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Effect of the Magnetic Field on the Characteristics of the Dusty Plasma FeO by Using the Direct Current System

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Abstract

In the present work, the effect of isolated dust particles (FeO) with radius of the grain **0.1µm - 0.5µm** of main plasma characteristics are investigated experimentally in direct current system by using magnetic field. The present of dust particle in the air plasma did effect on Paschen minimum and on the plasma properties in low pressure region. The effect of dust particles on discharge voltage, discharge current, plasma potential, floating potential, electron density, electron temperature and Debye length was investigation by using magnetic field. The measurements of parameters are taken by four cylindrical Langmuir probes. The results show the present of dust causes decreasing in discharge voltage with increase pressure while the discharge current was increased with increasing pressure. The floating potential and plasma potential of probe becomes more negatively. The electron density is increases in the present of dust particle which lead to decreases the electron temperature and Debye length.

Keywords: Dusty plasma, Plasma parameters, FeO dust, Electrical discharge.

تاثير المجال المغناطيسي على خصائص البلازما المغبرة FeO باستخدام منظومة ذات تيار مستمر

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الخلاصة

في هذا البحث ،تم اجراء دراسة عملية لتاثير دقائق الغبار العازلة (FeO) التي نصف قطر الحبيبة **0.1µm – 0.5µm** على خصائص البلازما بوجود الغبار في بلازما الهواء لمنظومة التيار المستمر باستخدام المجال المغناطيس. حيث لوحظ ان هناك تاثير على منحني باشن و على خصائص البلازما في منطقة الضغط الواطئ والمتمثلة بفولتية التفريغ وتيار التفريغ وجهد البلازما والجهد العائم وكثافة الالكترون ودرجة الحرارة وطول ديباي بوجود المحال المغناطيسي.يتم اخذ القياسات لمعلمات البلازما باستخدام اربع مجسات لانكمور الاسطوانية.فقد بينت النتائج بانه فولتية التفريغ تتناقص بزيادة الضغط بينما تيار التفريغ يزداد بزيادة الضغط . لوحظ جهد البلازما و الجهد العائم يصبح اكثر سالبية.بينما كثافة الالكترونات سوف تزداد وبلتالي يقود الى النقصان في درجة الحرارة وطول ديباي بوجود المجال المغناطيسي

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1. Introduction

Plasma is a quasi-neutral gas consisting of positively and negatively charged particles (usually ions and electrons) which are subject to electric, magnetic and other forces, and which exhibit collective behavior [1]. One type of plasma is dusty plasmas consist of electrons, ions and charged dust particles observed in several Astros-and space-physical environments such as nebulas, cometary tails, planetary rings, and planetary ionospheres[2, 3]. Theoretical and experimental studies of low-frequency electrostatic waves in plasmas containing negatively charged dust grains are described. Dusty plasma studies are normally limited to particles of size from few nanometers to 100μm because for these sizes, particles are more likely to be affected Important parameters of dusty plasma include dust grain radius (r_d), average distance between grains (a), plasma Debye radius (λ_D), and the dust cloud dimension[4] .the dusty plasma without magnetic field, Experimental study for the properties of Fe_3O_4 dusty plasma using the air in vacuum chamber system [5].and with magnetic field , Diagnostics of dusty plasma properties in planar magnetron sputtering device[6] . Experimental Investigation of the effect of isolated and non-isolated dust particles on glow discharge of air plasma in direct current system [7].

2. Theory

The electric (or electrostatic) probe has long been used as a fundamental tool for measuring the local properties of the plasma In 1924, Langmuir pioneered the use of the electric probe, which are often called Langmuir probes[8, 9]. The single Langmuir probe is a small conductor that can be introduced into the plasma to collect ion or electron current that flow into it in response to different voltage [10]. Langmuir probes measure electric currents which depend on their bias voltage with respect to the plasma potential. The details of the current- voltage (I-V) characteristics can be related to the plasma parameters that are present in the absence of the probe (electron temperature (T_e), unperturbed plasma density (n_e), plasma floating (V_f) plasma potential (V_p), and electron and ion beam energy) [11].

