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The effect of background argon gas pressure on parameters of plasma produced by Dc- glow discharge

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Abstract

Non-thermal plasmas have become popular as plasma technology has advanced in various fields, including waste management, aerospace technology, and medicinal applications. They can be used to replace combustion fuels in stationary hall motors and need little effort to keep running for longer periods of time. To improve overall system performance, non-reactive gases such as (Xe, Ar, and Kr) are utilized in pure or mixed form to generate plasma. Since DC glow discharge is a fundamental topic of importance, these gases have been researched. The paper concentrates on 2-D modeling and simulation. DC glow-discharge tubes are utilized with argon gas to create plasma and learn about its properties. The magnitude of the electron density, increases with rising pressure, whilst the rest of the parameters gradually decrease with increasing pressure

Keywords: Plasma Physics, COMSOL Multiphysics, simulation

تأثير ضغط غاز الأرجون على متغيرات البلازما الناتجة عن تفريغ توهج التيار المستمر

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الخلاصة:

أصبحت البلازما غير الحرارية شائعة حيث تقدمت تقنية البلازما في مختلف المجالات ، بما في ذلك إدارة النفايات وتكنولوجيا الفضاء والتطبيقات الطبية. يمكن استخدامها كمصادر احتراق الوقود وتحتاج إلى القليل من الجهد للاستمرار في العمل لفترات أطول من الوقت. لتحسين أداء النظام بشكل عام ، يتم استخدام الغازات غير التفاعلية مثل غاز الارغون والزينون والكريبتون في شكل نقي أو مختلط لتوليد البلازما .. نظرًا لأن تفريغ توهج التيار المستمر يعد موضوعًا أساسيًا ذا أهمية ومن أجل الحصول على أداء أفضل للنظام بشكل عام تم دراسة هذه الغازات. تركز الورقة على النمذجة ثنائية الأبعاد والمحاكاة. يتم استخدام أنابيب التفريغ المتوهج DC مع غاز الأرجون. لتكوين البلازما وكذلك معرفة تأثير تغيير الضغط في منظومة المحاكاة وكذلك على خصائص هذه البلازما الناتجة. اذ تشير النتائج التي تم الحصول عليها ان كثافة الإلكترون تزداد مع ارتفاع الضغط ، بينما تنخفض بقية المعلمات مثل درجة حرارة الالكترون وكذلك الجهد الكهربائي تدريجياً مع زيادة الضغط المسلط على منظومة التفريغ.

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1- Introduction

Glow plasma discharge has been investigated experimentally and conceptually for a variety of applications, including as thin solid layer deposition or etching; laser, spectrum, and illuminating light sources; surface modification; analytical and plasma chemistry Modeling helps us better understand gas discharge behavior,
which helps us control and optimize plasma reactors in a range of sectors. [1-2] plasma is an ionized state that differs from natural gas The plasma is very important in industrial and when an electric current is applied to the ionizing gas discharge system, plasma is formed in the laboratory. medical applications [3]. The usefulness of various economic gases such as Argon, Krypton, and other mixes and its effect on the parameters of the resulting plasma is the topic of this study. COMSOL Multiphysics package is used to execute a 2-Dimensional simulation for the glow discharge problem. Argon gas was used in the vacuum system for the purpose of studying its effect on the parameters of the resulting plasma.

2- Glow-Discharge Mechanism

Plasma is created by transferring energy through a neutral gas, causing charge carriers to develop. Electrons and ions are formed when high-energy electrons or photons clash with neutral atoms and molecules in a gas. The energy necessary for plasma formation may be given to a neutral gas in a number of ways. The most popular way of producing and sustaining a low-temperature plasma for technology and technological applications is to apply an electric field to a neutral gas. The electric field accelerates free charge carriers that are present in gas, either as a result of cosmic ray or otherwise. New charged particles are produced when these charge carriers clash with atoms and molecules in the gas or with the electrode surfaces [4]. A discharge occurs when a substantial potential difference is supplied between two separated electrodes over a perfect insulator gas, and the transition from an insulating to a totally conducting state happens at a point known as the electrical breakdown [5]. A glow discharge plasma is a low-temperature area of gas that is maintained ionized by powerful electrons. Consider two electrodes submerged in a gas-filled chamber, and the glow that would result from a high-impedance DC power source in a low-temperature gas. When voltage is initially applied, a very little current occurs due to the existence of a limited number of ions and electrons in the gas [6]. More energy is given to charged particles when the voltage is raised, resulting in more charged particles being created by collisions with electrodes and neutral gas atoms (secondary electron emission). As more charge is generated, the current continuously rises. However, since the voltage is still restricted by the output impedance of the power source, this area is referred to as Townsend discharge [7].

