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# Electrical characterization and plasma diagnostics of the dielectric-barrier discharge (DBD) plasma jet for bacterial deactivation

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## ARTICLE INFO.

**Keywords:** **dielectric barrier discharge DBD, non-thermal plasma, inactivation, bacteria.**

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## ABSTRACT

In this paper, the insulation barrier of the dielectric-barrier discharge (DBD) plasma jet is discharged at atmospheric pressure .Where the degradation efficiency of the DBD plasma jet is evaluated on bacteria of Staphylococcus aureus with different exposure times. The flow rate of the gas used is also studied. In addition, the optical emission spectrum of OES is examined to detect plasma parameters such as electron temperature and electron density. OES is also used to detect active species within a plasma column such as OI, $N_2$ and OH and other. The percentage of growth inhibition is increased directly with increased time of exposure from the DBD plasma jet .

## Introduction

Plasma jet (cold plasma) is the root of intense interest because of its enormous potential for the processing of materials and biomedical applications [1].Plasma jets generate plasma shafts in open space where they rotate different types of active gases[2].Cold plasma in the atmosphere are the most important subjects or projects, the task of researchers to obtain the desired results for biomedical applications[3][4]. Non-thermal cold plasma jet in atmospheric are able to inactivate bacteria or fungus or bio-macromolecules[5][6][7], relying on the jet configuration and the electrical agitation[2][8][9].

## Theoretical part

(K; partially ionized Low-temperature ~(300-1000) Cold plasma).

Gases. Thermal equilibrium ,the temperatures of the different plasma

species are not the same; more precisely, the critical part should be noted that the electrons are characterized by much higher temperatures than the heavy particles (ions, atoms, molecules);in the plasma discharge.

Electron temperature can be determined by using a ratio method given by[10].

$$\frac{I_1}{I_2} = \left(\frac{\lambda_{nm,z}}{\lambda_{ki,z}}\right)\left(\frac{A_{ki,z}}{A_{nm,z}}\right)\left(\frac{g_{k,z}}{g_{n,z}}\right) e^{\left(-\frac{E_{k,z}-E_{n,z}}{KT_e}\right)} \quad (1)$$

Where $I_1$ is the line intensity from the ki transition and $I_2$ is that from the nm transition.

The electron density can be determined by using Saha- Boltzmann equation , given by [10]

$$ne = \left(\frac{2\pi meK}{h^3}\right)^{3/2} \times \left(\frac{2Aki, zgki, z\lambda nm, zI2}{Anm, zgnm, z\lambda ki, zI1}\right) e^{\frac{-E_{ki}-E_{nm}}{Tex}} \times (Te)^{3/2} \quad (2)$$

## Experimental processes

The locally produced plasma jet was designed and generated in atmospheric and room temperature conditions using a pyrex tube. The length of the tube is essentially 95mm with a wall thickness of 0.90mm while the external polarity of the tube is 2mm and 3.88mm, respectively. The argon gas is also recharged at the top of the Pyrex tube . Flow rate by flow meter model (part number 11420and weight 0.14kg). The gas flow rate is fixed at 4liters per minute per argon (commercial grade 99.9%). The plasma jet is constructed on a double-ring structure as shown in Figure1, with two electrodes made of aluminum with 0.1mm thickness and 11mm width. These poles have the same measurement and specification, the distance between the electrodes is 15mm and the distance between the pipe nozzle and the tube 3mm.

