Analysis of the electron energy distribution function and its transport coefficient in SF_6-CO_2 applied gas mixtuers

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تحليل دالة توزيع طاقة الالكترون ومعلمات الحشد في خليط من غازي سداسي فلوريد الكبريت وثنائي اوكسيد الكاربون

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المستخلص

تم استخدام معادلة الأنتقال الطاقي لبولتزمان لحساب معلمات انتقال الألكترونات و دالة التوزيع الطاقي للألكترونات في كل من SF_6, CO_2 النقي وخليطيهما. وقد تم استخراج معلمات الحشد الألكتروني المتمثل بمعامل الانتشار للالكترونات و متوسط طاقة الالكترونات ضمن المدى ($9 \times 10^{-15} \le E / N \le 5 \times 10^{-16}$) فولت.سم^2. ان حركة الالكترونات في بلازما غاز SF_6 وخلطه مع CO_2 بوجود مجالات كهربائية منتظمة تمثل حسابيا من خلال معادلة الانتقال الطاقي لبولتزمان والمتمثلة في البرنامج code- Kinema-Elendif و المكتوب بلغة فورتران 77.وقد وجد بأن دوال التوزيع هي لاماكسويلية و تمتلك اختلافات في الطاقة تعكس دور عمليات تبادل طاقة الأكترون الجزيئي.

Abstract

The Boltzmann transport equation is used to calculate the electron energy distribution function (EEDF) and the transport coefficient in pure sulfur hexafluoride (SF_6) and pure Carbon dioxide (CO_2) and their mixtures. The electron swarm parameters are evaluated in the range of ($5 \times 10^{-16} \le E / N \le 9 \times 10^{-15}$) V.cm^2. These parameters namely are: The Diffusion coefficient of electrons and mean electron energy. The motion of electrons in plasma gas (SF_6) and mixing it with (CO_2) under an applied uniform electric field is simulated by using the numerical solution of Boltzmann's transport equation technique. The numerical solutions are utilized within the international computer code kinema-Elendif and written in Fortran 77 language software. The calculated distribution function is found to be remarked non-Maxwillian that has energy variations which reflect the import electron-molecule energy exchange processes.

Keyword: *Plasma, Electron Discharges, Dielectric property, Swarm Parameter, Kinetic Theory of Gases, Electron Energy Distribution Function.*

Introduction

For many years, the electric power industry has been using Sulfur Hexafluoride (SF_6) gas as a dielectric and insulating material. In the event that replacement gases are consider a reasonable approach to reduce the use of SF_6 in high voltage electrical equipment.

The SF_6 gas is popular due to its unique physical and electrical properties as: nontoxic, nonflammable, noncorrosive, chemically stable with high breakdown strength and its dielectric strength is twice that of air [1, 2 and 3].

Considering the relatively poor dielectric strength of environment-friendly pure gases and gas mixtures such as air, A gas used as a dielectric medium must have high dielectric strength, which is possible only with strong electronegative gases such as SF_6, from a practical view, at partial concentrations of a few percent as possible substitute gases for pure SF_6, which can reduce the negative effects on the atmosphere environmental pollution effectively. The candidates for pure gases mixed with SF_6 are required to have sufficient insulation and current interruption capability [4, 5].

Eventually, the N_2 and CO_2 gases are the possible candidates that can be used for their chemical stability and no flammability or explosiveness as a result of gaining superior dielectric strength. In point of fact, the CO_2 gas has started to gain attention as an arc-quenching medium.

In a matter of fact, CO_2 cannot completely replace SF_6 due to its low current interruption performance of high-voltage levels compared to that of pure SF_6 gas. As a result, the most promising candidates to substitute SF_6 gas is the SF_6–CO_2 mixtures. [3, 6]

A study of the electron energy distribution function in pure SF_6 and CO_2 and their mixtures are presented using the numerical solution of the Boltzmann equation for the Electron Energy Distribution Function in low-ionized plasma by using the code of kinema-Elendif which has been written in Fortran 77 language software. It is used to calculate the electron transport and kinetic coefficients in gas mixtures [7].

The data of momentum transfer (elastic collision) cross-section, the electronic excitation cross-section and the vibration cross-section for SF_6 gas has been taken from Diefenbacher [8].

Three types of inelastic cross-section in CO_2 have considered as:

1- The vibration cross-section has been divided into four main vibration levels as given by Pitchford & Phelps [9] with onset energies (0.0827, 0.291, 0.580 and 0.870) eV.
2- The total ionization cross-section having onset energies of 13.3eV is given by Soonja *et al* [10].
3- Excitation cross-section is given by Sierra *et al* [11].

Theory

Boltzmann equation.

