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LANGMUIR PROBE TO CHARACTERIZE THE DUST PLASMA OF ALUMINUM OXIDE (Al_2O_3) PRODUCED BY DC PLASMA SYSTEM

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Abstract

In this research, we have conducted an experimental study of the dusty plasma to the Aluminum oxide (Al_2O_3) dust material with a grain radius of (0.2) µm to (0.6) µm. In the experiment, we use air in the vacuum chamber system under different low pressure (0.1-0.8) Torr. The results have showed that the existence of dust particles in air plasma is equal to the Paschen minimum which is (0.4) Torr with Al_2O_3 dusty and without dust. The effect of Al_2O_3 dust particles on the plasma characteristics like floating potential (Vf), plasma potential (Vp), electron saturation current (Ies), temperature of the electron (Te), density of electron (ne) and density of ion (ni) of the DC system that can be calculated in the glow-discharge region. Parameter measurements are taken by four cylindrical probes which are diagnosed at a distance of (40) mm from the cathode diameter, the Paschen minimum at a pressure of (0.4) Torr. The plasma potential and the probe's floating voltage become more negative when dust is immersed in the plasma region. The features of these parameters show that the current discharge decreases while the discharge voltage increases when the aluminum oxide dust particles that are incorporated. And vice versa was in the absence of dust. Electron density increases in the existence of dust particles which causes the electron temperature to decrease.

Keywords: Plasma Parameters, Langmuir Probe, Properties of Aluminum Oxide Dust, Plasma Diagnostics, Glow Discharge, Paschen Curve.

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Introduction

A dusty plasma is considered as an electron–ion plasma containing a charged component of submicron- or micron-sized particulates. The addition of macro-particles to the system raises the system's complexity even more. This is why a complex plasma is sometimes known as a dusty plasma. Dusty plasmas are partially or fully ionized electrically by conducting gases with electrons, charged dust grains, ions, and neutral atoms as constituents (*P. K. Shukla, A. A. Mamun, A. M. Ignatov*). Much earlier, astronomical observations of other phenomena like nebulae and Saturn's rings have begun (*D. A. Mendis*). There have been several researches of plasma in the existence of dust and in the existence of a magnetic field (*Ala' F. Ahmed, Qusay A. Abbas and Raghad T. Ahmead, Ala' F. Ahmed el at.).* Plasma has also been explored from its environmental, industrial, and other applications *(Wadaa S. Hussein el al., Ala F. Ahmed el at., Qusay A. Abbas el at.)*. Using electrostatic probes is one of the most essential and often fundamental ways for studying the plasmas' properties. Irvin Langmuir has developed and introduced such approach roughly five decades ago, and it is commonly referred to as Langmuir probes approach *(Huddleston, R. and Leonard, S)*. A small metallic electrode, generally a wire, is introduced into plasma as an electrostatics probe. The probe is connected to a power supply that can bias it at different voltages relative to the plasma, and the current gathered by the probe after that it provides information on the plasma *(S.B.Singh el at.).* Electrostatics Langmuir probe is considered as a plasma physicist's condition for detecting electron densities and temperature theories. The approach is widely utilized, and the quantities evaluated in various circumstances are quite similar to those acquired via other methods. As a result, plasma properties such as density, electron temperature, and axial electric field will be changed from one region to the next under the same conditions *(M. Klindworth).* The probe approach is significant since it has an advantage over all other diagnostic techniques, in that it can do local measurements. The majority of other methods, as spectroscopy or microwave propagation that can provide information based on an average of a huge volume of plasma. The purpose of this research is to investigate the features of dusty plasma for $\mathbf{Al_2O_3}$ in a direct current system using a single Langmuir probe.

1. Langmuir probe limitations

The probe theory is well developed to cover variety of plasma states. It is no longer necessary to restrict its application to the study of the low-pressure plasma or dc gas discharge, where the mean free path of charge carriers is very much greater than the dimension of the probe, and where the sheath dimensions are known *(R. Merlino)*. In our experiments and for cylindrical probe used during these measurements that can be describe as a function of parameter namely: electron mean free path (λ_e) and probe Radius (r_p) that is: $\lambda_e >> r_p >> \lambda_D$ where λ_D is Deby length. The size of sheath around a probe is based on the bias voltage and the size of the Probe as well as the properties of the plasma. The current collected via the probe tip is measured as a function of the voltage between the electrode and the plasma Chamber in the single probe configuration. The electron energy distribution function, plasma, and floating potential are the main plasma parameters that can be identified. In the double probe configuration, the current is measured as a function of the voltage applied between the probe tips which are especially useful when dealing with electrode less discharges or in cases where a reference potential is hot well defined. Main plasma parameters, which can identify in this mode, are ion density, electron temperature and floating Potential *(F. F. Chen).* Figure (1) has showed the single and double probe circuits.