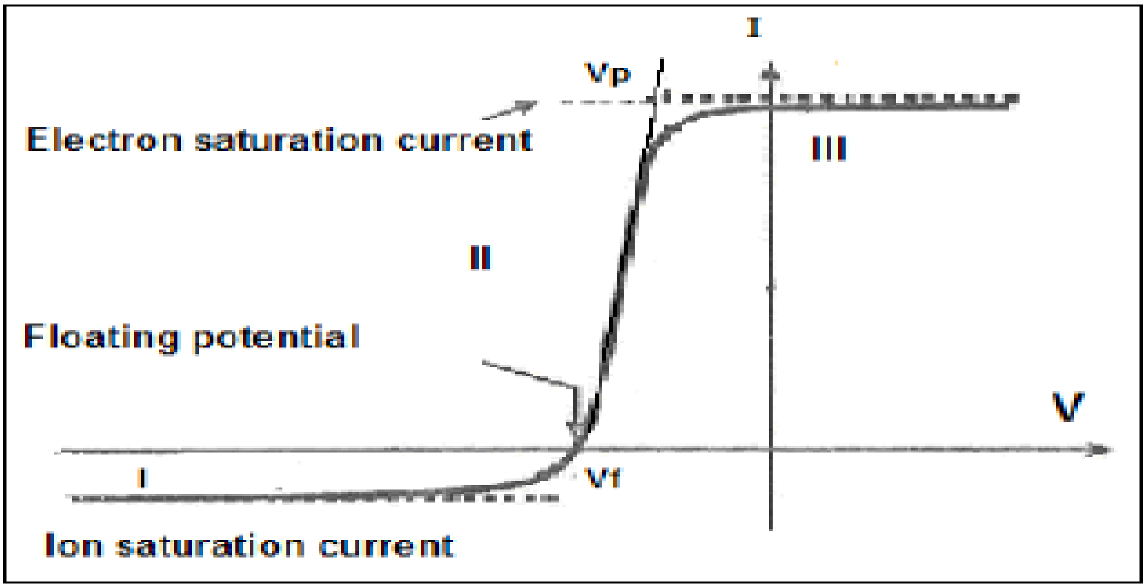

Figure1-Schematic of a typical probe current-voltage characteristic[12].

By applying a sweep voltage to the Langmuir probe which is referred to a grounded electrode (like the conducting wall chamber), we can measure the current in the probe and plot I-V curve. A typical I-V curve from single Langmuir probe is shown in Figure-1. The qualitative behavior of the I-V curve can be explained as follow. For large negative and positive values of the probe voltage, saturation currents called ion saturation current (I_{is}) and electron saturation current (I_{es}) respectively. The point at which the curve crosses the V axis is called floating potential (V_f), where the collected ion and electron, exactly balances each other and the net current is zero. At the space potential (V_p) the net current takes a sharp turn. [13].

- **Probe Measurements**

This section describes the basic aspects of Langmuir probe theory that are needed to construct a model probe for I-V characteristics.

- **Ion Saturation Current:**

When the bias voltage (V) on the probe is sufficiently negative with respect to the plasma potential (V_p), the probe collects the ion saturation currents I_{is}. Positive ions will continue to be collected by the probe until the bias voltage reach V_p. [14]. The ion saturation current is given by [10]:

$$I_i = A_p\, n_i\, e\left(\frac{(-|eV_p|}{8mi}\right)^{1/2} \quad (1)$$

$$n_i=\frac{\sqrt{8mi}}{e\sqrt{e}}\frac{(\text{slope})^{1/2}}{A_p} \quad (2)$$

where , slope = I_i^2 / V and Te=1/slope m_i is the ion mass.

- **Electron Saturation Current**

For V >>V_p the probe collects electron saturation current I_{es}. For V<V_p the electrons are partially repelled by the probe, and for Maxwell in electron velocity distribution, the electron current decreases exponentially with decreasing V. While for V <<V_p all electrons are repelled [15]. The electron current was calculated as[13]

$$I_e=\frac{n_e e A_p}{4}\left(\frac{8kT_e}{\pi m_e}\right)^{1/2} \quad (3)$$

Where, ne, A_p, k, Te, me, and e, are electron density, probe surface area, Boltzmann constant, electron temperature, electron mass, and electron charge, respectively.
Thus, the electron density (n_e) is determined as:

$$n_e = \frac{4I_{es}\sqrt{\pi m_e}}{eA_p\left(8kT_e\right)^{1/2}} \quad (4)$$

- **Floating Potential:**

The floating potential (V_f) is defined by $I_i = I_e$, [16]:

$$V_f = V_p + \left(\frac{kT}{e}\right)\ln\left[0.6\left(\frac{2\pi m_e}{m_i}\right)^{1/2}\right] \quad (5)$$

It is clear, from this equation that the floating potential depends, essentially, only on the electron temperature and the species of ions involved.

- **Plasma Potential**

To obtain the plasma potential (sometimes called space potential) is to draw straight lines through I – V curve in the transition and the electron saturation regions and call the crossing point V_p, $I_{es.}$ This does not work well if I_{es} is curved. In that case, there are two methods one can use. The first is to measure V_f and calculate V_p from equation (5). The second is to take the point where I_e starts to deviate from exponential growth, that is, where I_e' (V) is maximum or I_e'' is zero [16].

- **Debye length**

The Debye length is an important physical parameter in a plasma: it provides the distance over which the influence of the electric field of an individual charged particle is felt by other charged particles (such as ions) inside the plasma. The charged particles actually rearrange themselves in order to shield all electrostatic fields within a Debye distance. In dusty plasmas, the Debye length can be defined as follows [3]

$$\lambda_{De}=\sqrt{\frac{kT_e}{4\pi n_e e2}} \quad (6)$$

where T_e and ne are the electron and temperature and density of electron respectively

3. Experiment Instrument

D.C. discharge system (i.e. Vacuum Chamber, Vacuum system, power supplies, and Duster), the description of this system is given, Figure-2 shows a photograph of this system.

