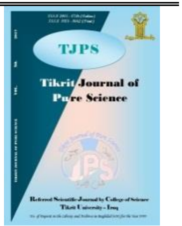
IASJ
المجلات الاكاديمية العراقية

Tikrit Journal of Pure Science
ISSN: 1813 – 1662 (Print) --- E-ISSN: 2415 – 1726 (Online)

Journal Homepage: http://tjps.tu.edu.iq/index.php/j



Electronic transport study for SF_6 Plasma

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https://doi.org/10.25130/tjps.v27i3.50

ARTICLE INFO.

Article history:
-Received: 2 / 4 / 2022
-Accepted: 15/ 5 / 2022
-Available online: / / 2022

Keywords: SF_6 gas, Transport equation, EEDF, Electronic transport coefficients

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ABSTRACT

Determination the electron transport parameters, (drift velocity (V_d) , mean electron energy ($\langle \in \rangle$), diffusion coefficient (D), mobility (μ) and ionization coefficient (α/N)), in an attempt to show the influence of the presence of dust on their behavior in a direct current low pressure SF_6 glow discharge .The Boltzmann Transport Equation (BTE), using two-term approximation are solved self-consistly. Making use of simulation model program for the numerical finite element method (FEM) of the boltzman equation to calculate the electron energy distribution function and the transport parameters in the range of reduced electric field E/N (300_1000 Td). As well as evaluated the electron temperature in pristine and dusty plasma and dust surface potential at E/N (40 Td) .

1. Introduction

In most cases the plasma contaminated with dust particles .These particles can range from nanometers up to microns in diameter and also become a significant electron sink , which can radically alter the local plasma parameters because of its importance for computing reaction rates , the EEDF has afundamental role in plasma modeling .The EEDF assumes that elastic collisions are dominating .

Dusty Plasma is the main interest recently due to its various technological fields such as accelerating chemical interactions and nanoscale material manufacturing [1,2,3], and used for industrial processes.[4,5].

Articles is focusing on DC,RF and MW discharges because of its values in the same fields as film deposition ,plasma etching [4,5,6,7,8] ,etc and the knowledge of the physical behavior of these glow discharges can be done through the determination of rate coefficients for Electron Energy Distribution Function EEDF ,excitation, ionization and transport parameters.

Several experiments [9] and numerical simulations [10,11] have been devoted to the determination of EEDF in dusty plasmas, and in most theoretical studies, the local approximation is used [12, 13, 14].

Here, we assumed a kinetic model (self-consistent) of dusty SF_6-glow discharge plasmas ,which is SF6 is a high electric strength gas,[15,16], by a solution of the Boltzmann Transport Equation (BTE) in case of a pristine and dusty plasma at low pressure weakly ionized which include the interaction between electron with dusty particle, and the dust charging balance relation [17], using currently cross-section data [18,19]

Our results contained a determination of electron transport parameters (mean electron energy ($\langle \in \rangle$), drift velocity (V_d), diffusion coefficient (D) ,mobility (μ) and ionization coefficient(α/N) in both cases .

The model includes a module for evaluate the Electron Energy Distribution Function (EEDF) in the range of reduced electric field strength E/N (300_1000 Td) in two cases as a result of between electrons and dust particles interactions.

2. Theory

2.1 Assumptions:

A steady state of electron DC-SF_6 discharge sustained in a spatially uniform electric field (E), pressure (1Torr) plasmas contaminated with a spherical dust particles (same sizes).Our assumptions also include the effects of superelastic collisions among electrons and atoms, as well as excitation from low to high atomic states are neglected .

The anisotropy of the EEDF remains low which mean the distribution function can be well represented by a two-term expansion in spherical harmonics .

DC glow discharges, the degree of gas ionization is also low so electron-electron and electron-ion collision are disregarded .