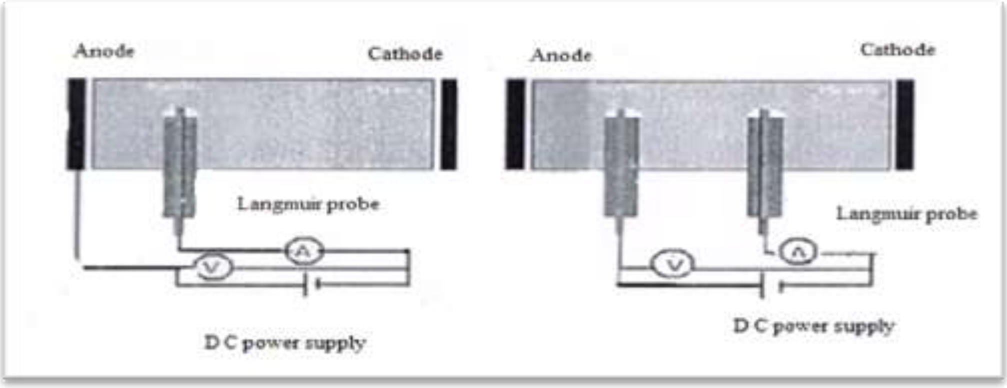

Figure (1): Schematic circuit of (a) single and (b) double probe *(M. Klindworth)*

2. Experimental Setup

The design of DC system (i.e. electrode and vacuum system) and the experimental procedures that give a suitable environment to study the dusty plasma characteristics, as well as, the design of Langmuir probes and the experimental procedure that should be followed to give suitable properties of the complex plasma. The vacuum chamber (which is made of glass and has two open ends) consists of two electrodes which are made of aluminum material. The diameter of both electrodes is (8) cm and (2) cm thickness. Both electrodes are putting on Teflon (see figure (2).in addition Al_2O_3 dust particles are immersed in to the chamber by a duster device.

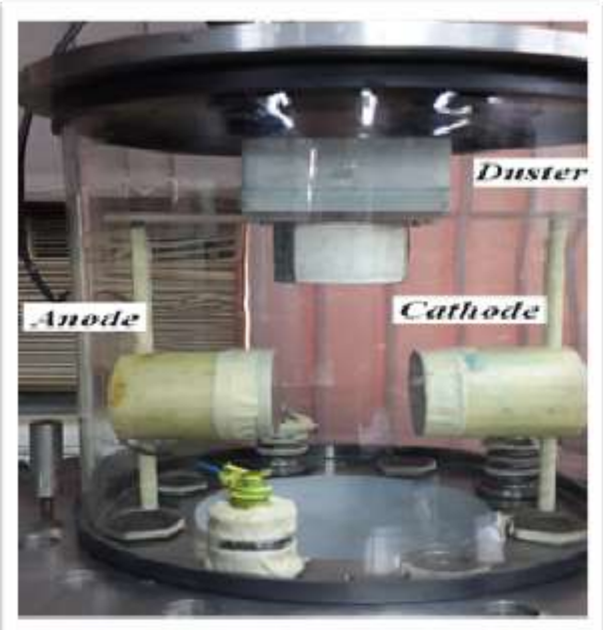

Figure (2): The shape of the electrode in the chamber.

3. 1. Langmuir Probe Design

Langmuir probe, in principle, provides a simple and relatively diagnostic device for measuring the plasma parameters in low pressure discharge such as these of interest. One group of cylindrical probes are designed and fabricated according to the single probe configuration (where the anode is used as a reference electrode). These probes consist of a tungsten wire of (3) mm in diameter, which is covered by thin glass tubes with outer diameter of (9)mm to insulate it from plasma. The length of exposed tip is 3mm that used in all cylindrical probes. The probe tip was located in the center of the insulator. The Langmuir characteristic is obtained by sweeping the applied probe voltage between (130)V to (-130)V to include all the important regions of the curve. The probe voltage obtained from a stabilized DC power supply.

Figure (3) Single Langmuir Probe.

4. Result and Discussion

The influence of the pressure of the main characteristics of glow discharge such as plasma column, discharge voltage, and discharge current in presence and absence of two kinds of dust particles Al_2O_3 are described. Moreover, the effect of pressure on radial profile of plasma characteristics (electron and ion density, electron temperature, plasma potential and other), are measured by using Langmuir probes, in presence and absence both kinds of dust particles in plasma column regions (plasma sheath) is studied too.

4-1 Effect of Pressure on D.C Glow Discharge structure

In this work, the air plasma discharge was produced when it is applied between two electrodes a constant D.C. potential of about (2.5) kV between electrodes. The applied potential is caused, the electric field is generated and then electric breakdown in air. The photographed of this range without dust particle is shown in figure (4) and figure (5) with dust Al_2O_3 at different low pressure (A, B, C, D, E, F the pressure was (0.8, 0.6, 0.4, 0.3, 0.2, 0.1) Torr respectively).

It is clear from this figure that when the pressure increases more collision occurs as the electrons travels from the cathode to the anode (i. e. mean free path of charged particles decreased). Therefore, the charged particles currents increase with the increase of pressure, since these currents (electrons and ions currents) cause many plasma losses, these losses are responsible for the luminous discharge, and this behavior is shown in the presence and absence of Al_2O_3 dust particles.