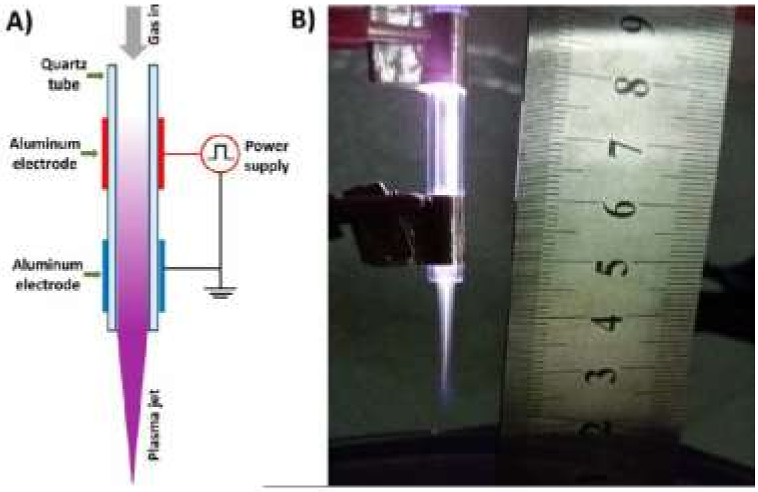


**Figure 1: (A) Schematic diagram and (B) photograph of the DBD plasma jets .**

DBD plasma jet is impelled by using a home-made high voltage power supply with a frequency of 13 KHz and peak to peak voltage of 8 KV. The waveforms of the applied voltage and discharge current, as shown in figure 2, are registered by a two-channel using pc USB oscilloscope (Hantek6022 be , with a 20 MHz bandwidth and a 48 MS/s sampling rate) a high-voltage probe(Tektronix p6015) and a current probe(AT-C202)

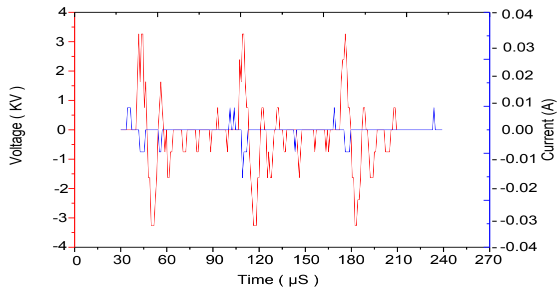


**Figure 2; waveforms of the applied voltage and current**

## Results and Discussion

Figure3 shows the plasma temperature against different flow rate; it is measured by thermometer using different flow rates at the distance of 2.3 cm from the nozzle to tube. The emission spectra of the DBDplasma jet is measured by spectrometer (SV2100. K-MAC) with the spectra range of 300-925nm, whereas the optical fiber is located at 11mm from the edge of pyrex tube. Figure3 shows the installed and measured distance between the pipe nozzle and the objective of which is 23mm with different flow rate at the plasma condition of 13KHz and peak to peak voltage of 8 KV . The results shows that the gas temperature is 53°C at argon gas flow rate of 1 slm, whereas the gas temperature reached 34°C at argon flow rate of 5 slm,the main reason for the low temperature and stability at each run is due to high gas flow rate.

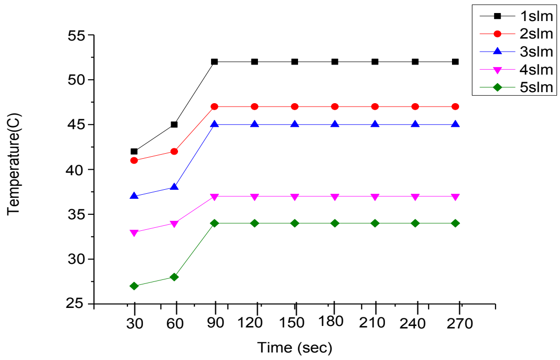


**Figure3; Plasma temperature with different flow rate .**

The length of the plasma column is measured from the end of the tube to the end of the plasma plume, where the length of the plasma inflator increases with the applied voltage increase due to high gas flow rate.

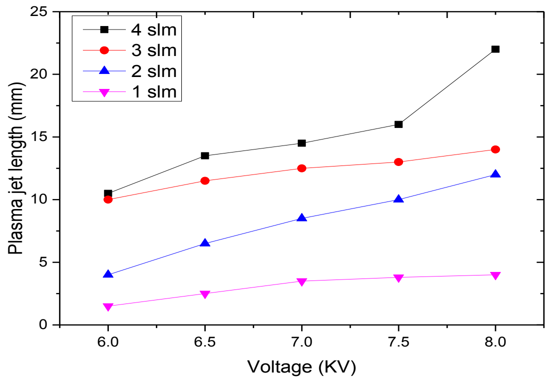


**Figure4: the length of the plasma column shows the function of the voltages with the gas flow rate**

Bacterial suspension are equipped for Staphylococcus aureus bacteria by a specific concentration. This concentration is measured by spectrophotometer at 625nm and as 0.4nm which is equal to a bacterial number 6.6 x 105 cells. Compared to the McFarland solution. At 0.1 ml of cells are deploys over the nutrient agar via spreading method by sterile swab and distributed in standard petri dish .
Making the agar plates

