Calculationof The Electron Distribution Function And Its Transport Parameters In $SF_6 - He$Applied Gas Mixture

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Abstract

There are two important types of basic gas-insulated apparatus used by electric power industry: i.gas-insulted transmission lines and ii.gas-insulated transformers.$SF_6 - He$Mixture are considered to be used in circuit breakers, helium has a very blow dielectric strength ($\sim 3\%$ that of SF_6 in uniform fields) and contributes virtually nothing to the dielectric strength of the mixture. Helium however, complements SF_6 in terms of its cooling capacity because it is very light, and does not react chemically eitherSF_6, or the gas impurities present in commercialSF_6, or the system components.

The motion of electrons in plasma gas sulfur hexafluoride (SF_6) and its mixture with inert gas He in the present of 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 program called "NOMAD" written in FORTRAN 77, by using the Finite difference method.

The energy distribution function and the swarm transport parameters of electron accelerated by DC electric field in a mixture of $SF_6 - He$, are evaluated and compared with experimental result of drift velocity (v_d), average energy ($\bar{\epsilon}$) ,characteristic energy (ϵ_k) , diffusion coefficient (D) ,and electron mobility (μ).

We conclude that the calculation value has a percentage agreement with international published experimental value over the range of E/N in Td units (E is the electric field and N concentration gas molecules). One can interpret the existence percentage error to the accuracy of the using cross section data for both elastic and inelastic collisions, since their exist many laboratory published data.

Keywords:$SF_6 - He$ gas mixture, dielectric properties, high voltage electrical equipment, arc quenching

الخلاصة

في الجانب الصناعي والتطبيقي ، يتواجد نوعين من الاجهزة الكهربائية العملاقة لإنتاج الطاقة، النوع الاول يطلق عليه خطوط نقل الطاقة الكهربائية والنوع الثاني يطلق عليها المحولات الكهربائية. الخليط الغازي $SF_6 - He$ يؤخذ بنظر الاعتبار كوسط عازل في دوائر القطع الكهربائي، حيث يمتلك غاز الهليوم (He) شدة عزل ضئيلة جدا مقارنة مع غاز سداسي فلوريد الكبريت (SF_6) في المجالات المنتظمة وبذلك تكون مشاركته محدودة جدا في عملية العزل. في الوقت ذاته يعمل غاز الهليوم مع غاز سداسي فلوريد الكبريت بزيادة سعة التبريد لكونه من الغازات الخفيفة ولكونه لايتفاعل كيمياويا مع الغاز ذاته.

حركة الالكترونات في بلازما غاز (SF_6) او خلائطه مع الغازات الخاملة بوجود مجالات كهربائية منتظمة تمثل حسابيا من خلال الحل العددي لمعادلة الانتقال لبولتزمان Boltzmann's transport equation والمتمثلة في البرنامج العالمي المعروف باسم NOMAD والمكتوب بلغة فورتران77 باستخدام طريقة التفريق المحدد Finite difference technique . دالة التوزيع

وعوامل الانتقال للإلكترونات المعجلة بواسطة المجال الكهربائي للخليط الغازي $SF_6 - He$ تم حسابها وقورنت النتائج مع نظيرتها العملية المنشورة عالميا، ولوحظ وجود توافق اوتطابق مقبول بنسبة معينة ويعزى التفاوت القليل الى دقة المقاطع العرضية للتفاعلات المرنة والغير المرنة بمختلف انواعها، حيث تتوفر بيانات عديدة لهذه المقاطع العرضية ولتجارب مختلفة الظروف والمنشأ.

Introduction

Sulfur hexafluoride (SF_6), the electric power industry's presently preferred gaseous dielectric (besides air), has been shown to be a greenhouse gas. In this report we provide information that is useful in identifying possible replacement gases, in the event that replacement gases are deemed a reasonable approach to reduce the use of SF_6 in high voltage electrical equipment. This report first describe the properties that make a good gaseous dielectric, that are necessary to demonstrate and document the appropriateness of a gas as a high voltage insulting medium, or to be used as an arc or current interrupting medium [1].