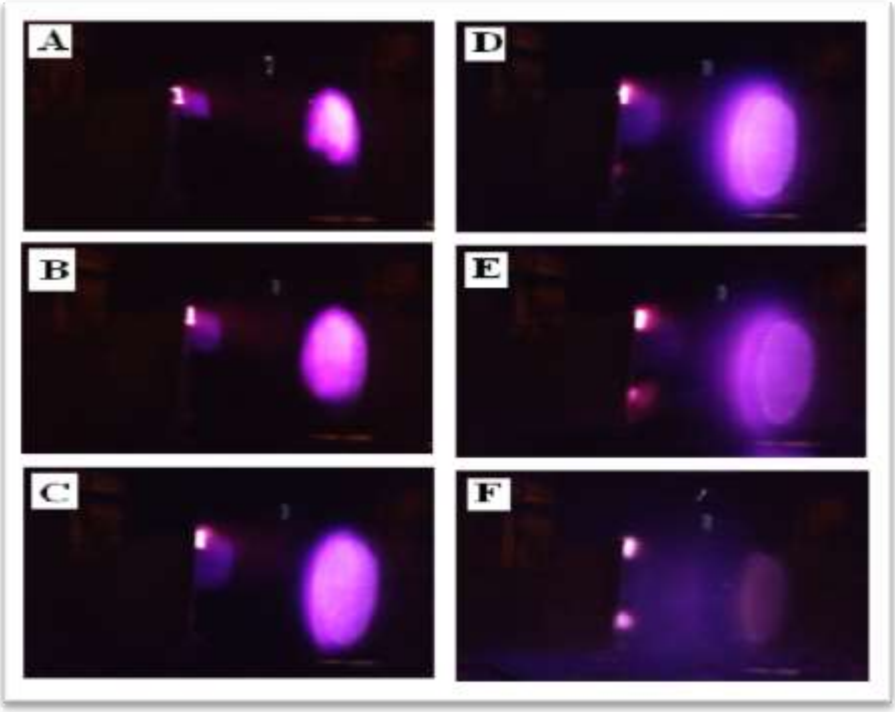

Figure (4): Photographs of plasma discharge at different pressures (A=0.8, B=0.6, C=0.4, D=0.3, E=0.2, F=0.1) Torr without dust particles

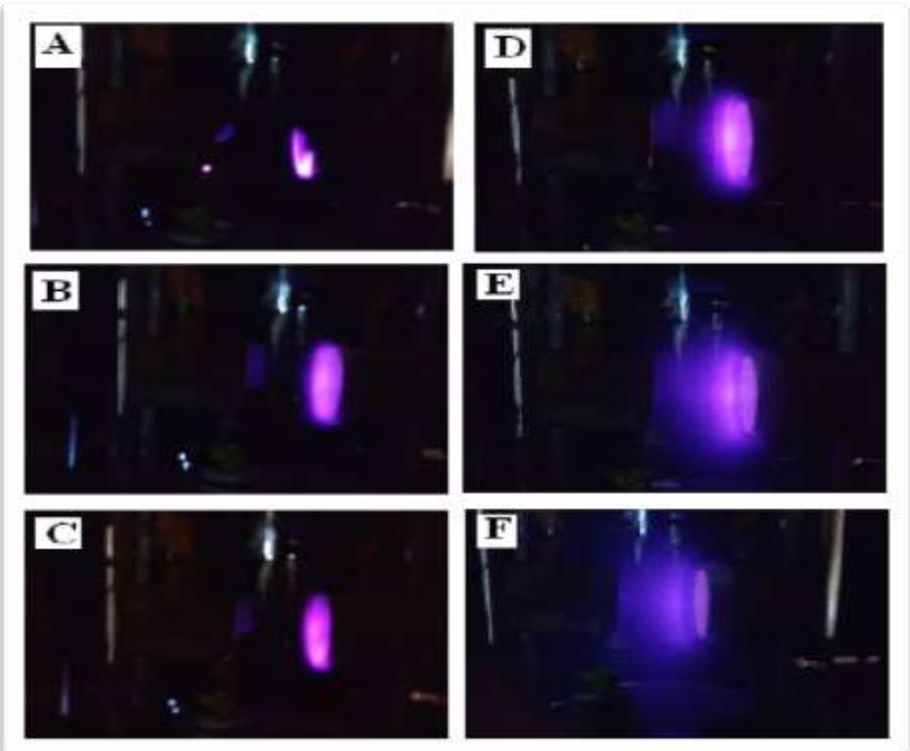

Figure (5): Photographs of plasma discharge for different pressure (A=0.8, B=0.6, C=0.4, D=0.3, E=0.2, F=0.1) Torr with dust (Al_2O_3) particles.

4-2 Basic Discharge Parameters

The DC glow discharge is produced when a DC constant potential of about (2.5) kV is applied between two electrodes, due to this external potential, the plasma discharge is formed, the space charge is established and then the electrode potential will be dropped Figures (6) and (7) show the current and voltage of discharge respectively with dust Al_2O_3 and without dust. It is clear from these figures, that when Al_2O_3 dust is embedded inside plasma, the discharge current is increased while the voltage of discharge is increased. This behavior can be explained as; the increasing of not losses of electrons can be caused by classical diffusion and the collection of electrons on the dust surface causes to increase the discharge current and voltage discharge.