2.2 EEDF :

The study of electron transport properties like drift velocity, mobility and mean electron energy shades more light on the physics of gases. To obtain these characteristics , knowledge is required for kinetic model of electron inside the gas and for accurate studies, one can use the Boltzmann Transport Equation (BTE) as a theoretical investigation tool. According to preceding assumptions, (EEDF) can be obtained by solving the BTE :

$$\frac{2eE^2}{3m_e}\frac{d}{d\in}\left[\frac{\in^{3/2}}{\nu(\in)}\frac{df(\in)}{d\in}\right]=S_{ea}(f)+S_{ed}(f) \quad (1) \quad ....$$

Which is normalized by :

$$\int_0^\infty f(\in)\in^{1/2} d\in=1\cdots (2)$$

The term on the left-hand side of equ.(1) describe the heating by the electric field. The right hand side contains both $S_{ea}(f), S_{ed}(f)$ the electron-atom and the electron-dust collisions integral terms, respectively. (E) externally applied electric field, ν is the total collision frequency and $\in = m_e \upsilon^2/2e$ is the electron kinetic energy .

The electron-atom collision term has many ingredients. One begins with

$$S_{ea}^{c}(f)=-\frac{d}{d\in}\left[\frac{2m_e}{m_i}\in^{3/2}\nu_{ea}^{c}(\in)f(\in)\right]\cdots (3)$$

The contribution from elastic collision, ν_{ea}^{c} is the electron-atom elastic collision frequency.

The inelastic processes can be decomposed into two main parts, the collision induced
atomic excitations are represented by:

$$S_{ea}^{ex}(f)=\sum_k\left[\nu_{ea}^{k}(\in)f(\in)\in^{1/2}-\nu_{ea}^{k}(\in+\mathrm{V_k})f(\in+\mathrm{V_k})(\in+\mathrm{V_k})^{1/2}\right]$$

… (4)

Where ν_{ea}^{k} is the collision frequency of the kth inelastic process with a threshold energy $\vee_k$ An ionizing collision results in an extra electron, assuming that the available energy of the original and the newly generated is equalizing. The term of collision ionization is written as [20]:

$$S_{ea}^{i}(f)=\nu_{ea}^{i}(\in)f(\in)\in^{1/2}-4\nu_{ea}^{k}(2\in+\mathrm{V}_i)f(2\in+\mathrm{V}_i)(2\in+\mathrm{V}_i)^{1/2}$$

…(5)

Our consideration is only one main ionization process with the frequency ν_{ea}^{i}, the threshold energy $\vee_i$ = 15.7 eV.

As explain in ref.(12) :"The electron-dust interaction includes the distortion of the electrons from the coulomb like potential on the dust, and the electron loss caused by absorption into the dust particle. The electron-dust collision term is modeled by" :

$$S_{ed}(f)=-\frac{d}{d\in}\left[\frac{2m_e}{m_d}\in^{3/2}\nu_{ed}^{e}(\in)f(\in)-\nu_{ed}^{c}(\in)f(\in)\in^{1/2}\right]$$

…(6)

Where ν_{ed}^{e} and ν_{ed}^{c} are the momentum transfer, and the electron absorption frequency of the electron-dust system respectively, and m_d the dust mass.[20,17]

The electron cross section for SF$_6$-atoms (momentum transport, excitation, ionization, vibration-excitation, attachment) are chosen for transport section from [21] ,excitation [22] and ionization [23] ,(all the sets of cross section used here were self-consisted).

2.3 Charging :

Widely and best known used model is the Orbital Motion Limited (OML),that able to estimate with a good accuracy in a very simple way the surface potential (ϕ_s) and number of charge on a dust .

For a given EEDF ,the electron current collected by a dust grain in the OML approximation is [24] :

$$I_e=-\pi a_d^2 e n_e\int_{-\phi_s}^{\infty}\left(1+\frac{\phi_s}{\in}\right)\sqrt{\frac{2e\in}{m_e}}f_0(\in)\sqrt{\in}d\in \cdots\cdots (7)$$

The ion current is [23] :

$$I_i=\pi a_d^2 e n_i\left(1-\frac{\phi_s}{\in}\right)\sqrt{\frac{2e\in_i}{m_i}} \quad ....(8)$$

Where $\in_i$ is the averaged ion energy

The Orbit Motion Limited (OML) theory used to obtain the dust surface potential from the equalization between the electron and ion currents. And apply the theory of orbit when the condition the following

$$a_d << \lambda_D << d$$

Suppose also that the radius of the particles are relatively small (a_d) and the distance between the dust grains (d) much larger than the Debye length (λ_D).