Figure 2-Vacuum D.C. discharge system

The vacuum chamber made from Quartz class. The length, thickness, and diameter of the cylinder is 40 cm, 2cm and 30cm respectively, this tube has two open ends closed by two stainless steel flange. One of the tube ends was connected to pumping systems, while the other was used to immerse the Nitrogen gas (which it is used as a back ground gas). The chamber consists of two parallel aluminum circular electrodes, which have diameters of 8 cm, and thickness of 2cm. One of them is powered electrodes in anode and the other electrode is connected to the ground cathode . The separation distance between the electrodes (d) is 8 cm. The chamber was pumped by two stages rotary pump, CIT-ALCATEL Annecy, to a basic pressure 2×10^{-2} torr. The Pirani gauge, Edward was used to measure the vacuum pressure of the chamber of about 10^{-3} torr. So that, the pressure can be read continuously over the whole range from atmospheric to base pressure of the vacuum system. The working gas (Nitrogen gas) has been supplied through a gas inlet placed in upper end of the vacuum chamber. The gas flow is controlled using needle valve. In order to provide high experimental accuracy we have kept a continuous gas flow. The range of pressures, in which the experiments have been performed, is approximately in the range of 0.08 torr to 1 torr. Two D.C. power supply devices are used for different experimental purposes. The first one, Local manufacturing, was used to operate the system to generate the normal plasma discharge. This power is a variable power supply of range (0-15KV), and maximum output current is 20mA,While the second, was used to operate the Langmuir probes which made by Phywe,. The duster (local manufactured) was used to drop the dust particles inside the glow. Where, the remote control used to operate the duster from outside the chamber, this mechanism is very important to control the operating of the duster. A disk was used as circular container, which was made from Teflon and covered by small sieve (mesh). This mesh used to control of dust particle size. The acentric disk rotation gives us the rotational and vibration motions in the same time, these motions which give a security for the presence of dust inside the glow discharge.

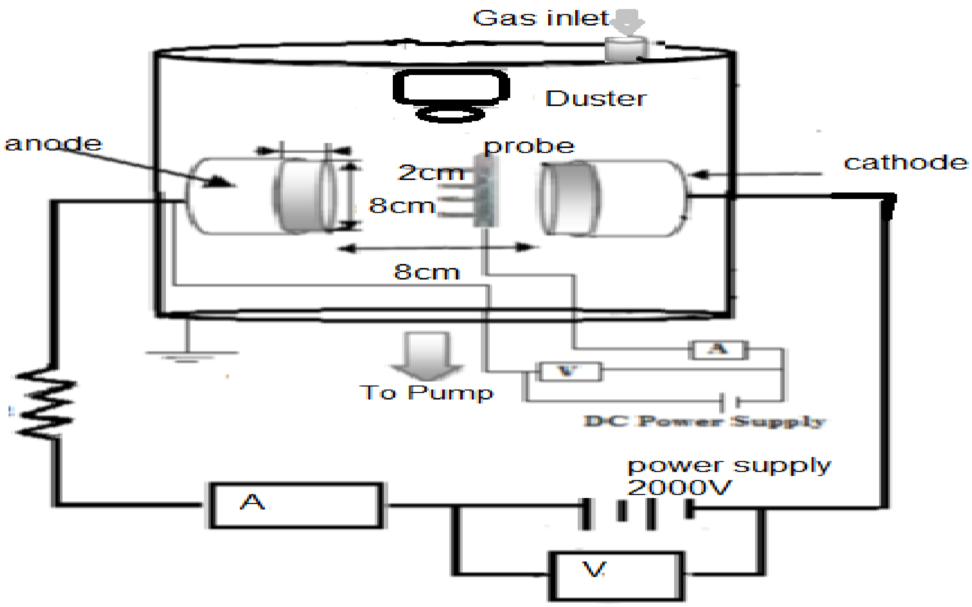

Figure 3- Schematic diagram of vacuum chamber with electric circuit.

There are two plasma magnetic field configurations, which they are the opened and the closed field configurations [17]. The closed field configuration was used in this work. In this configuration, the magnetic field lines close on themselves on the assumption that, the charged particles trace the same path repeatedly. Two types of the permanent magnetic field were used (located under the cathode electrode); the first is the outer and the second is the inner which is located inside the outer circular permanent. This arrangement of the circular permanent magnet is necessary to obtain on the closed magnetic field configuration As shown in Figure-4.

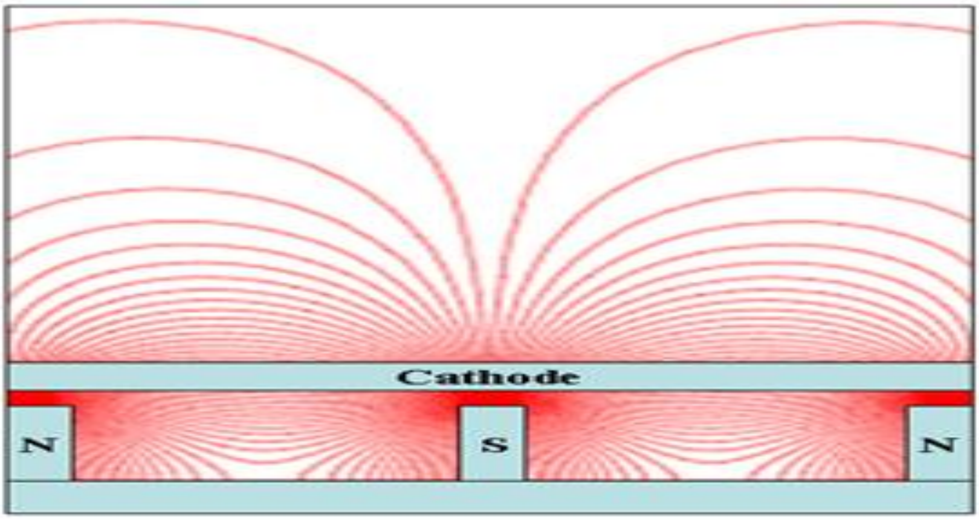

Figure 4- Schematic of the lines of the magnetic field of induction surrounding a cathode electrode [20].