The classical theory of transport processes is based on the Boltzmann transport equation; this equation can be driven simply by defining a distribution function and inspecting its time derivative. From this equation many important swarm parameters could be derived that it is still being used in many contemporary research projects to model transport phenomena [3].

The general form of the Boltzmann equation is [1, 2 and 3]:

$$\left(\frac{\partial}{\partial t} + V.\nabla_r - \frac{eE}{m}.\nabla_V\right) f(r,v,t) = \left(\frac{\delta}{\delta t}\right)_{coll.} \quad \ldots\ldots\ldots\ldots (1)$$

Where $f(r,v,t)$ is the electron velocity distribution function (EVDF) at time t and spatial location r, V is the electron velocity, ∇_r is the gradient in r-space while (e/m) is the ratio of electron charge to its mass which is refers to the acceleration due to applied electric field (E) in ($V.cm^{-1}$), ∇_V is the gradient in V-space and $\left(\frac{\delta}{\delta t}\right)_{coll.}$ is the collision integral which accounts for electron energy transferred in elastic and inelastic collision.

The left hand side of the equation describe the behavior changes of electrons energy distribution function (EEDF) by the verity independent collisions while the right hand side describes the binary collisions of charges particles with the neutral gas species [5,6].

It is well known that the swarm parameters of electrons and collision cross-sections with molecules are related to each other's through the medium of the velocity distribution function of the swarm.From the electron energy distribution function one can calculate the swarm parameters which they are diffusion coefficient of electrons and mean electron energy.

The diffusion coefficient of electrons is:-

$$D = \frac{1}{3}\sqrt{\frac{2e}{m}}\int_0^\infty \frac{u}{N\sigma_m} f_o(u)d\varepsilon \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where N is the gas density, σ_m is the momentum transfer cross section for elastic scattering and u is the electron energy expressed in electron volts.

The Mean electron energy is [2]:

$$\varepsilon = \frac{2}{3}\int_0^\infty u^{3/2} f_o(u, E/N, T)du \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Values of $f_o(u)$ is calculated from Boltzmann's equation using overall collision cross-sections.

It's necessary to note that there exists another mathematical technique for solving the Boltzmann transport equation by using the Monte Carlo method and involving the calculation of the electron transport or swarm parameters [4, 7].

Calculations and results

The EEDF for pure SF_6 and pure CO_2 and their mixture (SF_6-CO_2) for the different concentration are plotted as a function of E/N values and they are completely described in Figure (1, 2 & 3).

The present study has resulted in a set of cross-sections for SF_6 and CO_2 which is consistent with measured swarm parameters for pure SF_6 and CO_2 respectively**.** The Reliability of these cross-sections and the Boltzmann equation procedure has been further tested by the comparison of measured and predicted values.

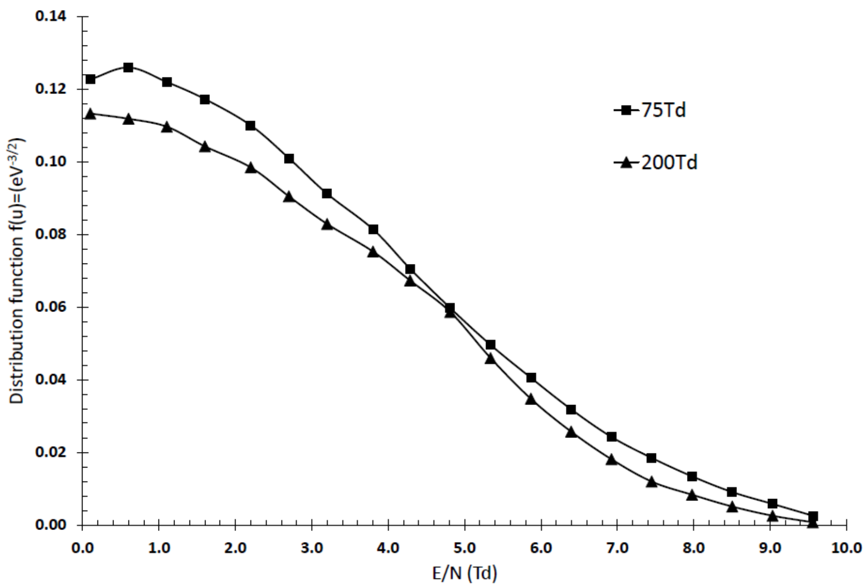

Figure (1): The distribution function as a function of E/N for pure SF_6.