The dust surface potential related to the number of charge (Z_d) by [26] :

$$Z_d = 0.692 * 10^3 / \phi_s / .a_d(\mu m) \quad ....(9)$$

and the quasineutrality condition :

$$n_e + n_d|z_d| = n_i \quad ..... (10)$$

is satisfied.

2.4 Electron Transport Coefficients:

Once the EEDF is a number of electron transport factors can be determined in clean and dusty plasma for a wide range of E/N (300-1000Td).

The electronic drift velocity (V_d) was calculated as follows:

$$V_d=-\frac{E}{3}\left(\frac{2e}{m}\right)^{1/2}\int_0^\infty\frac{\in}{N\sigma_m}\frac{\partial f_0(\in)}{\partial\in}d\in \quad .....(11)$$

The mean electron energy ($\langle\in\rangle$) was computed as [27,28]:

$$\left\langle \in \right\rangle = \frac{2}{3}\int_0^\infty \in^{3/2} f_0\left(\in\right) d\in \text{.....(12)}$$

and the electronic diffusion coefficient(D):

$$D = \frac{1}{3}\left(\frac{2e}{m}\right)^{1/2}\int_0^\infty \frac{\in}{N\sigma_m} f_0\left(\in\right) d\in \;\text{.... (13)}$$

Then, the electronic mobility (μ) was obtained as :

$$\mu = \frac{V_d}{E} \;\text{.... (14)}$$

And ionization coefficient (α/N) calculated from: (: ionization factor)

$$\frac{\alpha}{N} = \frac{1}{V_d}\left(\frac{2e}{m}\right)^{1/2}\int_0^\infty \sigma_i\left(\in\right)\in f_0\left(\in\right) d\in \;\cdots\text{ (15)}$$

2.5 Numerical method :

Finite Element Method (FEM) is used in our present investigation as a numerical approach. The solution of equ. (1) have been lead to EEDF in pure pristine argon discharge plasmas in firstly and with dust (r_d = 0.5 µm, n_d = 3.0 x 10^8 cm^{-3}) in the second run for the E/N range (300_1000 Td) . Under the condition the gas pressure is 1 Torr, the gas temperature is 300 K^0 ,the gas density is N = 3.22 x 10^{16} cm^{-3}, the average ion energy is E_0 = 0.06 eV and the mass ratio of electron to dust is m_e / m_i = 3.4 x 10^{-6}

The two-term approximation is a very simplified technique which we expand the EEDF that lead to determined the electron transport coefficients for two cases.

Solution of the equation (1) numerically using the selected item and thus get a set of linear algebraic equations that can be solved using Gauss Elimination Method.

In order to boot to solve the equation (1) in a selected item, it must be simplified and converted into a form which can use the numerical method, after conducting several operations we can write mathematical equation generally follows :

$$f''(\in) + p(\in)f'(\in) + q(\in)f(\in) = 0 \quad \text{...... (16)}$$

Where :

$$p(\in) = [\frac{1}{\in} + \frac{C2\sigma^e_{ea}\in}{C1} + \frac{\sigma^e_{ea}\sigma^{ex}_{ea}\vee_{ex}}{C1} + \frac{\sigma^e_{ea}\sigma^{ex}_{ea}\vee_{ex}}{C1\in} + \frac{4\sigma^e_{ea}\sigma^i_{ea}\vee_i}{C1} + \frac{4\sigma^e_{ea}\sigma^i_{ea}\vee_i^{\,2}}{C1\in} \qquad (17)$$
$$+ \frac{3\sigma^e_{ea}\sigma^{vex}_{ea}\vee_{vex}}{C1} + \frac{3\sigma^e_{ea}\sigma^{vex}_{ea}\vee_{vex}^{\,2}}{C1\in} + \frac{N_d}{N}\frac{2C3\sigma^e_{ea}\sigma^e_{ed}\in}{C1}]$$

