E+13	5.7E-05	1.2E+06
		1	0.945	1.21E+18	1.0E+13	2.5E-05	8.2E+05

Table 4 shows the changing of plsama parameters at constant gas flows .

Diameters (mm)	Applied Voltage (V)	Gas Flow (L/Min)	T_e (eV)	n_e (cm^{-3})	f_p (Hz)	λ_D (cm)	N_d
Large Needle 2.75mm	410	4	1.201	1.51E+18	1.1E+13	6.2E-05	1.5E+06
	630		1.358	7.90E+18	2.5E+13	2.9E-05	7.7E+05
	860		1.496	7.08E+18	2.4E+13	3.2E-05	9.5E+05
	950		1.499	7.16E+18	2.4E+13	4.2E-05	2.1E+05
	1360		1.655	1.32E+19	3.3E+13	2.4E-05	8.1E+05
Medium Needle 1.75mm	410	4	0.945	3.90E+17	5.6E+12	1.1E-04	2.0E+06
	630		1.086	6.72E+17	7.4E+12	8.8E-05	1.9E+06
	860		1.259	2.14E+18	1.3E+13	5.3E-05	1.3E+06
	950		1.338	3.33E+18	1.6E+13	4.4E-05	1.2E+06
	1360		1.473	6.38E+18	2.3E+13	3.3E-05	1.7E+06
Small Needle 0.75mm	410	4	0.925	3.44E+17	5.3E+12	1.1E-04	2.1E+06
	630		0.990	3.01E+17	4.9E+12	1.3E-04	2.5E+06
	860		1.180	1.31E+18	1.0E+13	6.5E-05	1.5E+06
	950		1.235	1.86E+18	1.2E+13	5.6E-05	1.4E+06
	1360		1.393	4.41E+18	1.9E+13	3.9E-05	1.1E+06

Table 3 and 4 shows the measurement of the plasma parameters at different gas flows and different applied voltage using the different Needle diameter tube, Ar-gas used and flow rate of gas used. The flow rate of gas used which are 1 to 5 L/min was chosen based on the minimum and maximum suitable flow rate gas for plasma generation using atmospheric plasma jet.

Atmospheric plasma was produced by combining the high voltage and a gas flowing into Needle tube. Generating atmospheric plasma is different for each gas. The plasma parameters are measuring shows that the T_e are range from (1.655 – 0.945) eV for the gas flow (1-5) L/min with large needle and n_e (1.32E+19 - 4.43E+18) cm^{-3}, where for the medium needle size the T_e range (1.473 -1.174) eV for the gas flow (1-5)L/min and n_e (6.38E+18 -1.26E+18) cm^{-3} ,finally for small needle size the T_e range (1.393 – 0.945) eV for the gas flow (1-5)L/min and n_e (4.41E+18 -1.21E+18) cm^{-3} .

When the Applied voltage range from (410-1360) V at constant Gas flow = 4 L/min , the Te for L.N , M.N. and S.N. are range (1.201- 1.655) eV , (0.945 – 1.473) and (0.925 – 1.393) eV respectively . While the electron density ne are range for L.N. , M.N. and S.N. ,(1.51E+18 -1.32E+19) cm^{-3} , (3.90E+17 -6.38E+18) cm^{-3} and (3.44E+17 -4.41E+18) cm^{-3} respectively

Composition of the Spectrum of the plasma jet discharge

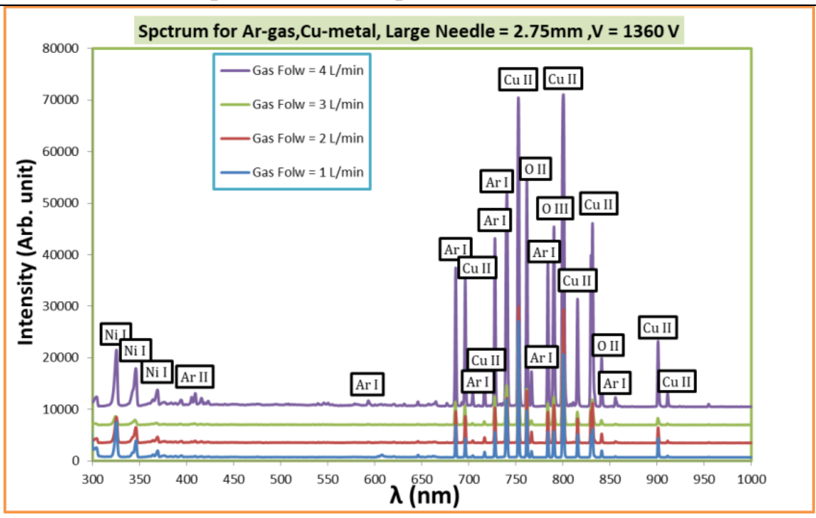
Atmospheric plasma exposure is a complex process, since there were multiple plasma particles such as ultraviolet (UV) excited species, ions or electron and others which can interact with any samples that being treated. The elements present in the atmospheric plasma jet emit certain wavelengths, which can be observed using an OES. An OES was used to investigate the intensity changes for plasma generated reactive species that are believed influence in plasma treatment especially in medical applications.