3- Modeling of the glow discharge

The hybrid model as well as the fluid model and the kinetic model are the three types of mathematical models for plasma [9]. To solve particles in the kinetic model, the Boltzmann equation [8] is utilized, which takes a long time to compute. The fluid model, on the other hand, is made by applying the moment to the Boltzmann equation, which yields a form that is similar to that of Euler equations in fluid flow [10]. The (2-D) equations are well-documented in the literature. A pair of drift diffusion equations must be solved to determine the electron density and mean electron energy.

4.1 Equation of Drift Diffusion

The Poisson equation, which depicts a balancing the density of particles, is the mathematical explanation for the DC glow discharge (electrons and positive ions). As indicated in the equations below [11]. the set of drift equations has been solved and utilized to determine the average electron energy and electron density.

$$-\nabla.\epsilon_0\epsilon_r\nabla V=\rho \quad (1)$$

$$\frac{\partial(n_e)}{\partial t}+\nabla.[-n_e(\mu e.E)-De.\nabla ne]=Re \quad (2)$$

$$\frac{\partial(n_\varepsilon)}{\partial t}+\nabla.[-n_\varepsilon(\mu_\varepsilon.E)-D_\varepsilon.\nabla n_\varepsilon]+(E.\Gamma_\varepsilon)=R_\varepsilon \quad (3)$$

$$\Gamma_e=-n_e(\mu e.E)-De.\nabla ne) \quad (4)$$

Later on, the energy loss R_ε, from elastic collisions and the R_e electron source will be specified. The formulae below will be used to compute electron and energy diffusion, as well as energy mobility [11].

$$D_\varepsilon=\mu e\,T_e\,,\ \mu_\varepsilon=\left(\frac{5}{3}\right)\mu e\,,D_\varepsilon=\mu_\varepsilon T_e \quad (5)$$

Source coefficients in equations using plasma chemistry where we assume that (M) is the number of interactions that involved to some of neutral inelastic collisions(P) where in general P >> M. Where the source of the electron in terms of rate coefficients is given by the following relationship [11].

$$Re=\sum\nolimits_{(j=1)}^{(M)}X_j\,K_jN_nn_e \quad (6)$$

x_j The mole fraction of the target species in reaction j, k_j is the reaction j rate coefficient (m^3/s), and (N_n) overall neutral number density ($1/m^3$). When defining reaction rates, it is preferable to utilize Townsend coefficients rather than rate coefficients. We can better explain the events in the cathode subsidence region. The electron source is given by using Townsend coefficients [11].

$$R_e=\sum\nolimits_{j=1}^{M}X_j\,\alpha_jN_n|\Gamma_e| \quad (7)$$

Townsend's coefficient is (α_j) and Γ_e is the electron flux ($1/(m^2s)$). The Townsend coefficients improve the stability of numerical calculations. The summation of the energy loss due to collisions in the reaction leads to the loss of electron energy [11].

$$R_\varepsilon=\sum\nolimits_{j=1}^{P}X_j\,K_jN_nn_e\Delta\varepsilon_j \quad (8)$$

where $\Delta\varepsilon_j$ is the amount of energy lost in reaction j. Using the cross-section data and the following integral, the rate coefficients are calculated [11].
The mass fraction of each non-electron species is calculated using the following equation:

$$\rho=q\int_{\infty}^{0}\varepsilon\,\sigma_k\,(\varepsilon)f(\varepsilon)d\varepsilon \quad (9)$$

$$R_\varepsilon=\sum\nolimits_{j=1}^{P}X_j\,K_j\alpha_jN_n|\Gamma_e|\Delta_{\varepsilon j} \quad (10)$$

The equation determines the mass fraction of each non-electron species:

$$\rho=\frac{\partial}{\partial t}w_k-\rho(u.\nabla)w_k=\nabla.j_k+R_k \quad (11)$$