4. Results and Discussion

Exploring the Paschen curve and plasma parameters (V_p , V_f, I_{es}, n_i ,n_e , T_e , λ_{De}) by using the direct current system Figure-2 by using magnetic fields on the cathode electrode. fig (5) display effect dust particle on Paschen curve, This figure explained that type of dust particle Iron oxide (FeO) which are not effect on the voltage discharge. In addition, Figure-6 display the effect of isolated dust particles FeO on the discharge current.

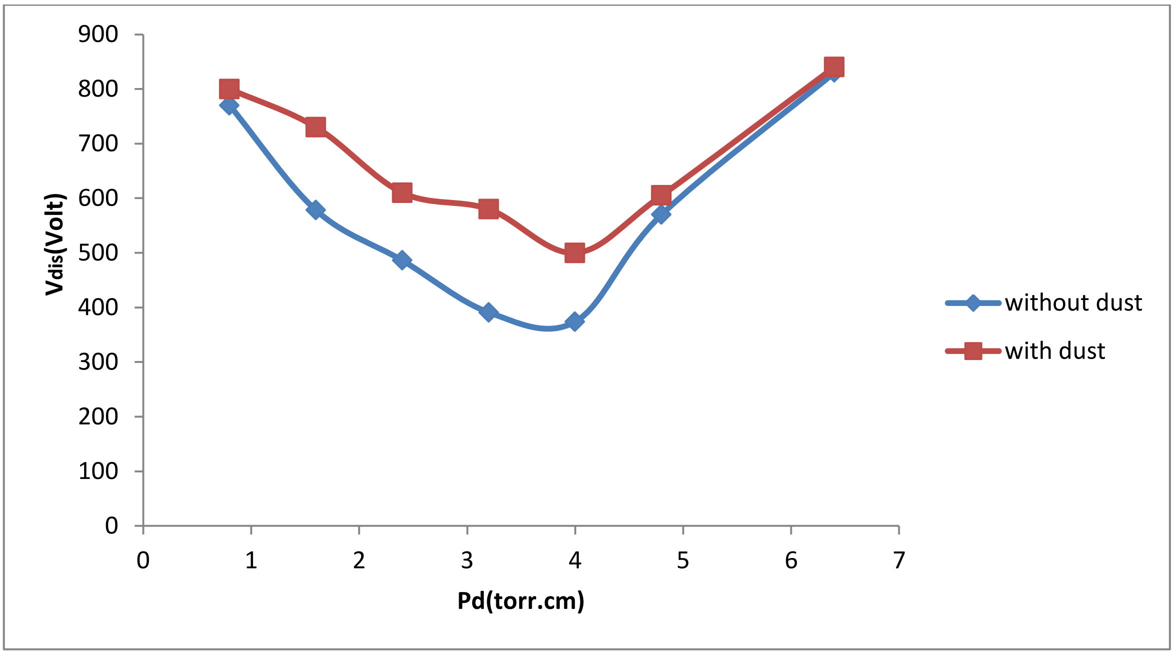

Figure 5- Represent the discharge voltage as a function of pressure without and with of dust particles

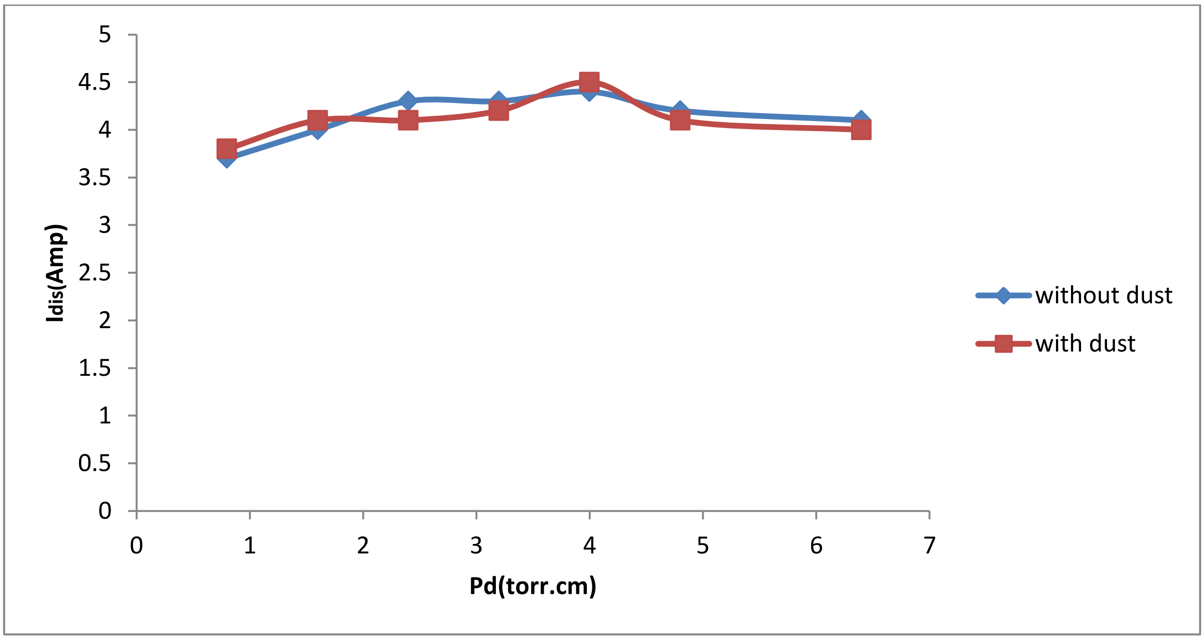

Figure 6- Represent the discharge current as a function of pressure at without and with of dust particles.