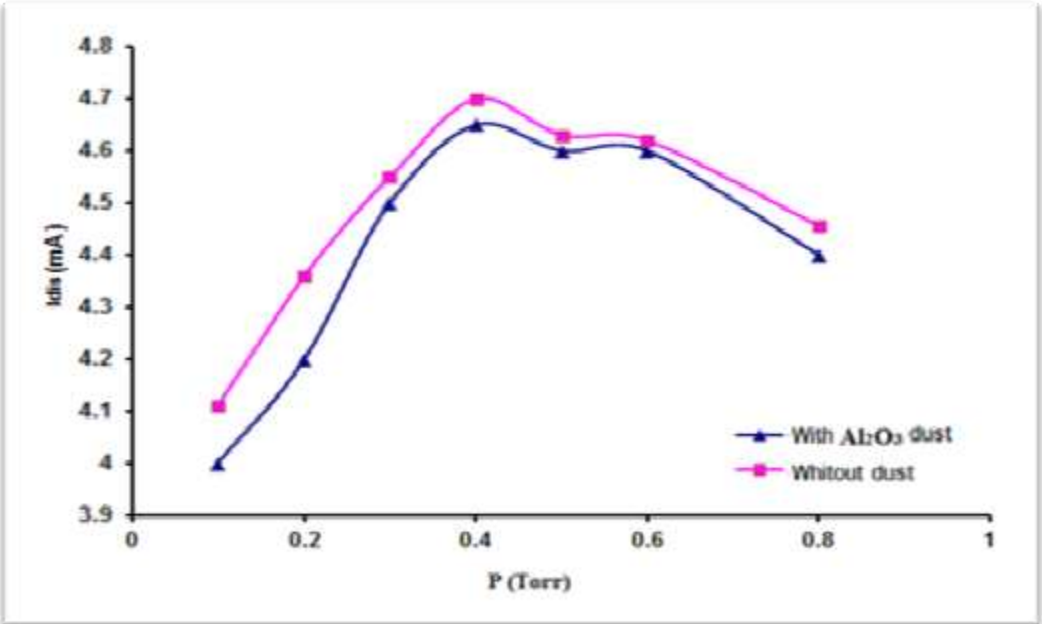

Figure (6): Schematic of the discharge current to different pressure

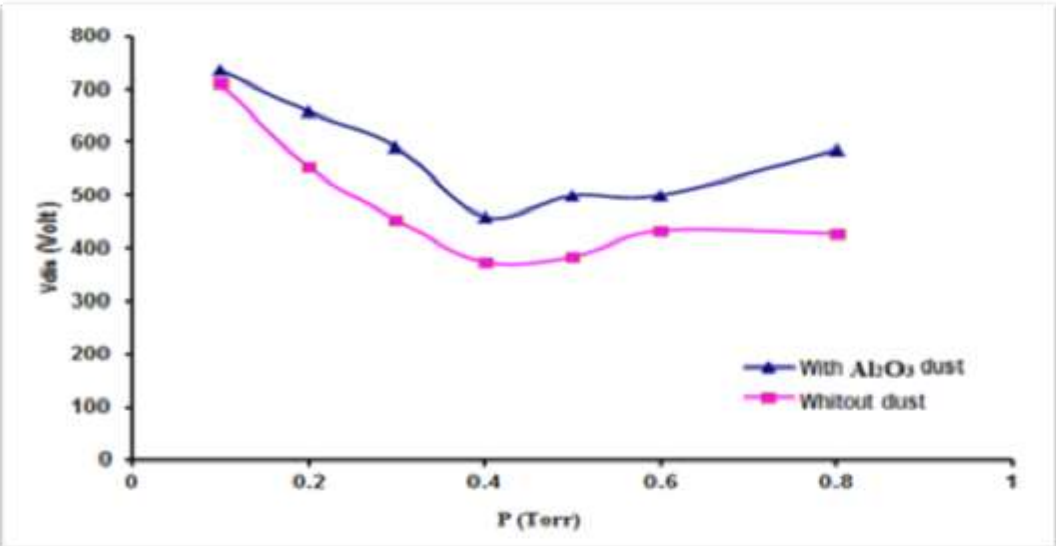

Figure (7): Schematic of the discharge voltage to different pressure (Paschen curve)

4-3 Langmuir Probe Measurement

The plasma characteristics of (electron and ion density, electron temperature, plasma potential and other) are measured by using cylindrical Langmuir probes at pressure (0.45) Torr at distance (20) mm from the cathode that will be evaluated and investigated. Figure (3) has showed that the photographs for the four probes (P1, P2, P3, P4) at distance (10, 30, 50, 70) mm are respectively from the top edge of the diameter of the cathode.
Figures (8, 9, 10, and 11) have shown that the behavior of the current and voltage of the fourth probes at different distances. From this figures one can conclude that the plasma characteristics (such as V_p, n_i, n_e, T_e).