To calculate the electrostatic field, use the equation below.
For the purpose of calculating the density of space charge, plasma chemistry is used in this model [11].

$$\rho=q\sum\nolimits_{K=1}^{N}Z_jn_k-n_e \quad (12)$$

4.2 Boundary Conditions

The cathode's generation of secondary electrons keeps the discharge going. An electron is emitted when the cathode surface is bombarded with high probability. A high field is formed near the cathode. The liberated electrons are accelerated, allowing them to obtain enough energy to begin ionization. The cathode falls, also known as Crookes dark void, is the result of this rapid increase in electron density at the cathode. Due to secondary emission effects caused by random mobility within a few mean free paths of the wall, electrons are lost to the wall and acquired, resulting in the following electron flow boundary condition.

$$n.\Gamma_e = \left(\frac{1}{2}\, v_e\, n_e\right) - \sum\nolimits_p \gamma_p\, (\Gamma_p . n)\epsilon_0 \tag{13}$$

Where(Γ_p) Ion flux of the pth positive ion species at the surface
In the equation, the electron energy flow is provided.

$$n.\Gamma_\varepsilon = \left(\frac{5}{6}\, v_e\, n_\varepsilon\right) - \sum\nolimits_p \varepsilon_p \gamma_p\, (\Gamma_p . n)\epsilon_0 \tag{14}$$

The gain of electrons as a result of secondary emission is represented by the second term on the right side of equation (13). Where (γ_P) is the secondary emission factor while the secondary emission energy is the second term of equation (14) [11].

4- Plasma Chemistry

Table 1 shows argon plasma chemistry for elastic, excitation, and ionization type processes with various cross section energies. They're also known as volumetric reactions, and they're included with the argon surface reactions in Table 2. The coefficient of adhesion given in the table represents the possibility of the atom returning to the ground state when it hits the wall

Table 1: Argon gas reaction and collisions [11]

	interactive formula	**its type**	**(Δε (eV))**
I.	Ar +e ≥ e +Ar	Elastic,	0
I.	Ar + e ≥ Ars + e	Excitation,	11.5
I.	Ars + e ≥ Ar + e	Superelastic,	-11.5
/.	Ar + e ≥ Ar^+ + 2e	Ionization,	15.8
/.	Ars + e ≥ Ar^+ + 2e	Ionization,	4.24
I.	Ars+ Ars≥ Ar^++Ar+e	Penning Ionization,	-
I.	Ar + Ars ≥ Ar + Ar	Metastable quenching,	-

Table 2: Argon gas reaction and collisions [11]

interactive formula		***Adhesion factor***
I.	Ars ≥ Ar	1
II.	Ar^+ ≥ Ar	1

5- simulation, Results and Discussion

Using the COMSOL Multiphysics code with necessary data extracted from LXCAT [12] a two-dimensional simulation was carried out using an electrical discharge tube with a width of

0.05 meters and a height of 0.4 meters, as shown in (Figure 2). Where a voltage was between the poles equal to 125 volts. The geometry of the discharge is assumed to be two-dimensional parallel-plane discharge. The cathode should to be grounded, and a positive voltage is provided to the anode via an external circuit having a resistance R and a capacitor C connected in series with the discharge (Figure 2). Since the numerical methods available today are capable of accommodating a wide range of sizes and shapes, in addition, computers have a specific memory and speed. Careful choices must be made to simplify the actual geometry; If not, networking will be difficult, and must face CPU and memory limitations. Small and simple forms are used to divide the arithmetic domain. Obtained Electric potential, density and temperature of the electrons as well as graphs were drawn
for these quantities. The differences in the above quantities were noted along the axis.