Four cylindrical Langmuir probes are used to determine the radial profile of plasma in center region (plasma bulk) ,calculated of electron saturation current (I_{es}). I_{es} are uniform in without and with dust at all pressures. Since, the plasma particles (electrons and ions) are collected by the dust grain which acts as a probe when it immersed in the plasma, so the dust grains are charged by the collection of the plasma particles flowing onto their surface. Consequently, I_{es} is affected by with dust. Because of the dust particle which used in this work are different in work function and grain size, so that with dust (FeO) and other kinds of dust did not have the same influence on the glow discharge structure. It measures all of the floating potential(V_f) ,plasma potential (V_p),electron density(n_e),ion density (n_i), electron temperature (T_e) ,Debye length of electron (λ_{De}) .

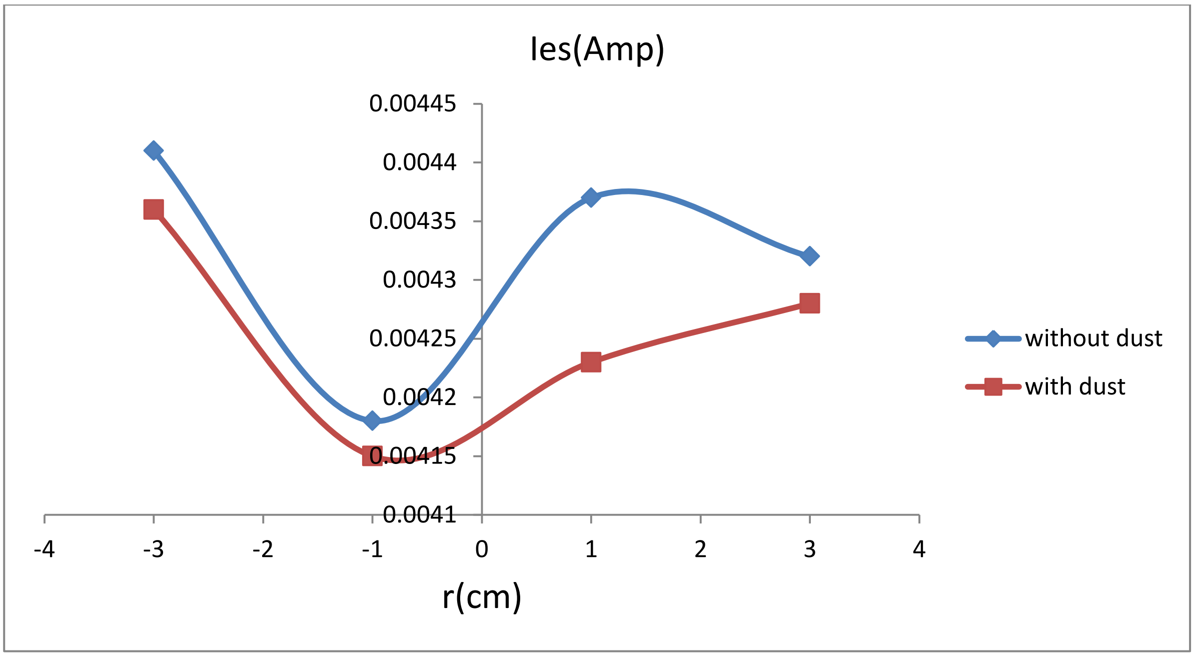

Figure 7-Represent the electron saturation current as a function of radius without and with dust in the present magnetic field.

It clear from Figure-7 the electron saturation current due to the equation (3) is decreased with and without dust in the present of magnetic field.