The large amount of available physical and laboratory data suggests that a $40\%SF_6 - 60\%N_2$ mixture may exhibits dielectric characteristics suitable to be used as insulation in high voltage equipment. However, it is realized that there are difficulties in using this mixture for arc or current interruption, and as a replacement gas in already existing equipment [2].

This report focuses on the properties of SF_6 as a dielectric gas and on the data available for possible alternatives to pure SF_6 (i.e., SF_6 alone). On the basis of published studies and consultation with experts in the field, it was attempted to identify alternative dielectric gases to pure SF_6 for possible immediate or future use in existing or modified electrical equipment. The possible alternative gases are discussed as three separate groups: (i) mixtures of $SF_6$and nitrogen for which a large amount of research results are available; (ii) gases and mixtures (e.g., pureN_2, low concentrations of SF_6inN_2, and$SF_6 -$ He mixtures) for which a smaller yet significant amount of data is available; and (iii) potential gases for which little experimental data is available [1].

Sulfur hexafluoride (SF_6), is a man-made gas which became commercially available in 1947. It is one of the most extensively and comprehensively studied polyatomic molecular gases because of its many commercial and research applications. Its basic physical and chemical properties, behavior in various types of gas discharges, and uses by the electric power industry have been broadly investigated [3]. Sulfur hexafluoride (SF_6), exhibits many properties that make it suitable for equipment utilized in the transmission and distribution of electric power, it is a strong electronegative (electron attaching) gas both at room temperature and at temperature well above ambient, which principally accounts for its high dielectric strength and good arc-interruption properties. The breakdown voltage of SF_6 is nearly three times higher than air at atmospheric pressure [4].

Furthermore, it has good heat transfer properties and it readily reforms itself when dissociated under high gas-pressure conditions in an electrical discharge or an arc (i.e., it has a fast recovery and it is self-healing). However, SF_6have some undesirable properties: it forms highly toxic and corrosive compounds when subjected to electrical discharges (e.g., S_2F_{10}, SOF_2); non-polar contaminants (e.g., air, CF_4) are not easily removed from it; its breakdown voltage is sensitive to water vapor , conducting particles, and conductors surface roughness; and it exhibits non-ideal gas behavior at the lowest temperatures that can be encountered in the environment.

Theory

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.

The general form for the Boltzmann transport equation may be written as [5,6].

$$\left(\left(\frac{\partial}{\partial t}\right) + \nu \, . \nabla_r + \left(\frac{eE}{m}\right) . \nabla_\nu\right) f(r, \nu, t) = \left(\frac{\partial f}{\partial t}\right)_{collisions} \qquad \ldots(1)$$

Or

$$\left(\frac{\partial f}{\partial t}\right) + \nu \, . \nabla_r f + a \, . \nabla_\nu f = \Sigma \iint [f(\nu', r, t)F_j(V_j', r, t) - f(r, \nu, t)F_j(V_j, r, t) * \nu_{rj}\sigma_j(\theta, \nu_{rj})d\Omega_j dV_j$$

Where, ν is the velocity of charge particles, a is the acceleration of charges particles, $f(r, \nu, t)$ is the electrons distribution function, $F_j(V_j, r, t)$ is the neutral species distribution function,$\nu_{rj} = |\nu - V_j|$ is the relative velocity of charges particles, V_j is the velocity of neutral species, $\sigma_j(\theta, \nu_{rj})$ is the differential microscopic cross section of interaction the charges particles (electron) with neutral gas species j, $d\Omega_j = Sin\theta d\theta d\phi$ is the element solid angle, where θ and ϕ are the polar and azimuthally angles, respectively.

The left and right hand sides describe the behavior changes of electrons distribution function by the Varity independent collisions and also the binary collisions of charges particles with the neutral gas species, respectively. The electron distribution function ,$f(r, \nu, t)$ is approximated by $f(\nu)$, since it is assumed that electrons fields are independent of space and time and the problems of electrons interactions are spatially uniformed, so that the velocity dependence distribution function can be written by Legendre series expansion as follows.

$$f(r, \nu, t) \approx f + \sum f(\nu, r, t) \, P\,(Cos\,\theta) \qquad \ldots(2)$$