1. Remove sterile Petri dishes (VWR 25384-208) from plastic bag
2. Pour of nutrient Agar (~20mL) into each plate.
3. Each plate cool until its solid.
5. Store plates in plastic bags in fridge with: name, date and contents (note any additive).

10 ml of bacterial culture were transferred to a sterilized glass petridish, then after plasma treatment of the plate was applied. Dilutions were made and 10µl for each dilution were transferred to nutrient agar plates by using spreading technique the sample plates were incubated over night at 37°C to allow survivors to grow Plates were incubated overnight after plasma treatment. Next day, the Colony Forming Units (CFU) were counted in order to check the efficiency of bacterial inactivation using cold plasma treatment.

Through OES, the active particles present within the plasma column can be obtained by OES analysis. The spectral lines of the DBD argon are shown at the peak of the 8KV voltage as in the figure 5.

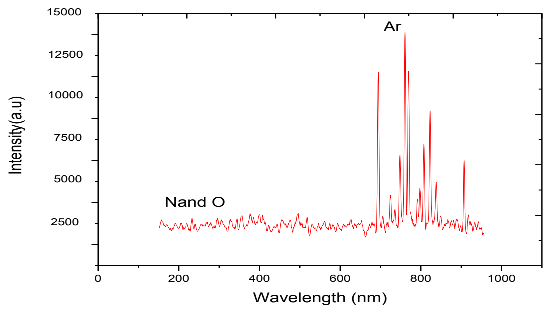


**Figure 5; Spectra of Ar DBD plasma jet**

The electron temperature (Te) and electron density (ne) are important parameters to prescribe the characteristics of the Argon DBD plasma jet. Electron temperature can be determined by using a ratio method given by equation (1):

Where $I_1$ is the line intensity from the ki transition and $I_2$ is that from the nm transition.

**Table: values of transition probability , upper energy level and statistical weight that used to calculate $T_e$ .**

| Wavelength (nm) | | A , ($S^{-1}$) | | g | | E , ( ev ) | |
|---|---|---|---|---|---|---|---|
| ArI | ArII | $A_{ki}$ | $A_{nm}$ | $g_{ki}$ | $g_m$ | $E_{ki}$ | $E_{nm}$ |
| 750.296 | 434.052 | $4.45 \times 10^7$ | $1.17 \times 10^8$ | 3 | 6 | 11.8280 | 16.6438 |

The electron density can be determined by using Saha- Boltzmann equation , given by equation(2) [10]
The electron density was estimated to be $n_e = 1.88 \times 10^{13} cm^{-3}$ and electron temperature $T_e = 1.67 ev$.

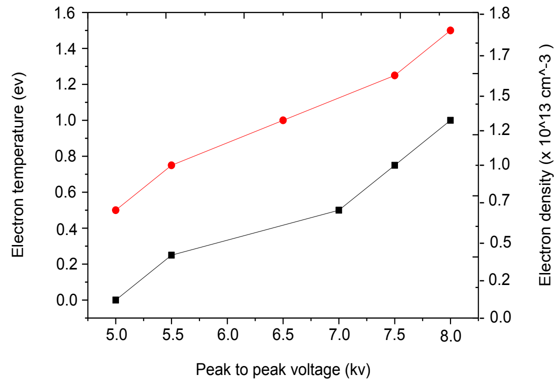


**Figure 6: Electron density and electron temperature as afunctionality of peak to peak applied voltage.**

figure 7 shows the bacterial percentage of inhibition with a different time exposure of ( DBD) plasma jet. It was observed in this figure that the size of inhibition percentage was permanently larger than the diameter of the (DBD) plasma jet, this was due to the action of ROS which formed from surrounding air.