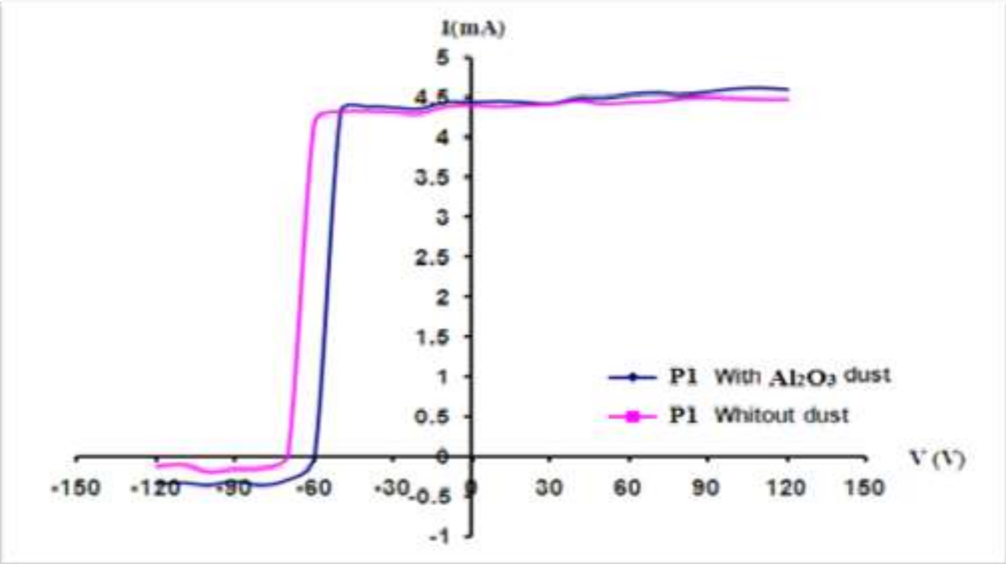

Figure (8) Characteristics of the first probe (P1) at distance 10 mm

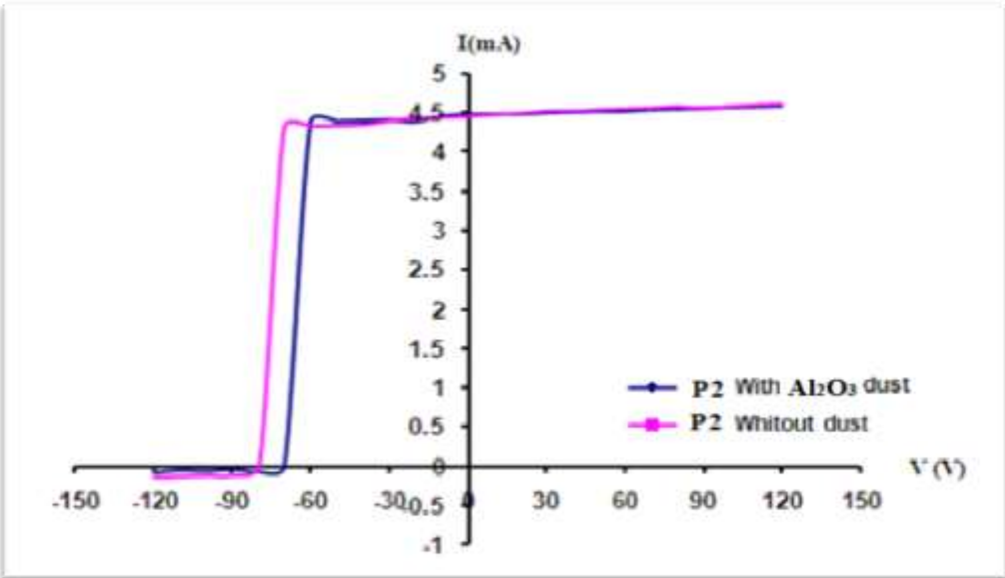

Figure (9) Characteristics of the Second probe (P2) at distance 30 mm

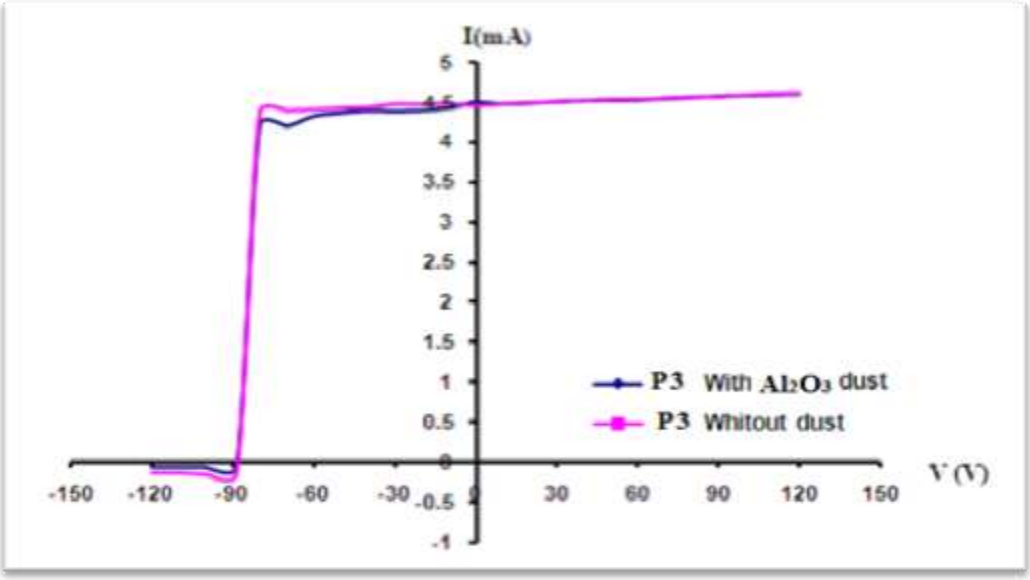

Figure (10) Characteristics of the Third probe (P3) at distance 50 mm

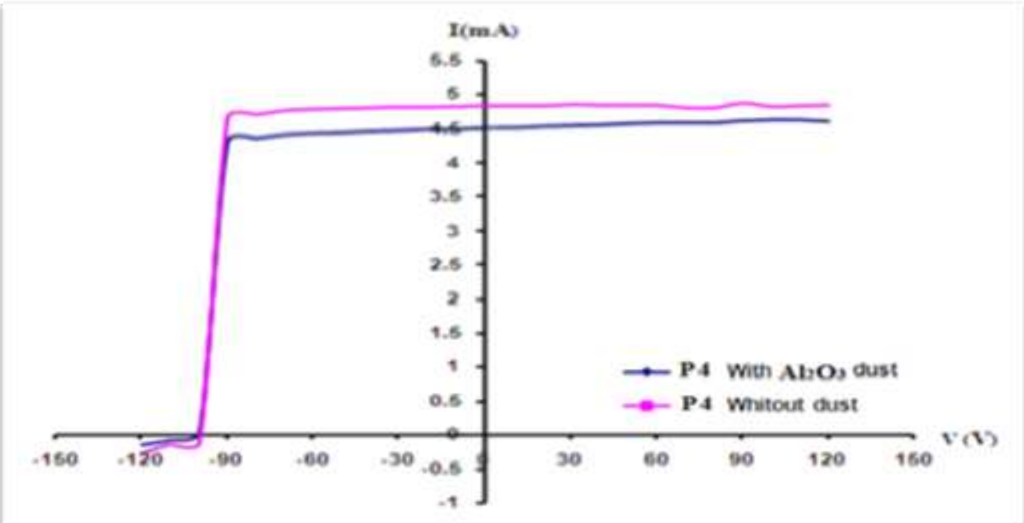

Figure (11) Characteristics of the Fourth probe (P4) at distance 70 mm

4-4 The measurement of Plasma Characteristics

Figure (12) shows the schematic of radial profile of plasma potential with and without Al_2O_3 dust particle in plasma, it is explicit from this figure. The presence of dust inside cathode sheath causes the plasma potential which goes toward negative values. This behavior can be explained