Or, in terms of the velocity dependence approximation

$$f(v) \approx f(v) + \sum f(v)P(\cos\theta) \quad ...(3)$$

The use of a Maxwellian electron energy distribution function is justifiable on the basis that the rotation and vibration excitation occur in molecular gases at the low electron energy ranges appropriate to a breakdown of gaseous insulation. From the electron energy distribution function we can calculate the swarm properties by using the relations.

$$\omega = -\frac{1}{3}E\int_0^\infty \frac{\epsilon}{N\theta}\frac{d}{d\epsilon}\frac{F(\epsilon)}{\epsilon^{1/2}}d\epsilon \quad ...(4)$$

$$\mu = \frac{\omega}{E} \quad ...(5)$$

$$\bar{\epsilon} = \int_0^\infty \epsilon F(\epsilon)d\epsilon \quad ...(6)$$

$$\frac{\alpha}{N} = \frac{1}{W}\int_{\epsilon_i}^\infty Q_i\,\epsilon^{\frac{1}{2}}F(\epsilon)d\epsilon,$$

$$\frac{\eta}{N} = \frac{1}{W}\int_{\epsilon_a}^\infty Q_a\,\epsilon^{1/2}F(\epsilon)d\epsilon \quad ...(7)$$

Where W is the drift velocity (m s^{-1}), θ the momentum transfer cross section (in cm^2), $\bar{\epsilon}$ the mean energy, μ the electrons mobility (in cm^2/V), α (in cm^{-1}) the ionization coefficient, η (in cm^{-1}) the attachment coefficient, Q_i (in cm^2) the ionization cross section, Q_a (in cm^2) the attachment cross section, and ϵi is the ionization potential. It is important to note that equations (4)-(7) are applicable for all types of energy distribution function.

Substitution of the breakdown criterion of gases $\frac{\alpha}{N} = \frac{\eta}{N}$gives the value $\frac{E}{N}$ at which breakdown occurs in highly electronegative gases.Its 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 [8,9]

Calculation and results

Helium as an inert gas is mixed with sulphur hexafluoride. The calculated transport parameters, drift velocity (V_d), characteristic energy (ϵ_k), electron mobility (μ), and diffusion coefficient (D) of$SF_6 - He$ for the case of 50% concentration of Helium gas in the mixture were listed in Table(1). And, The electron distribution functions of $SF_6 - He$ for the same case are plotted for specified E/N values and its completely described inFigure (1).

Table (1): The calculated transport parameters for electron in $SF_6 - He$Mixture (50% Mixing ratio).

	N = 1.27×10^{19} Molecules/ cm^3		
Electric field/gas densityE/N (T_d=10^{-17} V.cm2)	Drift velocity $V_d \times 10^7$ (cm/sec)	Characteristic energy D/μ (eV)	electron mobility μ (cm^2/V.sec)
150	1.78	15.342×10^1	9.00 x10^2
200	1.98	13.784×10^3	7.749 x10^2
300	2.65	11.246 ×10^5	6.925 x10^2
400	3.34	11.1×10^6	6.570 x10^2
500	4.08	25.2×10^6	6.346 x10^2
550	4.39	37.2×10^6	6.226 x10^2
600	4.64	55.2×10^6	6.013 x10^2