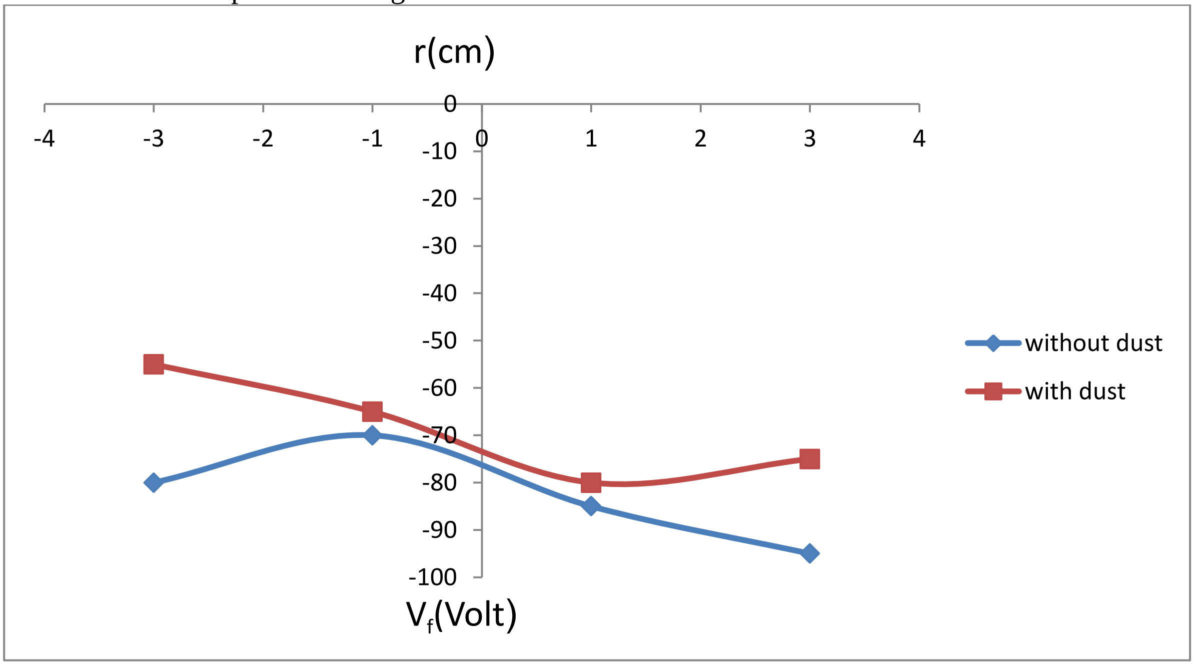

Figure 8-Represent the floating potential as a function of radius without and with dust in the present magnetic field.

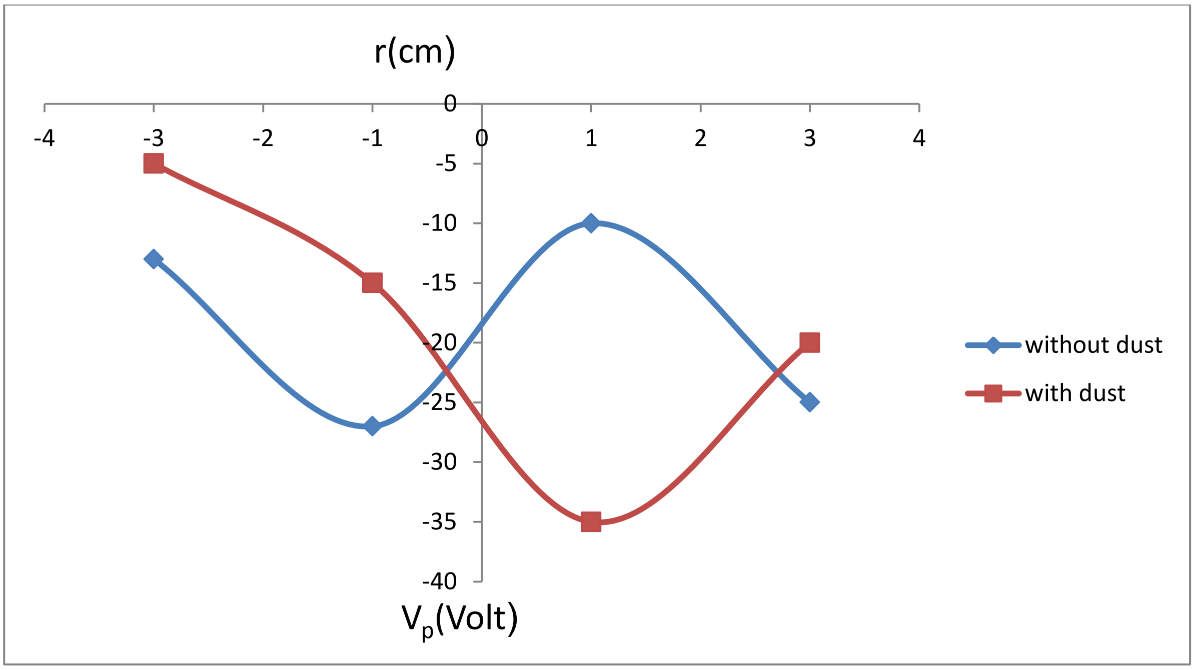

Figure 9- Represent the plasma potential as a function of radius without and with dust in the present magnetic field.

Shows from Figures- (8,9) the floating and plasma potential due to the equation (5) are more negatively with and without dust in the present of magnetic field. The behavior may be associated with the existence of high – energy electron flux. Since the probes faces a longitudinal electrons when it travel from cathode toward anode. These electrons that approaching from the probes are both larger and more energetic than in any other direction.