as, when the Al_2O_3 dust embedded inside the plasma sheath, the electrons comes first (because of high mobility) after that the ions comes later. Because of the polarity of dust charged which depends on the emission of electrons. So that, the density of the ions decreases more than the density electrons. Therefore, the potential of plasma becomes negative.

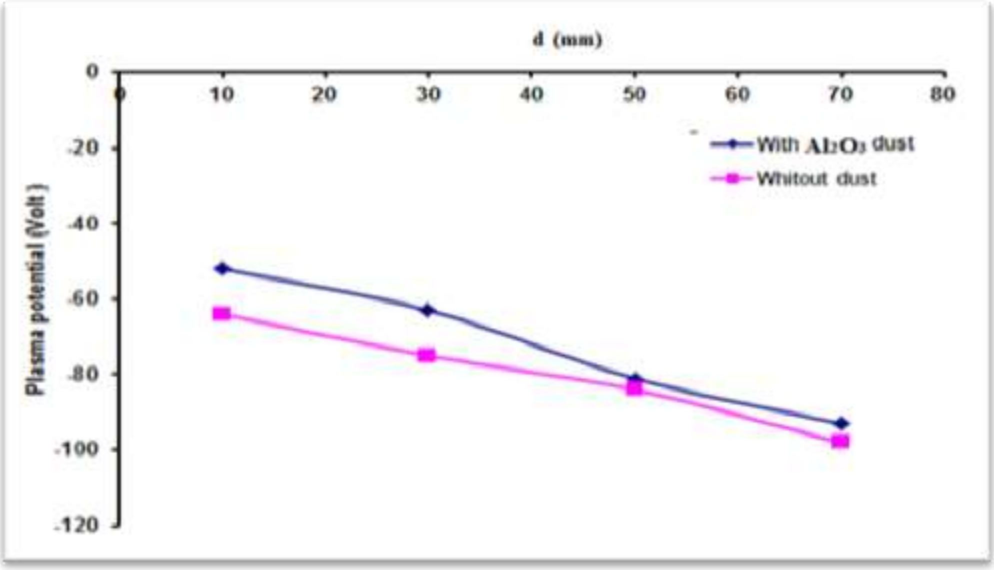

Figure (12): The plasma potential (V_p) with radial position distance (10, 30, 50, 70) mm of the probe

Moreover; figure (13) illustrates the experimental data of electrons saturation current (I_{es}). As mentioned above, the presence of Al_2O_3 dust in cathode sheath (cathode fall) has collected the electrons. According to that behavior, the saturation current of the electron is reduced.