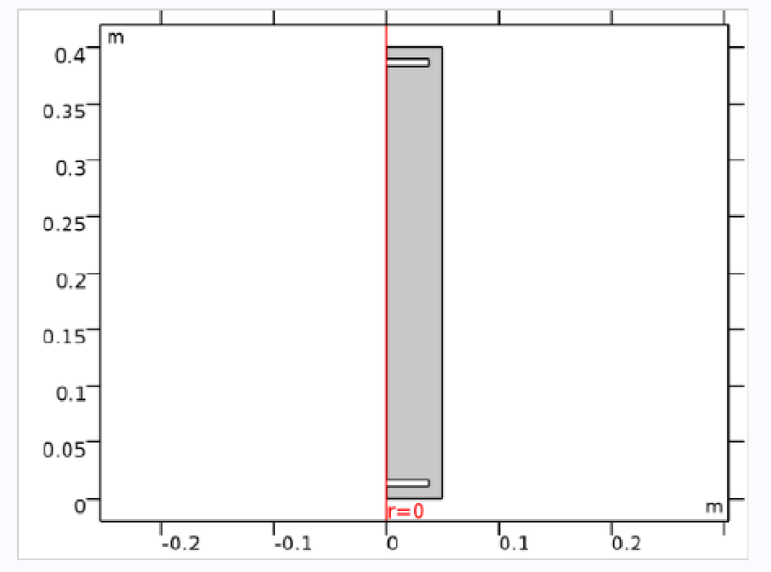


Figure 1: Geometry of a tow dimensional glow [11].

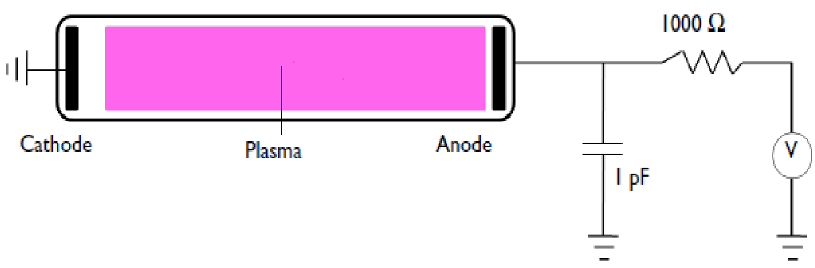
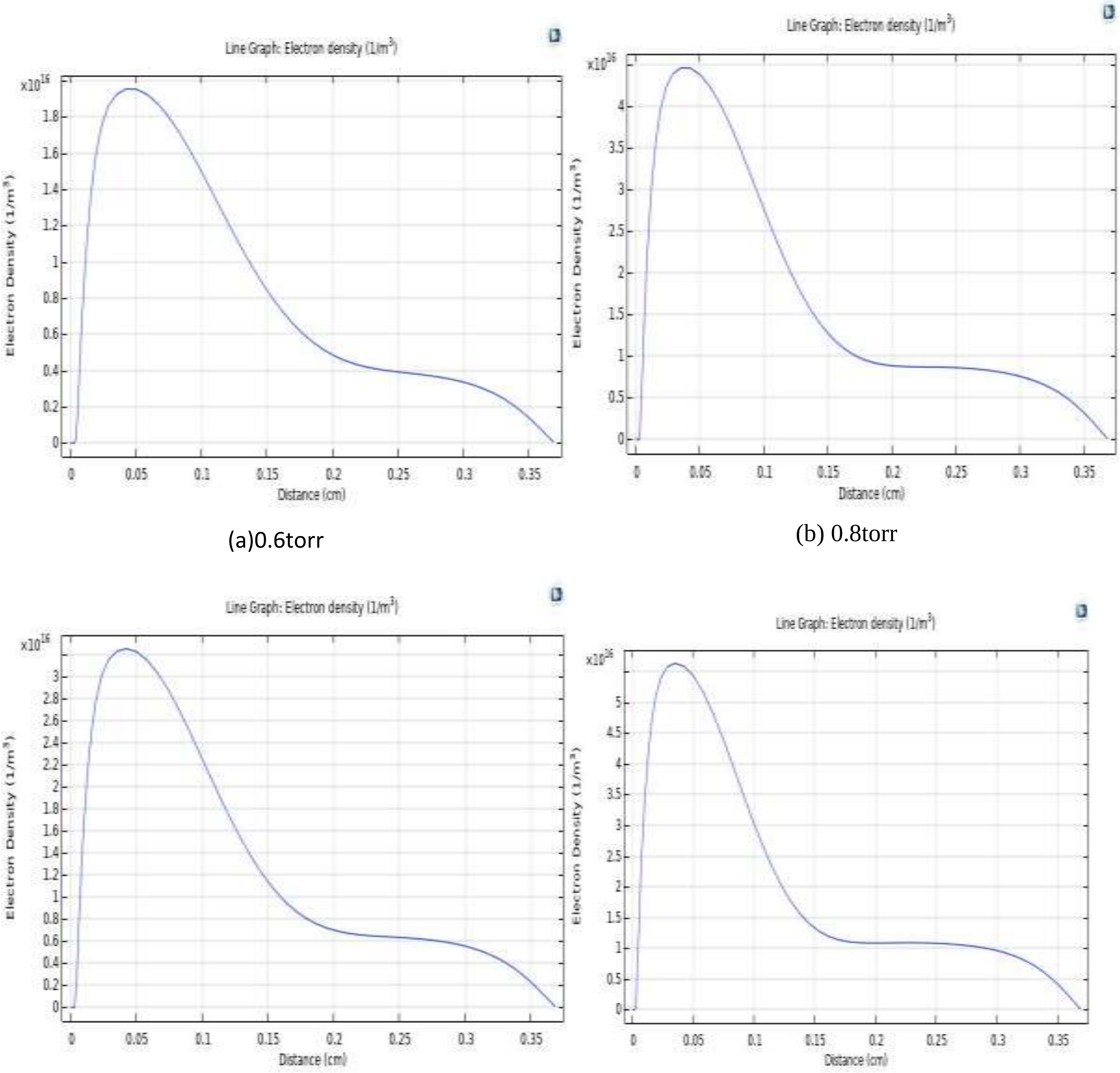