And

$$q(\in) = [\frac{2C2\sigma^{e\;2}_{ea}}{C1} + \frac{\sigma^e_{ea}\sigma^{ex}_{ea}\vee_{ex}}{C1\in} + \frac{3\sigma^e_{ea}\sigma^i_{ea}}{C1} + \frac{4\sigma^e_{ea}\sigma^i_{ea}\vee_i}{C1\in} + \frac{3\sigma^e_{ea}\sigma^{vex}_{ea}\vee_{vex}}{C1\in} \qquad (18)$$
$$+ \frac{N_{att}}{N}\frac{3\sigma^e_{ea}\sigma^{att}_{ea}\vee_{att}}{C1} + \frac{N_d}{N}\frac{4C3\sigma^e_{ea}\sigma^e_{ed}}{C1} - \frac{N_d}{N}\frac{\sigma^e_{ea}\sigma^c_{ed}}{C1}]$$

Where :

σ^e_{ea} ‘ σ^{ex}_{ea} ‘ σ^i_{ea} ‘ σ^{vex}_{ea} ‘ $\sigma^{a\ t}_{ea}$ ‘ σ^e_{ed} ‘ σ^c_{ed} : elastic, excitation, ionization, vibration-excitation, attachment, momentum transport (e-d) and collected (e-d) cross sections.

And re-arrange the equation (18) :

$$f''(\in) = -[\frac{1}{\in} + \frac{C2\sigma^e_{ea}\in}{C1} + \frac{\sigma^e_{ea}\sigma^{ex}_{ea}\vee_{ex}}{C1} + \frac{\sigma^e_{ea}\sigma^{ex}_{ea}\vee_{ex}}{C1\in} + \frac{4\sigma^e_{ea}\sigma^i_{ea}\vee_i}{C1}$$
$$+ \frac{4\sigma^e_{ea}\sigma^i_{ea}\vee_i^{\,2}}{C1\in} + \frac{3\sigma^e_{ea}\sigma^{vex}_{ea}\vee_{vex}}{C1} + \frac{3\sigma^e_{ea}\sigma^{vex}_{ea}\vee_{vex}^{\,2}}{C1\in} + \frac{N_d}{N}\frac{2C3\sigma^e_{ea}\sigma^e_{ed}\in}{C1}]f'(\in) \quad \text{.... (19)}$$
$$-[\frac{2C2\sigma^{e\;2}_{ea}}{C1} + \frac{\sigma^e_{ea}\sigma^{ex}_{ea}\vee_{ex}}{C1\in} + \frac{3\sigma^e_{ea}\sigma^i_{ea}}{C1} + \frac{4\sigma^e_{ea}\sigma^i_{ea}\vee_i}{C1\in} + \frac{3\sigma^e_{ea}\sigma^{vex}_{ea}\vee_{vex}}{C1\in}$$
$$+ \frac{N_{att}}{N}\frac{3\sigma^e_{ea}\sigma^{att}_{ea}\vee_{att}}{C1} + \frac{N_d}{N}\frac{4C3\sigma^e_{ea}\sigma^e_{ed}}{C1} - \frac{N_d}{N}\frac{\sigma^e_{ea}\sigma^c_{ed}}{C1}]f$$

Where :

$$C1 = \frac{1}{3}(\frac{E}{N})^2 \;,\quad C2 = \frac{2m_e}{m_i} \;,\quad C3 = \frac{m_e}{m_d}$$

Using the selected item can be written main matrix equation as follows:

$$A = \frac{1}{l}\left[-1 + \frac{1}{2}p_i l + \frac{1}{6}q_i l^2 \quad 2 + \frac{2}{3}q_i l^2 \quad -1 - \frac{1}{2}p_i l + \frac{1}{6}q_i l^2\right] \;\text{.... (20)}$$

The secondary matrix produces after applying boundary conditions would be formed by General follows:

$$B=\begin{bmatrix} 1-\frac{1}{2}p_0 l-\frac{1}{6}q_0 l^2 \\ 0 \\ . \\ . \\ . \\ 0 \\ 1+\frac{1}{2}p_{300} l-\frac{1}{6}q_{300} l^2 \end{bmatrix}$$

After the formation of the main and secondary matrices we use Gauss Elimination Method to account EEDF: [28-30]

$$f=A^{-1}B \quad ....(21)$$

3. Results and discussion

In the present paper, a self-consistly BTE are solving to determine the normalized EEDF in DC-SF_6 glow discharge and the electron transport parameters in the pristine and contaminated plasmas by using FEM.