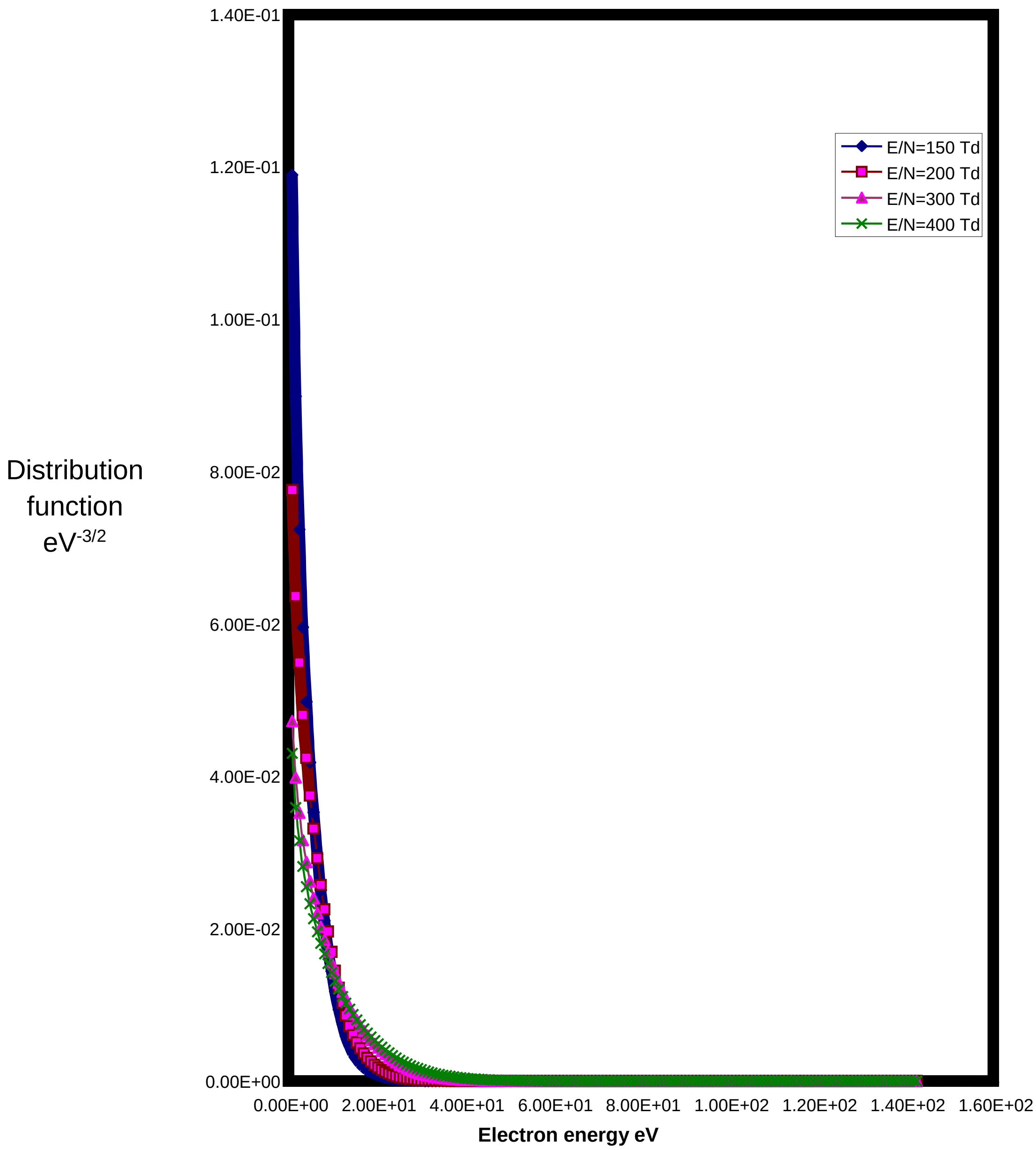

Figure.(1): The electron distribution function versus the energy of electrons in SF_6-He (50/50) gas mixture

Figure (2) shows the electrons drift velocity (V_d) as a function of E/N in SF_6, He, and$SF_6 -$ Hemixture (mixing ratio 50/50). This figure shows that, the case of adding HetoSF_6, will cause an increase in the drift velocity(V_d) in $SF_6 -$ Hemixture, so that the effect of adding the He as a buffer gas to$SF_6 -$ He gas mixture can change the collision processes and therefore a change in the electron transport properties exists. Andit's clearly appear that the increaseof the concentration percentage of HeinSF$_6 -$ He gas mixture, will cause a rapidly increase in the drift velocity of electrons.