Figure 2: schematic of axisymmetric DC discharge [11].

Figure (3) show the electron density of Ar plotted versus the electrode's gap length (the radius of the tube (0.05m). where four values of pressure have been taken. A clear increase in the electron density was observed, which was at a pressure of (0.6 torr) equal to ($1.9 * 10^{16}$) ($1/m^3$), while it was at a pressure of (1.2 torr) equal to ($5.7 * 10^{16}$) ($1/m^3$) The majority of electrons are pushed towards the anode region in the negative glow area, which is located between the cathode glow area and the Faraday dark area. High mean electron energy causes electrons to accelerate due to the large electric field in the cathode area. From the Faraday region to the positive electrode where the majority of the electrons of the incoming gas molecules are ionized. Here the electron density will decrease.



(a)0.6torr

(b) 0.8torr

(c) 1torr

(d) 1.2torr

Figure 3 Plot of electron density at different pressure values a) 0.6 torr, b) 0.8 torr, c) 1 torr, d) 1.2 torr.

the distribution of the electron temperature is shown along the radius of the tube in graphs are shown in Figure (4) at different pressure values a total of four pressure readings were recorded. The temperature of the electrons in the cathode glow region is significantly greater because a large number of electrons discharged from cathode acquire adequate mean kinetic energy and high ionic energy, driving them towards the positive column because the temperature of the electron is proportional to the number of inelastic collisions that occur, the electron temperature of Argon pressure peak at 0.6 Torr (10eV) and 1.2 Torr (9.7eV). At low pressure, this is significant because as the possibility of ionization becomes low, which allows the gas in the column to ionize and excite more quickly. The slow initiation of electron electron temperature even further. recombination with gas ions out of the cathode light zone