Fig.1. show the EEDF for the cleaned and dusty plasma as a function of electron energies at E/N = 40 Td .Due to the high collision frequency in the very low electron energies, because of the dominated momentum transfer electron – dust collision, a small peak appear in the very low energy region because of the generation of the large number of low electron energy. Its also found a shift in the dusty EEDF curve to the left because of the absorption and collection of the high energy electrons by dust. as well as, decreasing in its behavior after the electron energy (4.58 eV). Also, noted the dusty (EEDF) in the low energy region larger than the (EEDF) in pristine case because of the increased the total collision frequency due to the presence total momentum transfer (e-d), causing increasing in the number of electrons in this region.

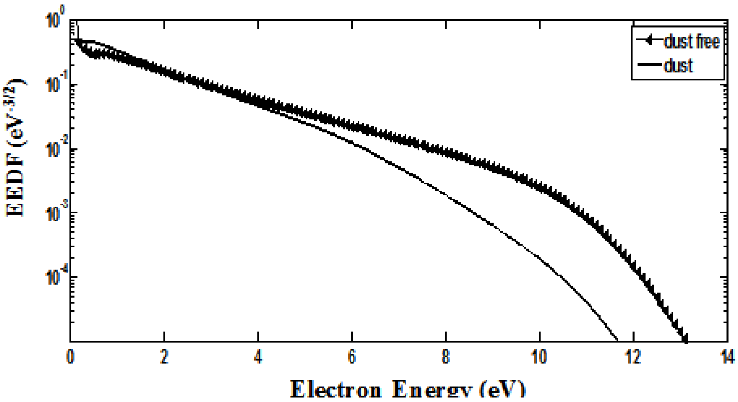

Fig. 1: EEDF in dust-free (solid triangle line) and dusty (dashed line) plasma at E/N = 40 Td.

Our calculating contained values of electron temperature (T_e =1.93 eV) in the dust free and (T_e =1.48 eV) with the dust surface potential (ϕ_s = - 4.58 Volt) in the dusty case under the same conditions. The number of charge on dust particles (1584.68) are evaluated from equ.(9) through dust surface potential (-4.58 V), Which is calculating from the equalization between electron and ion currents. We observed that the increasing in the total collision frequency in the low (E/N) region leads to a further loss of electron energy in dusty case, which making a depression in its temperature ($\in$ kT_e Maxwellian) and the large difference at the beginning is due to a high surface potential, which collected a large number of electrons.

We found in fig.2 that the drift velocity in dusty plasma become less than in case of pristine plasma, because of the presence of inelastic processes (interactions vibration - excitation and attachment interactions) as well as the processes resulting from the presence of dust in very low energies regions which prevents electrons from lifting its energies or prevents the electrons from appearance .

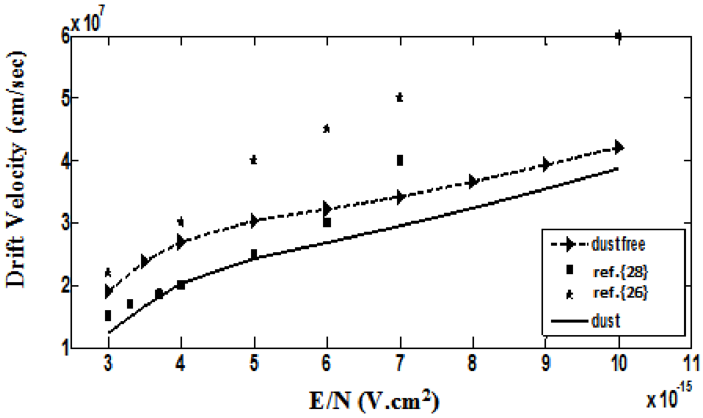

Fig. 2: Electron drift velocity in dust-free (dashed triangle line) and dusty (solid line) SF6 glow discharge as a function of (E/N)

Due to the increasing of the momentum transfer electron-dust collisions in the low E/N region, the mean electron energy as in fig.3 of dusty plasma become less than in case of the pristine plasma, and the difference in high E/N region very small because of dusty particles become more negatively.