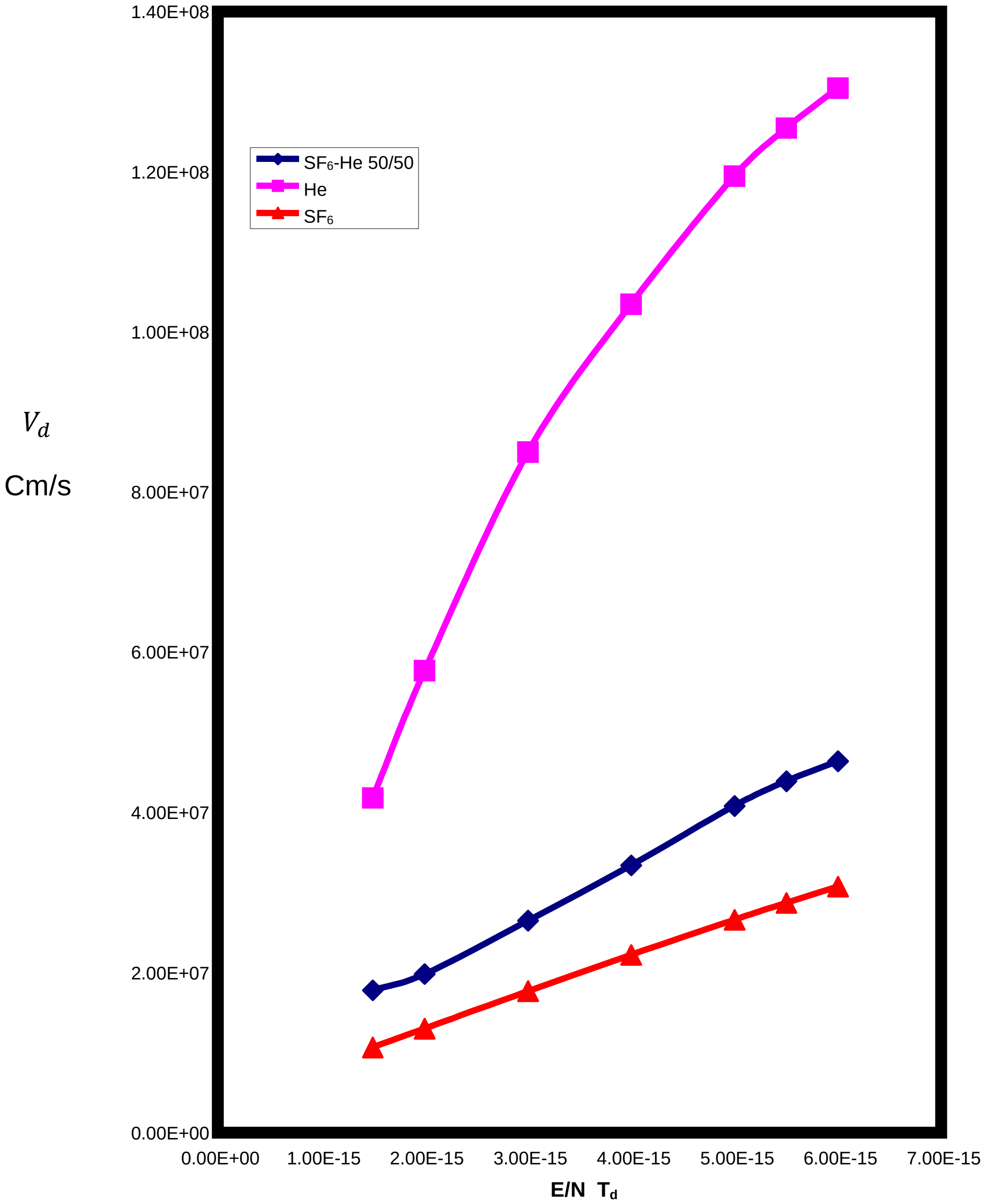

Figure. (2): The drift velocity as a function of E/N in SF_6-He (50/50) gas mixture .

Table(2) lists the variety consternation percentage of SF_6 in $SF_6 - He$ gas mixture, and Figure (3) shows the variation of electrons drift velocity V_d as a function of E/N in $SF_6 - He$for various consternations percentage.

The electrons characteristics energy, andthe electrons mobility of $SF_6 - He(50/50)$ gas mixture as a function of E/N are plotted in Figures (4) and (5). Finally a comparison between the calculated and experimental drift velocities are described in Figure(6).

Table (2): Variation of number density with mixture concentration percentage in SF_6-He gaseous mixture.