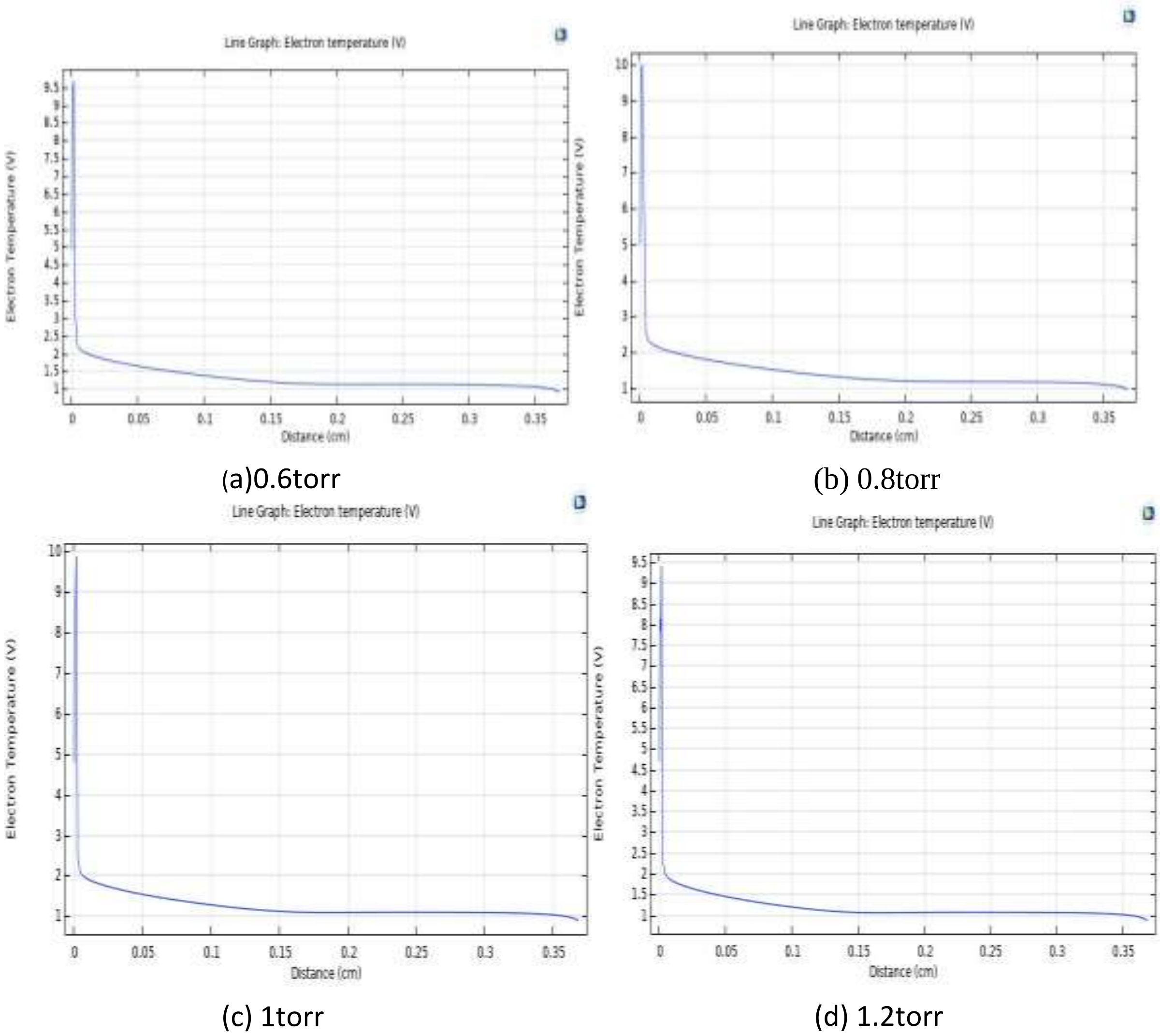
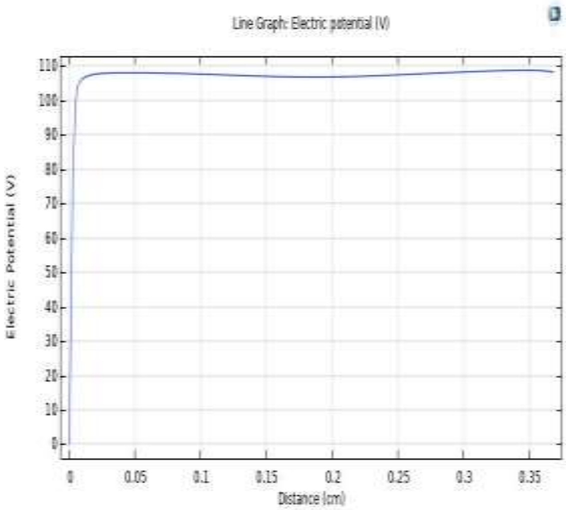
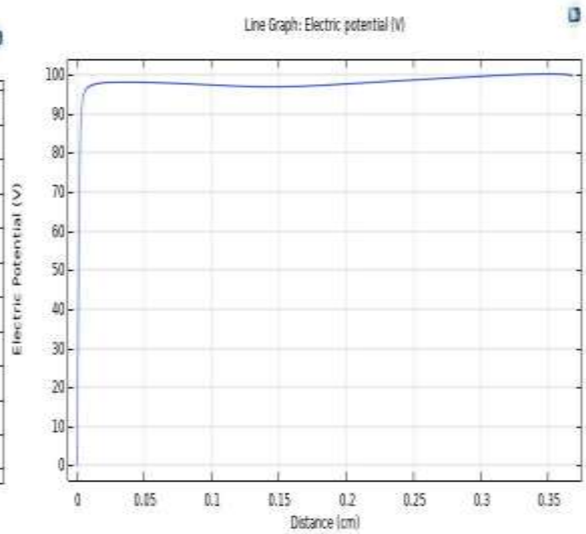


Figure 4: Temperature distribution at different pressure values a) 0.6 torr, b) 0.8 torr, c) 1 torr, d) 1.2 torr.