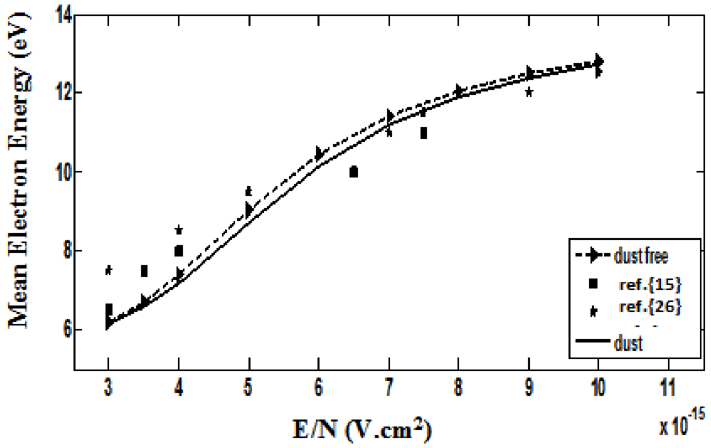

Fig. 3: Mean electron energy in dust-free (dashed triangle line) and dusty (solid line) SF6 glow discharge as a function of (E/N)

The fig.4 explain clearly increasing in diffusion coefficient with E/N because of presence inelastic processes (interactions vibration - excitation and attachment interactions) low energies regions. And with the presence dusty particles, the diffusion coefficient become less than in case of the pristine plasma because the collected collision frequency (e-d) very larger than momentum transfer collision frequency .

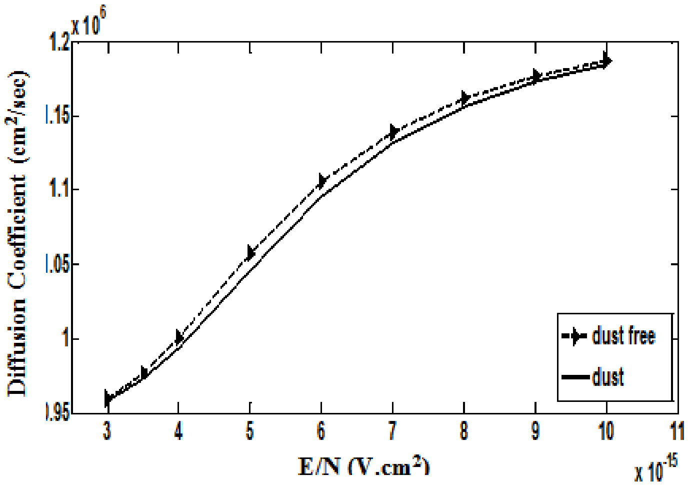

Fig. 4: Electron diffusion coefficient in dust-free (dashed triangle line) and dusty (solid line) SF6 glow discharge as a function of (E/N)

Fig.5. confirm the behavior of the electronic mobility in dusty plasma become less than in case of cleaned plasma because the direct proportion between mobility and drift velocity. And we notes increased mobility of electrons with increase in the both curves within the range (400 ≥ E / N ≥ 300) Td due to presence inelastic interactions which led to make the mobility in dusty case less than in pristine plasma.