No.	Mixture concentration percentage (SF_6/He)%	Number density (molecules/cm^3)
1	90-10	2.232 $x10^{19}$
2	80-20	1.991 $x10^{19}$
3	70-30	1.751 $x10^{19}$
4	60-40	1.511 $x10^{19}$
5	50-50	1.271 $x10^{19}$
6	40-60	1.031 $x10^{19}$
7	30-70	0.792 $x10^{19}$
8	20-80	0.550 $x10^{19}$
9	10-90	0.310 $x10^{19}$

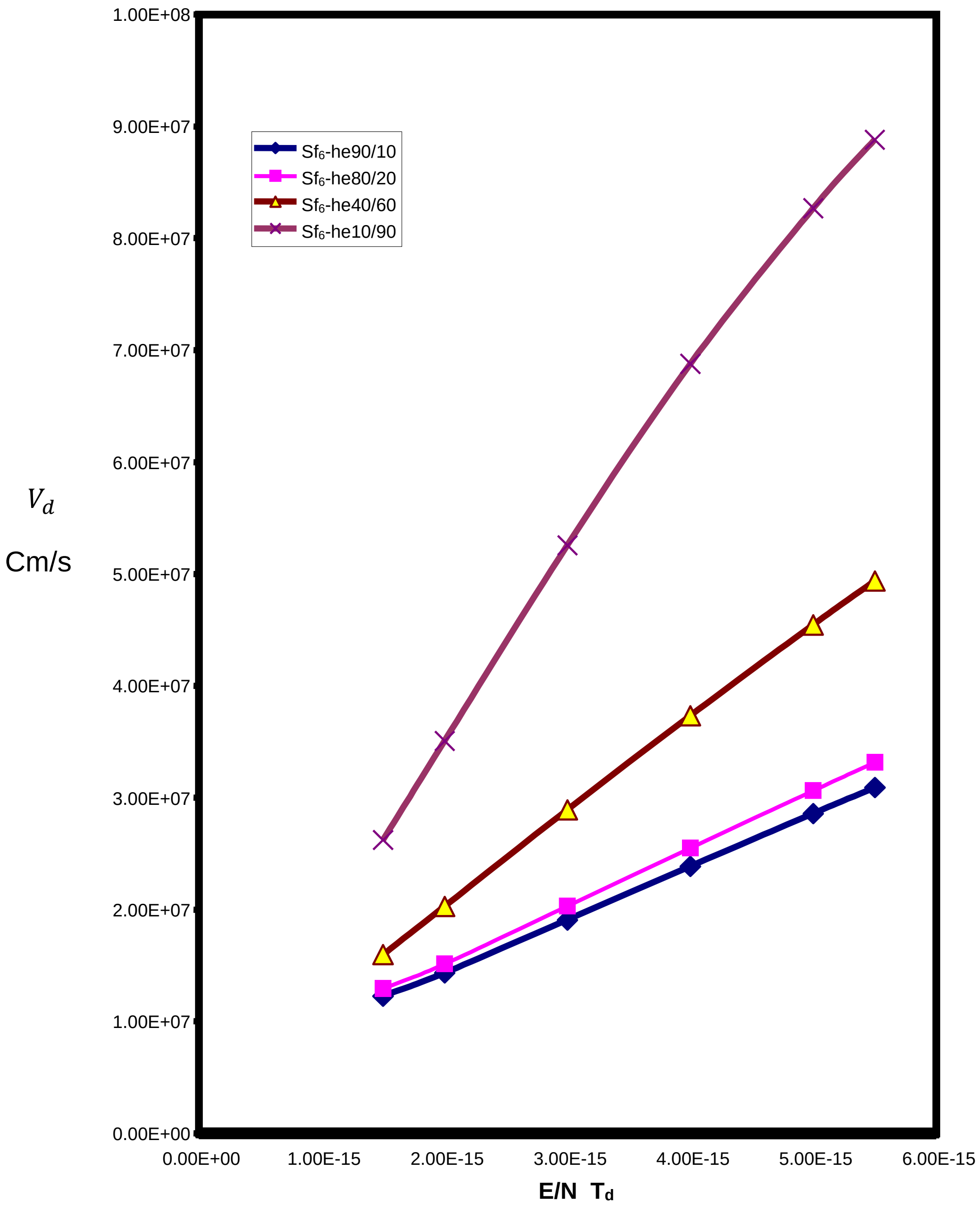

Figure.(3):The drift velocity of electrons versus E/N in SF_6-He gas mixture for variety concentration percentage.