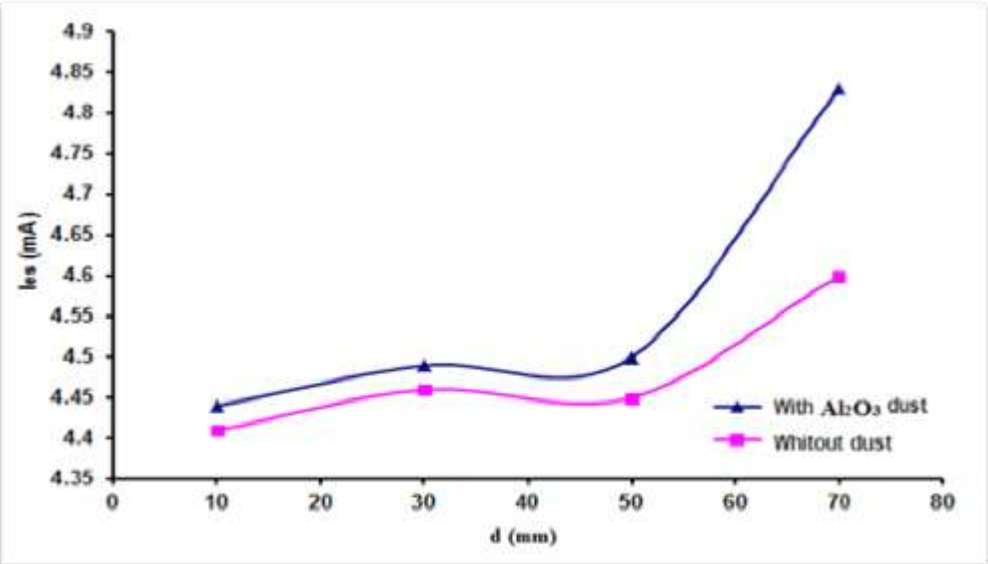

Figure (13): Radial profile of electron saturation current at distance (10, 30, 50, 70) mm of the probe

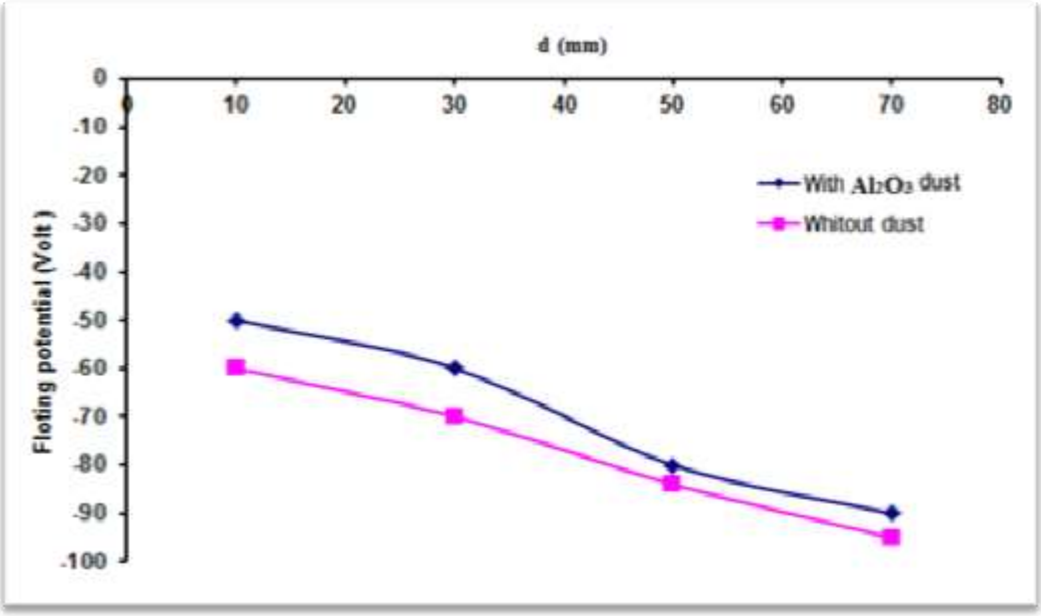

Figure (14): The floating potential (V_f) with radial at distance (10, 30, 50, 70) mm of the probe

The electron temperature is measured from the slope of Langmuir probe I_e-V curve of the probe characteristics. Figure (15) indicates the influence of Al_2O_3 dust on radial profile of T_e. The figure shows the pressure of dust particle that reduces the electron temperature. This reduction may be caused by the electrostatic potential of dust grain surface in order to repel the electrons from it. Thus the electron energy according to the experimental data of I_{es} from figure (13) and experimental data of T_e from figure (15), the radial distribution of ne with and without dust particles is plotted in figure (16).

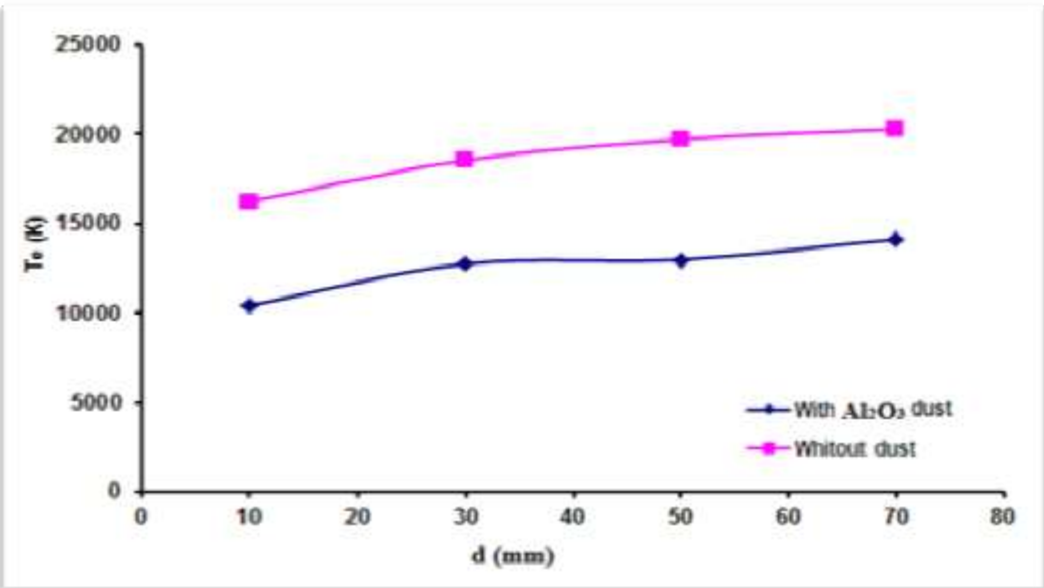

Figure (15): The electron temperature to the radial position at distance (10, 30, 50, 70) mm of the probe

It can be explicated from this figure, the losses of electrons causes by the classical diffusion, the collision of electrons with other plasma particle (ions and neutral atoms) and the electrostatic potential of dust causes to reduce of electron density in the presence of dust is plotted in figure (16). The figure (17) shows that the distribution in the density of ions is irregular with Al_2O_3 dust and without dust along the cathode at different distances; the presence of dust particles affects the ion density greater than the plasma mass.