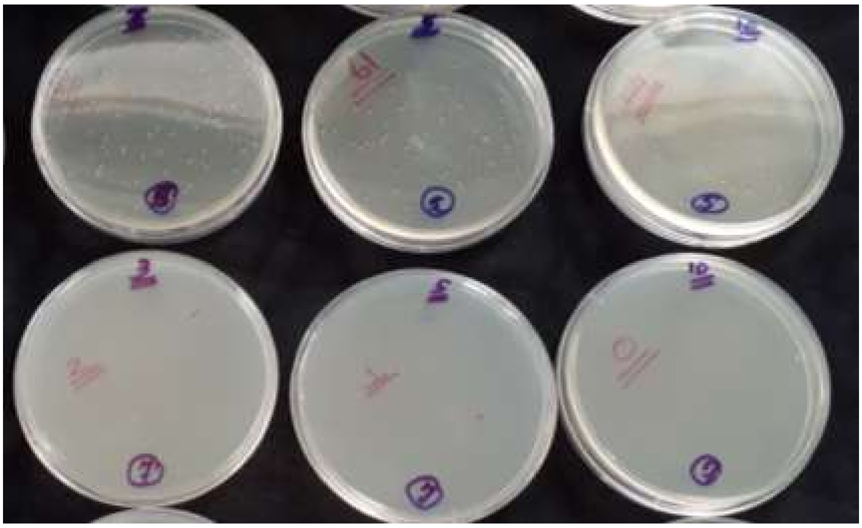

**Figure 7; photographs staphylococcus aureus samples on Ar in Petri dishes ; 3 min, 5 min, and 10 min.**

The relationship between the percentage of inhibition percentage with different treatment time can be shown in (Figure 8). where it is seen that the area of growth inhibition percentage increased with increased the exposure time.

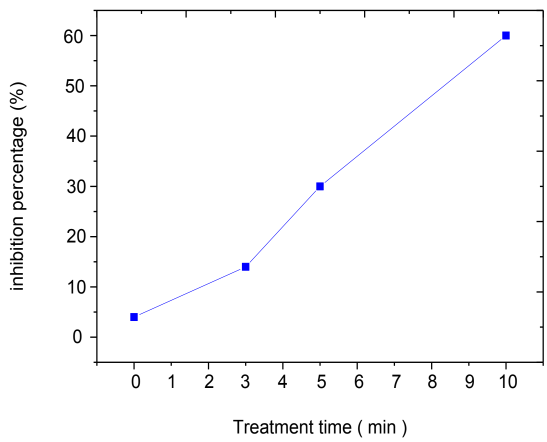


**Figure 8; Inhibition percentage as a function of treatment time.**

## Conclusions

The argon gas plasma works in atmospheric conditions as well as room temperature, to kill bacteria Staphylococcus aureus, and the high efficiency plasma jet argon affects bacteria at increase time.

## Acknowledgments

we offer all respect, appreciation and gratitude to the Dept. of Physics, College of Sciences, University of Tikrit, Iraq,and Ministry of Science and Technology, Center of Applied Physics,Baghdad,Iraq.

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# التوصيف الكهربائي والتشخيص البلازمي لنافث البلازما (DBD) لإبطال مفعول البكتيريا

فارس صالح عطا الله [1] ، هديل الربيعي [2] ، محمد خماس خلف [2] ، محمد شهاب أحمد [1]

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**الملخص**

في هذا البحث ، يتم تفريغ حاجز العزل لنافث البلازما (DBD) عند الضغط الجوي. حيث يتم تقييم كفاءة تحلل نافث البلازما DBD على بكتيريا المكورات العنقودية الذهبية مع أوقات التعرض المختلفة. يتم أيضا دراسة معدل تدفق الغاز المستخدم. بالإضافة الى ذلك، يتم فحص طيف الانبعاث الضوئي OES للكشف عن معلمات البلازما مثل درجة حرارة الإلكترون وكثافة الإلكترون يستخدم OES أيضا للكشف عن الأنواع النشطة داخل عمود البلازما مثل OI و $N_2$ و OH وغيرها. يتم زيادة نسبة النمو بشكل مباشر مع زيادة وقت التعرض من نافث البلازما DBD.