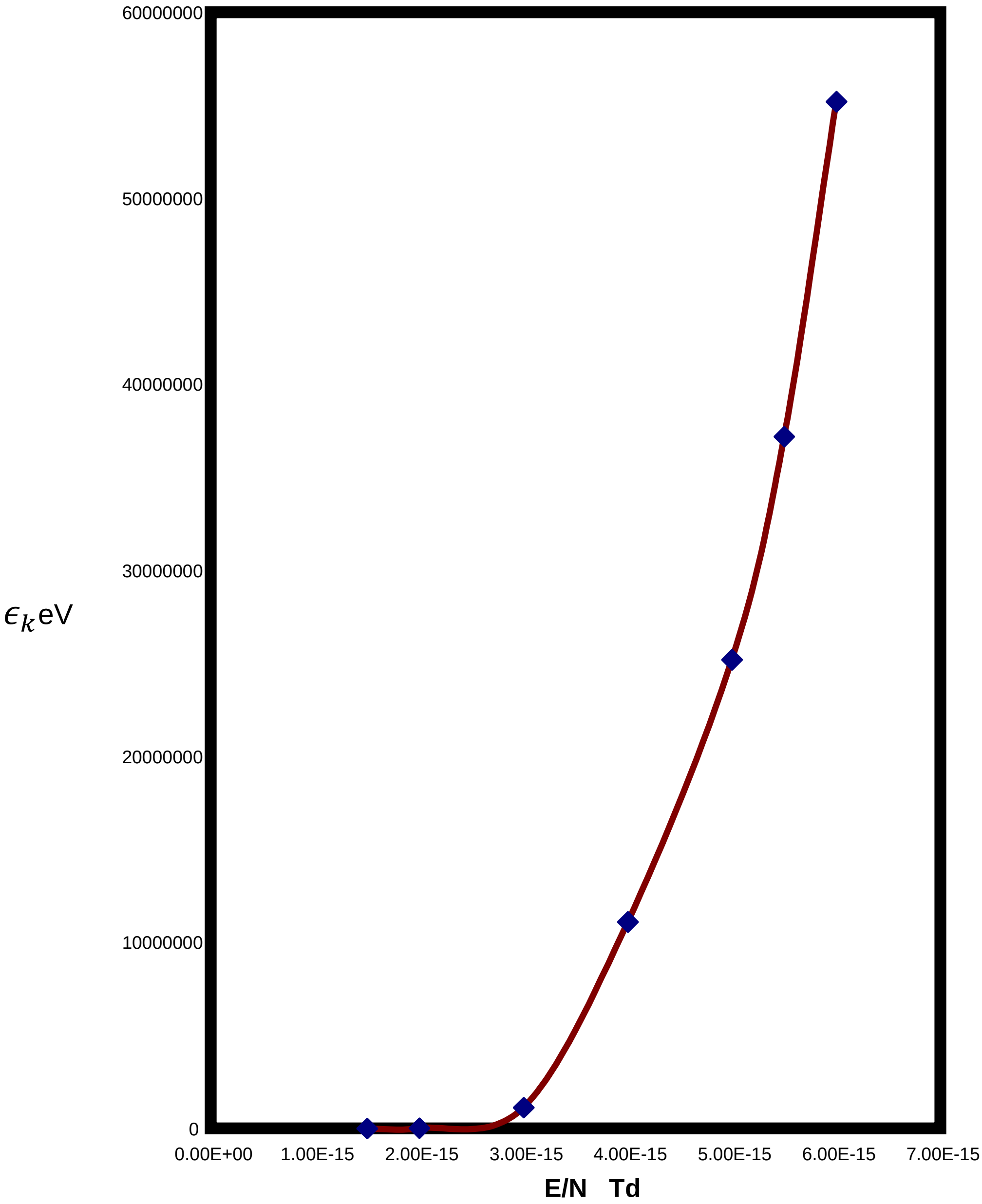

Figure (4): characteristic energy of electrons versus E/N in SF_6-He (50/50) gasmixture