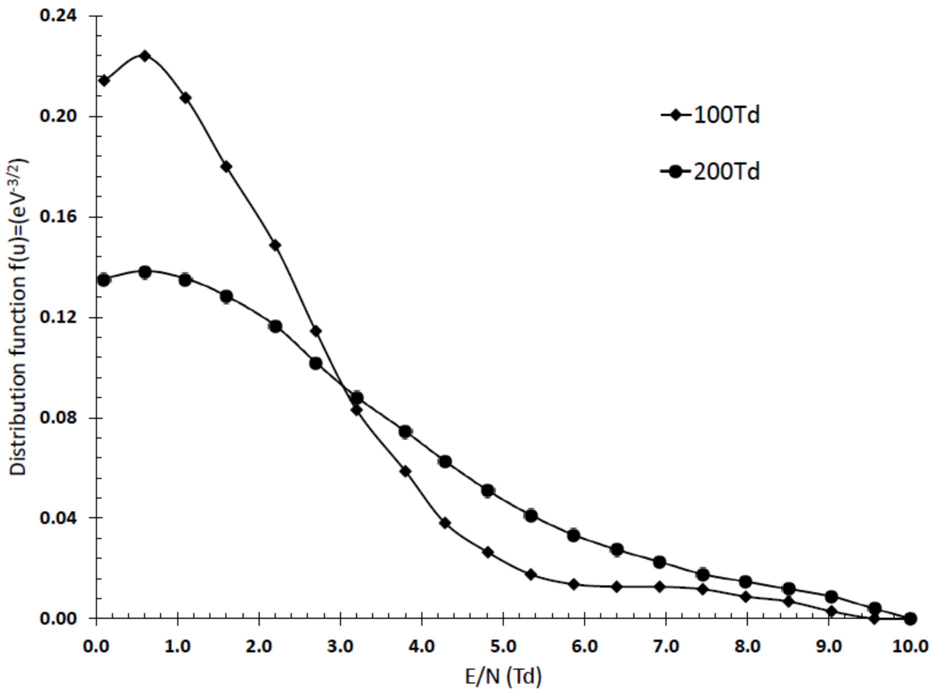

Figure (2): The distribution function as function of E/N in pure CO_2.

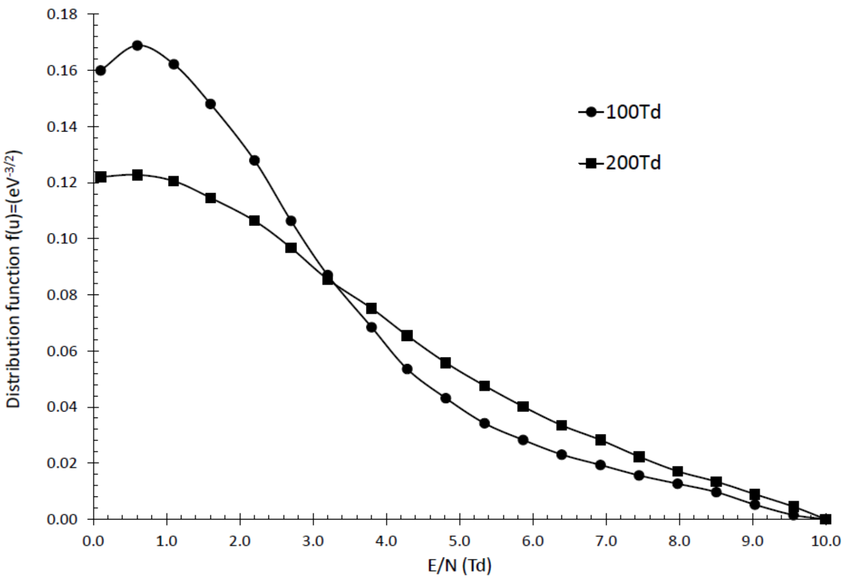

Figure (3): The distribution function of (SF_6-CO_2) (50-50) % as a function of E/N value.

respectively for pure SF_6, pure CO_2 and their mixtures as a function of E/N values.

The calculated transport coefficient which are the diffusion coefficient of the electron (D) and the mean electron energy (ε) presented in figure (4 and 5)

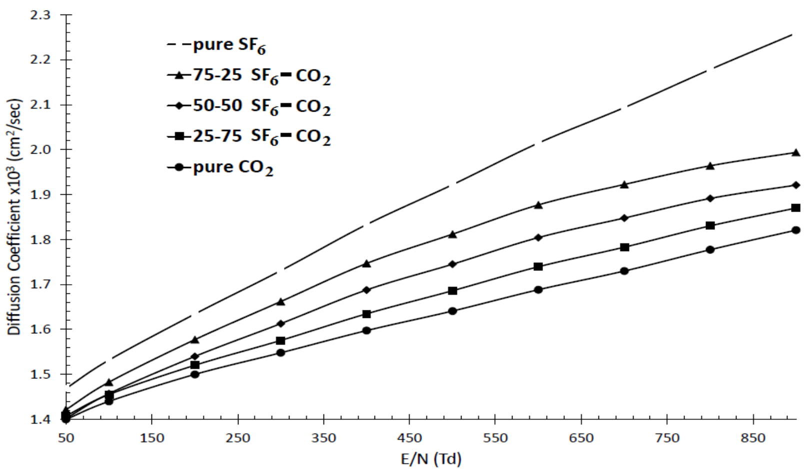

Fig (4): The diffusion coefficient of as a function of E/N for different ratio gas mixtures.