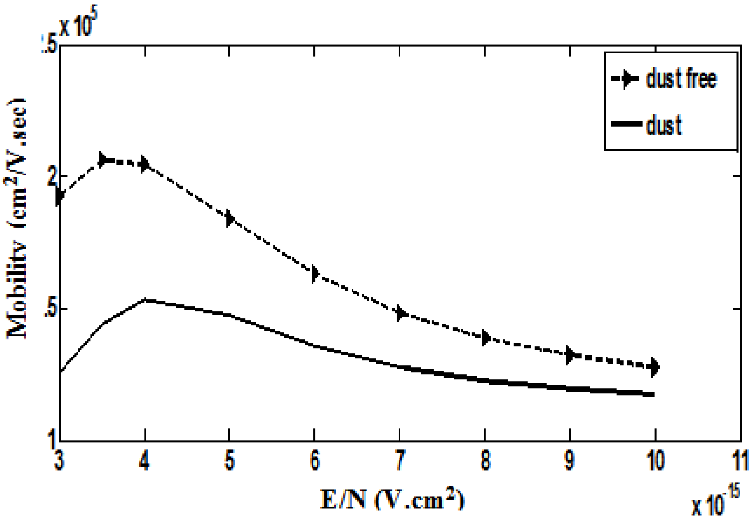

Fig. 5: Electron mobility in dust-free (dashed triangle line) and dusty (solid line) SF6 glow discharge as a function of (E/N)

In fig.6, plotted ionization coefficient as a function of E/N and we noted a decreasing of the ionization coefficients in the dusty plasma since the redistribution of the high energy portion of the EEDF results in a corresponding decrease in the ionization coefficient

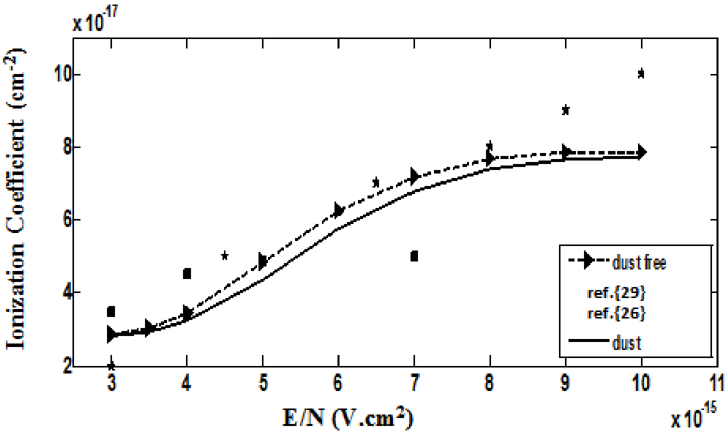

Fig. 6 :Ionization rate coefficient in dust-free (dashed triangle line) and dusty (solid line) SF6 glow discharge against (E/N)

4. Conclusions

By solving the steady state boltzmann equation, the electron energy distribution function and transport coeficients have been calculated and making a comparison to that which are published. Results show that as E/N increases, the dust potential becomes more negative and dust grains affected clearly on EEDF and electron transport coefficients. In most figures of electron transport coefficients we found the influence of dust particle in low E/N region larger than high E/N region. In most figures at low E/N region we found the large effect of dusty particles on transport coefficients in both cases.

Acknowledgments

The authors would like to thank Dr. Salem Y A for his assistance.

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الدراسة الانتقالية الالكترونية لبلازما سادس فلوريد الكبريت

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الملخص

تحديد المتغيرات الانتقالية الالكترونية (سرعة الانجراف (V_d)، معدل الطاقة الالكتلرونية ($\langle \in \rangle$) معامل الانتشار(D)، الحركية (μ)، معامل التأين (α/N)) كمحاولة لتوضيح تأثير وجود الغبار على سلوكية هذه الالكترونات في التفريغ الكهربائي لغاز (SF6) للتيار المستمر. تم حل معادلة بولتزمان الانتقالية عدديا باستخدام طريقة العنصر المحدد ومن خلال تقريبها بتطبيق التقريب ذي الحدين ضمن مدى المجال الكهربائي المختزل (E/N) (300-1000 Td)، فضلا عن حساب الدرجة الحرارية الالكترونية في البلازما النظيفة والمغبرة اضافة الى الجهد السطحي لجسيمة الغبار عند (40 Td).