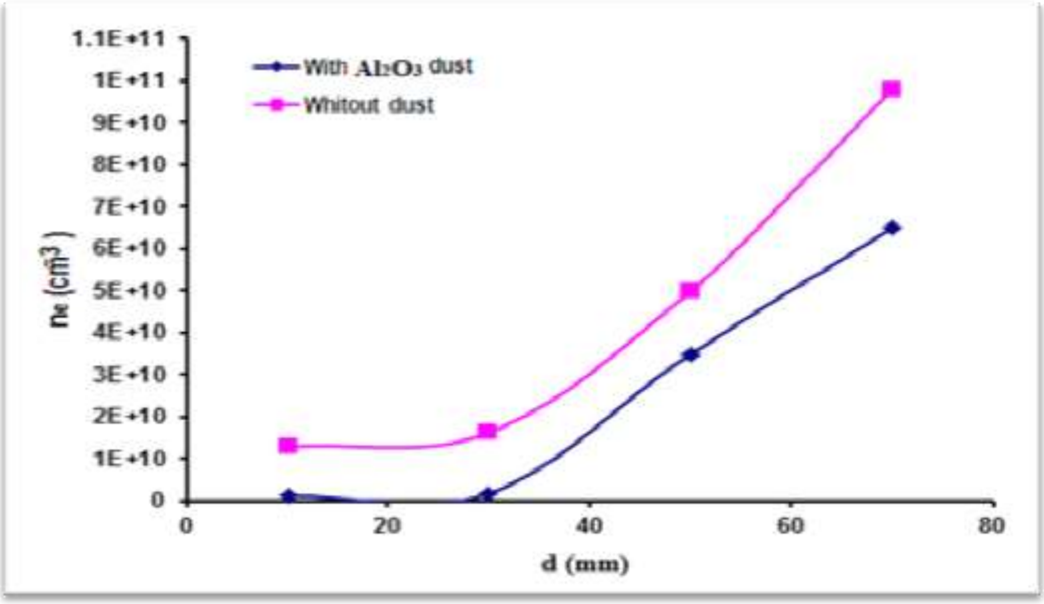

Figure (16): The electron density to the radial position at distance (10, 30, 50, 70) mm of the probe

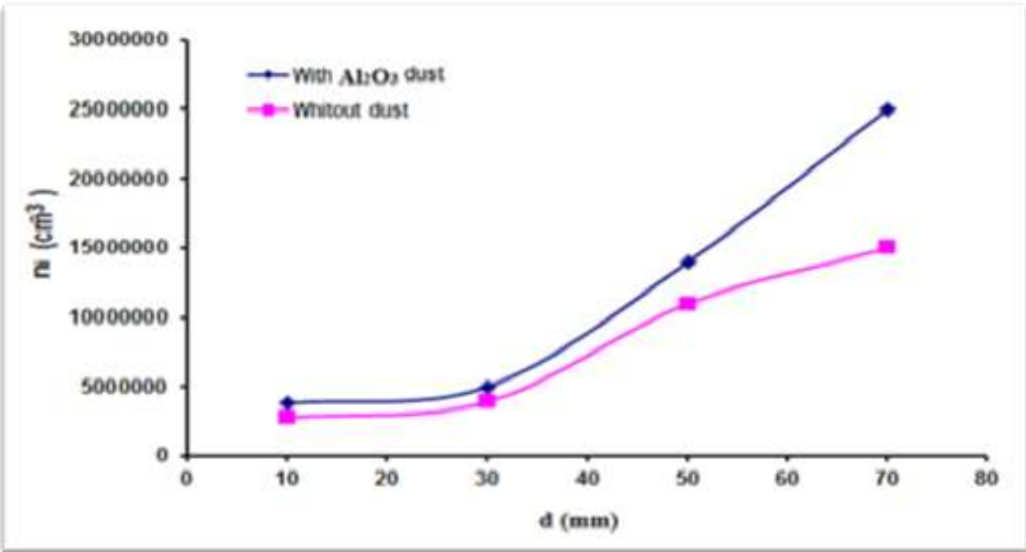

Figure (17): The ion density to the radial position at distance (10, 30, 50, 70) mm of the probe

5- Conclusion

This study has reached at the following conclusions:

- Paschen minimum stability in the presence of aluminum oxide dust and without dust is value of 0.4 Torr
- The properties of the plasma are studied along the cathode at a Paschen minimum (0.4 Torr) in which a decrease in the discharge current and an increase in the discharge voltage are observed in the presence of Al_2O_3 dust.
- The presence of aluminum oxide dust leads to increase the negativity of the floating potential of probe and plasma potential in the plasma region, resulting in an increase in the electron density and decrease its temperature.

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