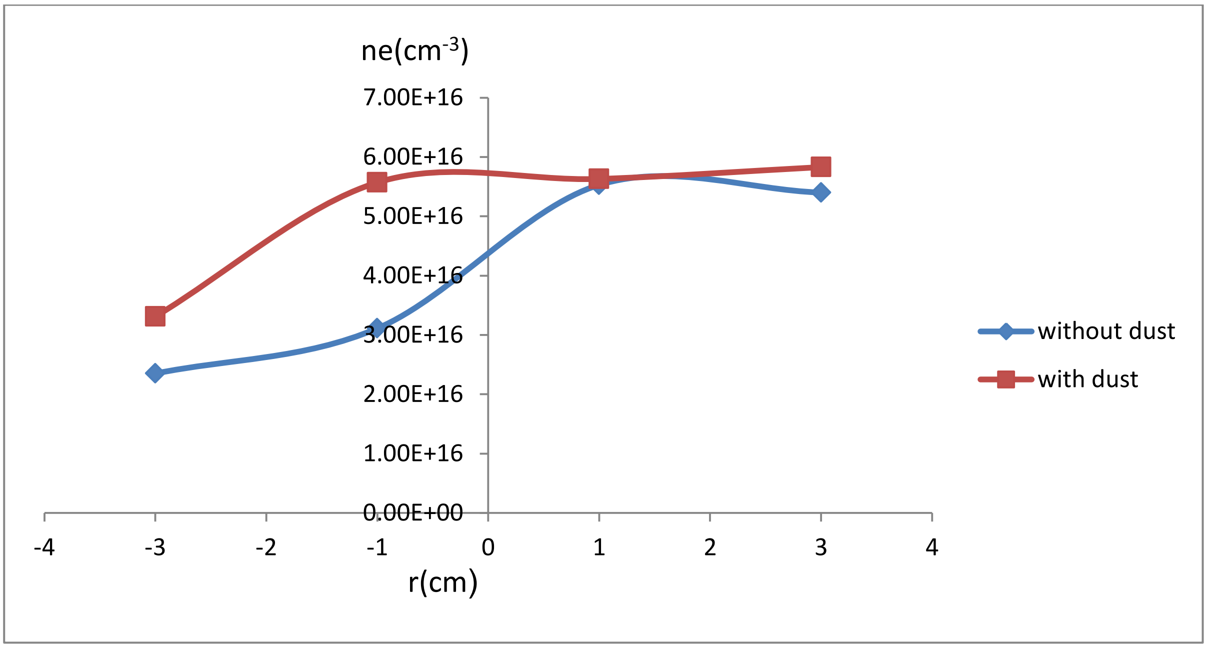

Figure 10- Represent the electron density as a function of radius without and with dust in the present magnetic field.

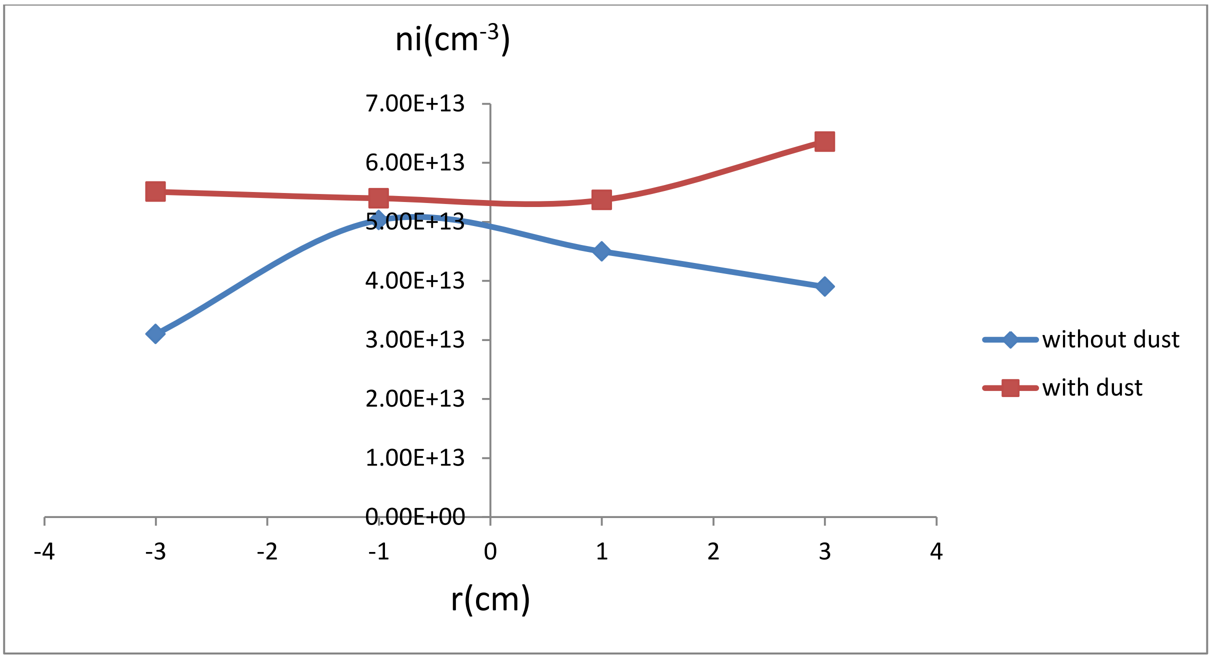

Figure 11-Represent the ion density as a function of radius without and with dust in the present magnetic field.

It explicated from fig (10,11) the electron and ion density due to the equations (4,2) are increased with and without dust in the present of magnetic field .This observed increasing of electron and ion density may be the result of a standard secondary electron release by ionic bombardment and the inability of electrons to reach the surface of charged particles in the afterglow.