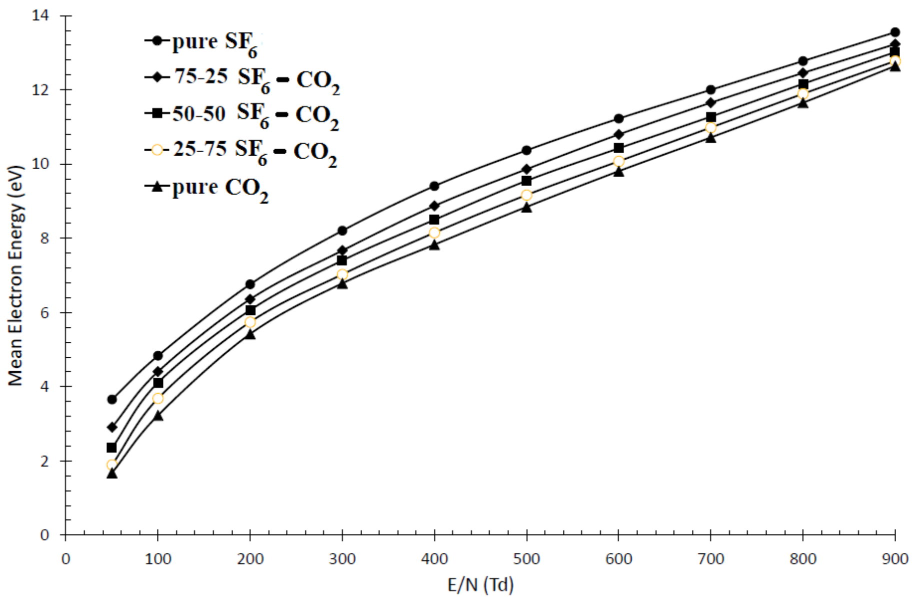

Figure (5): The mean electron energy of as a function of E/N for different ratio gas mixtures

Discussion and conclusion

It is important to say that the calculations of the electron transport parameters in (SF_6-CO_2) gas mixture reflect the advantages and disadvantages of each concentration mixing ratio. Therefore, one can choose the optimum cases that give a good compatible applied gaseous mixture.

A set of electron collision cross section, which is chosen to be as a consistent as possible with experiment to each of pure gases has been used.In Figure (1), the electron energy distribution function is affected by changing the parameter E/N. At low E/N values, the SF_6 gas having higher attachment cross sections at low energy. This mean that, low E/N fluctuation results from the acceleration of each electron during the interval between collisions in the low energy region where the direction of the electrons is easily changeable by the electric field. Therefore, at high E/N values the SF_6 become higher electronegativity gas. So, one can see the distribution functions are clearly non-Maxwillian and having variable distinct curvatures at all electron energies.

In figure (2), the vibrational energy losses in CO_2 is distributing more energy, therefore, structure in *f(u)* is less apparent. Nevertheless, the dip in *f(u)* can be identified with electron energy loss to the asymmetric stretch vibration in CO_2 for which the cross section is relatively large in this energy range. Also the distribution functions is clearly non- MaxwillianGenerally, collisions between electrons would cause the electron energy distribution function to tend towards a Maxwellian distribution. The influence of these collisions mainly depends on the ionization degree, but in Fig (3), the calculated distribution function are again markedly non-Maxwillian and having distinct varying curvatures at all electron energies. The pronounced dip in the distribution function are emphasized at low electron energy occur as a result of the high cross-sections for vibrational excitations of (SF_6, CO_2) (50:50) mixture.

In Figurers (4, 5) which represents the diffusion coefficient and the mean energy of the electron respectively, in these two figure, the pure SF_6 has the highest values of the diffusion coefficient and mean electron energy while the pure CO_2 has the lowest values of each of them. So, with decreasing SF_6 concentration in the mixture both of the diffusion coefficient and the mean electron energy is decrease and opposite of that with decreasing CO_2 concentration the diffusion coefficient and the mean energy is increase this is implies that the number of collision in SF_6 is lower than CO_2 as a result of the sets of cross-section data of the electron energy distribution in SF_6 and CO_2 gases and because of the growth of the inelastic collisions of electrons.

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