In the emission spectrum, spectral bands were observed in the ranges from 300 nm to 1000 nm, to investigate the behavior of atoms and molecules and other constituent species. Due to the ionization and excitation that plasma undergoes in an open-air environment, it tends to produce certain types and number of the reactive species [3].

By using the largest Needle diameter size , the elements present in the atmospheric plasma jet emit certain wavelengths. The optical emission spectrum shown in **Table 5** was similar to those collected by several authors studying on the atmospheric plasma at cold temperature L/min flow rate of Ar-gas used.

An emission peak at a wavelength 320 nm was detected, but it is a very small one. The strongest emissions were observed in the 660 to 850 nm wavelength range, with nitrogen molecules dominating. Nitrogen (N2) emission peaks have been observed at 330.5, 335.69, 346.10 and 389.30, while Argon (Ar) emission peaks at 587.81 and 684.91 nm. Oxygen molecules (O2) were observed at 754 nm and 785 nm [9-12]. So that, many researchers had suggested to use the Argon gas in atmospheric plasma set up for cancer treatments.

Table 5 Optical emission spectrum.

<table>
<tr><th>Different Needle Size</th><th>Optical emission spectrum at V= 1360 V</th></tr>
<tr><td>Large Needle 2.75mm</td><td>
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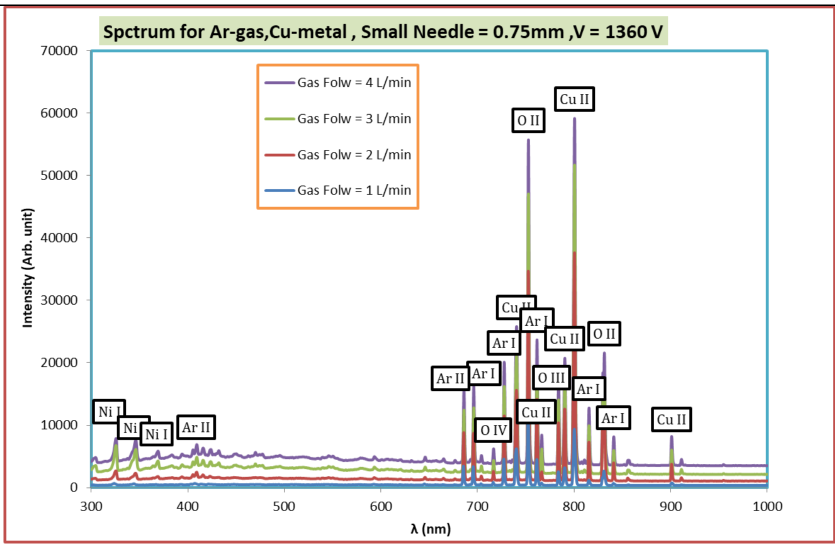
<table>
<tr><td>Medium Needle 1.75mm</td><td>
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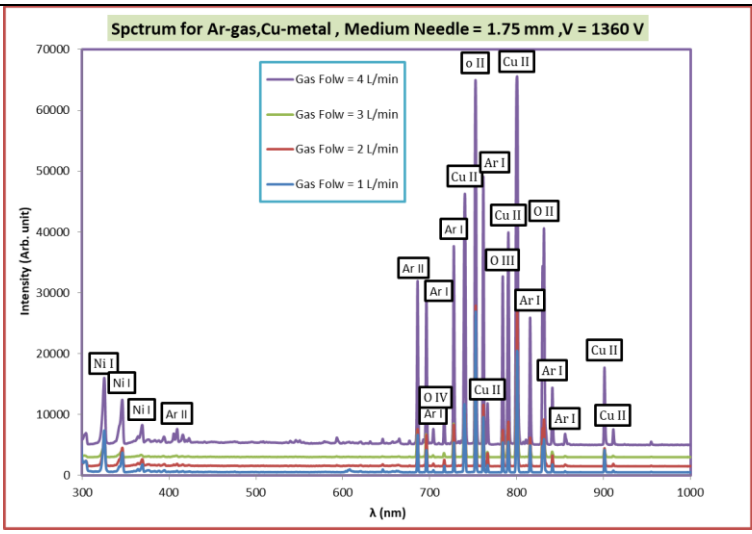
<tr><td>Small Needle 0.75mm</td><td>
</td></tr>
</table>

Conclusions

Based on the results, the type of Needle diameters size, the flow rate of gases used and different applied voltages are important in atmospheric plasma jet set up. Optimization of plasma generation can be achieved by using Argon with flow rate at 1 L/min as working gas. This can be applied in plasma applications especially in medical applications. Our experimental results strongly suggest that the atmospheric plasma jet as a promising tool in plasma applications because it is capable to reach 3 cm in length and also contains various reactive species that can be essentially in plasma applications. For atmospheric plasma jet set up, the higher flow rate of gas used and the bigger value of the voltage will produce a better plasma discharge.

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