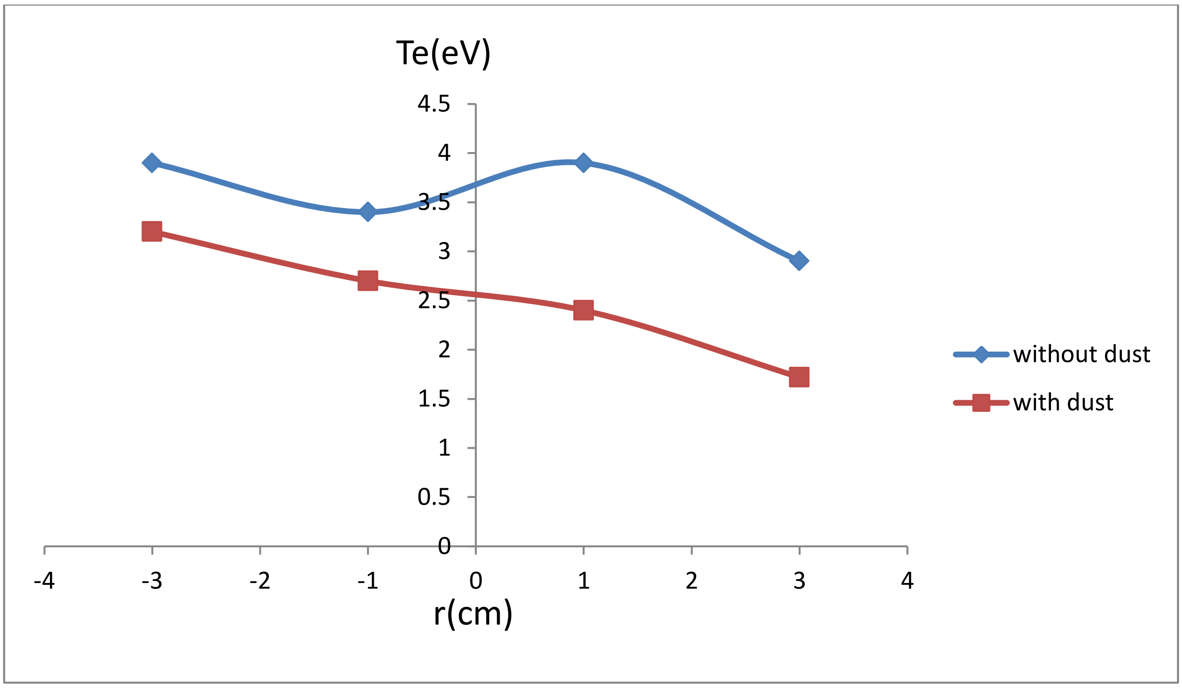

Figure 12- Represent the electron temperature as a function of radius without and with dust in the present magnetic field.

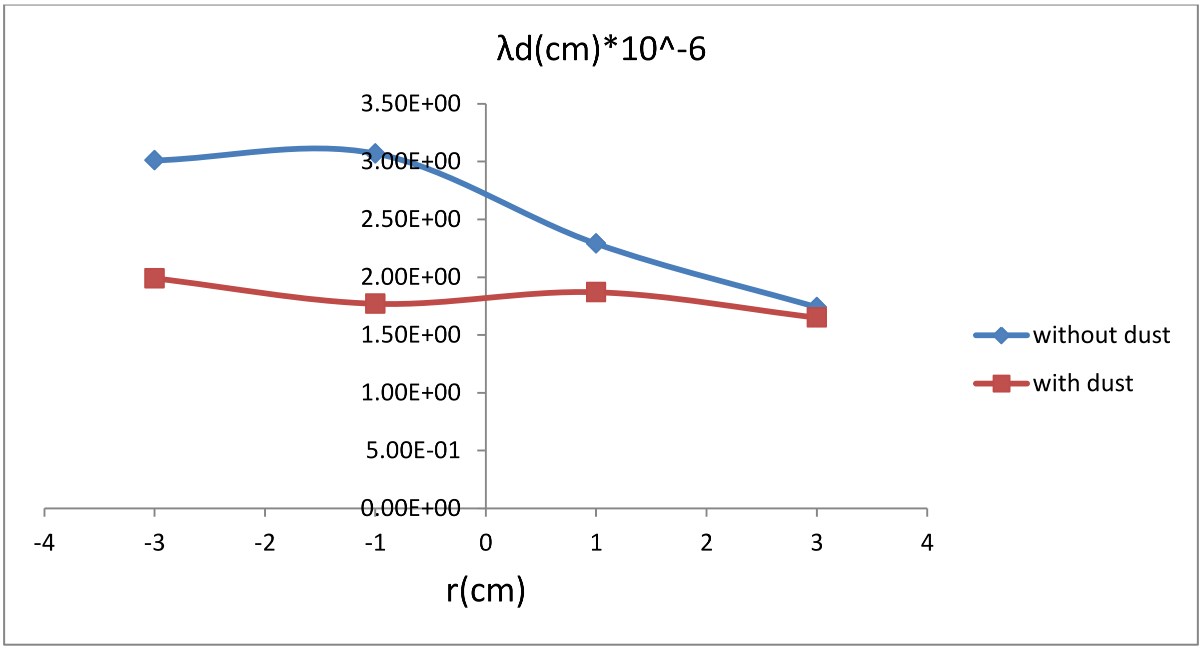

Figure 13-Represent the Debye length of electron as a function of radius without and with dust in the present magnetic field.

Shows from Figures- (12,13) the electron saturation current due to the equation(6) are decreased with and without dust in the present of magnetic field. the electron temperature decreases in the present of dust particles because the electrons energy reduced in the presence of Al dust. The presence of dust shows the energy of electrons approximately uniform. This reduction in the electron temperature may attributed to increases in the electron density associated with enter of Al dust particles inside glow discharge. This result is agreed with previous research such as Miloch et. al. [18]

Conclusions

Based on the above figure, the following points can be concluded:

1. The effect of all dust particles (FeO) on discharge voltage and discharge current of Nitrogen gas ,the curve of the discharge voltage is the same to the Paschen minimum which is (pd) equal 4 torr.cm.
2. The floating potential (V_f) and plasma potential(V_p) , present magnetic field with dust FeO particles, has more negatively.
3. The influence of dust particles on the electron density and ion density in the present magnetic field are increases but the temperature is decrease led to the Debye length decrease too.

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