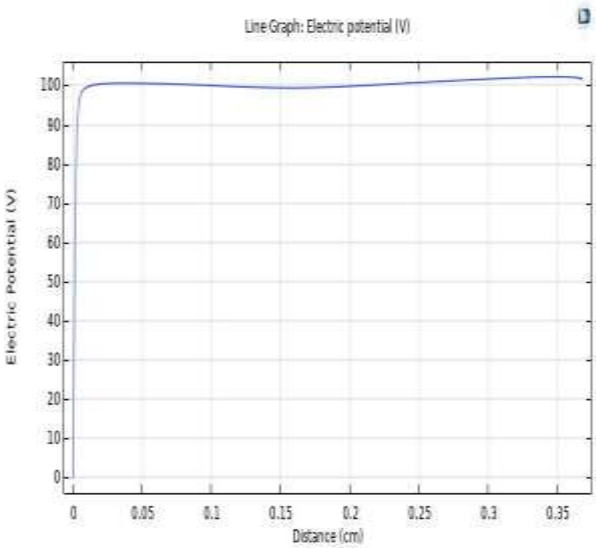
potential distribution between the two electrodes along the radius as a function of column length is seen in Figures (5) There were a total of four pressure measurements taken. The electric potential was 105V at a pressure of (0.6 torr), and 95V at a pressure of (1.2 torr). The electron potential in the cathode fall zone is found to decline because this area has a very strong electric field, as the concentration of ions from the cathode region is much greater than the concentration of electrons. Accordingly, the peak voltage refers to the accumulation of charged particles in this region, which are often ions.



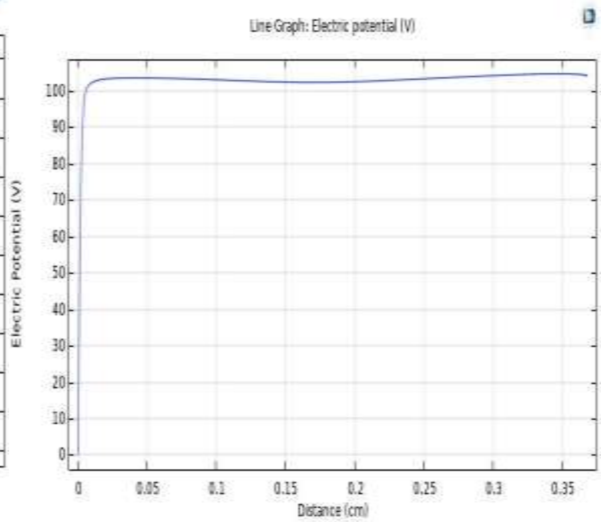
(a)0.6torr



(b) 0.8torr



c) 1 torr,



d) 1.2 torr

Figure 5: Electric potential distribution at at different pressure values a) 0.6 torr, b) 0.8 torr, c) 1 torr, d) 1.2 torr.

6- Conclusions:

To look into the impact of argon gas pressure based on DC glow discharge problem, numerical simulation using COMSOL software is used. Solve a pair of density of electrons and energy of electrons drift propagation equations, as well as the species equation and the electrostatic field equation. Two-dimensional simulations at pressures (0.6 torr) ,(0.8 torr) (1 torr) and (1.2torr) and type of aluminum electrodes(Its work function is 4.08) at a voltage of 125 volts .Because it is through these voltages that optimal results for plasma parameters can be obtained. showed that there is a clear effect of pressure on the some plasma parameters resulting from the argon gas discharge such as the density of electrons and the temperature of electrons and voltage. The results revealed that as the applied pressure rises, the electron density rises as well. While the data suggested that both the electron temperature and the electric potential had decreased slightly. The future analysis will be to determine the model parameters' sensitivity and their effect on various types or mixtures of gases, as well as the effect of voltages and electrode types on the derived parameters.

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