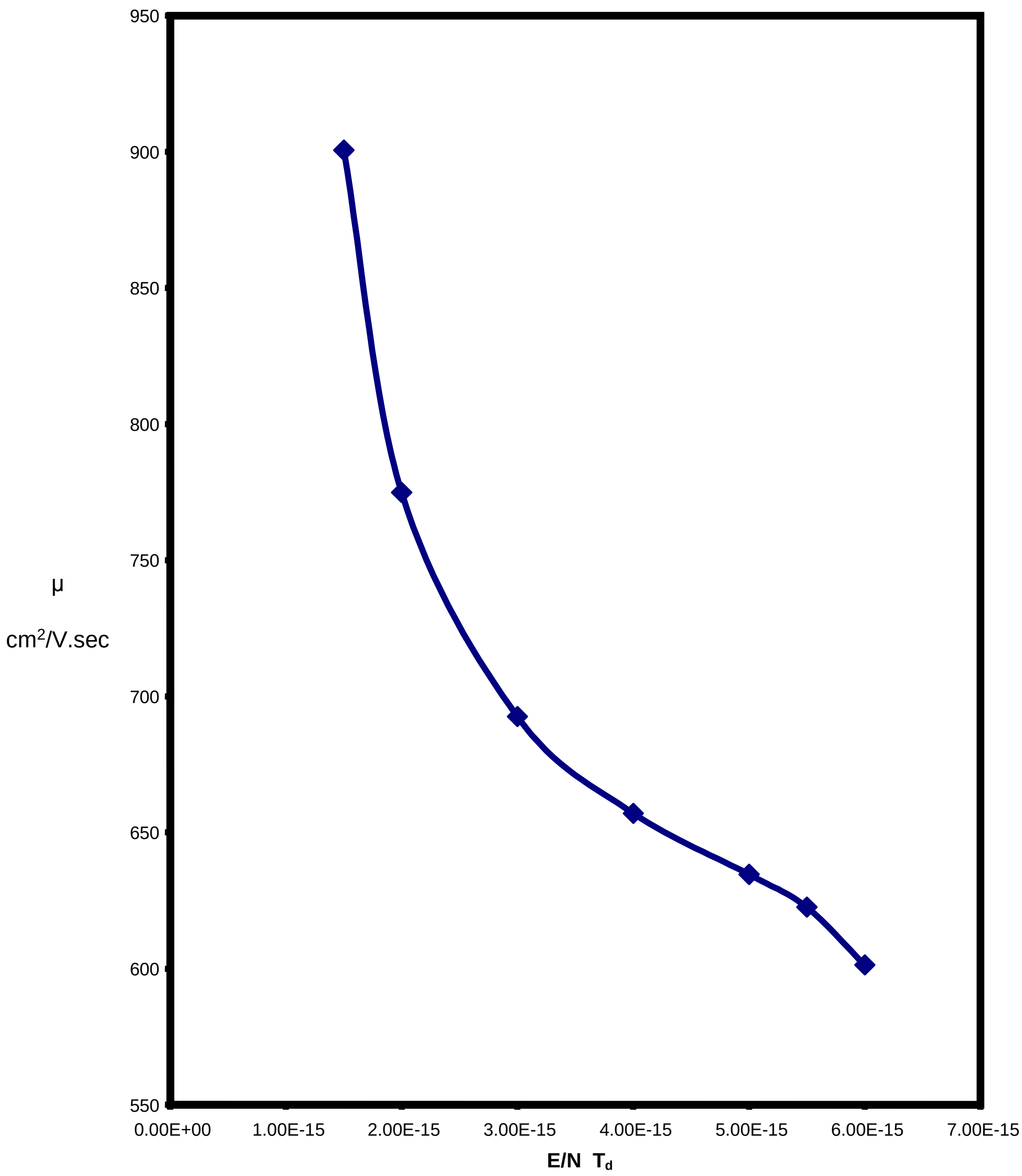

Figure (5): The mobility of electrons versus E/N in SF_6-He (50/50) gas mixture

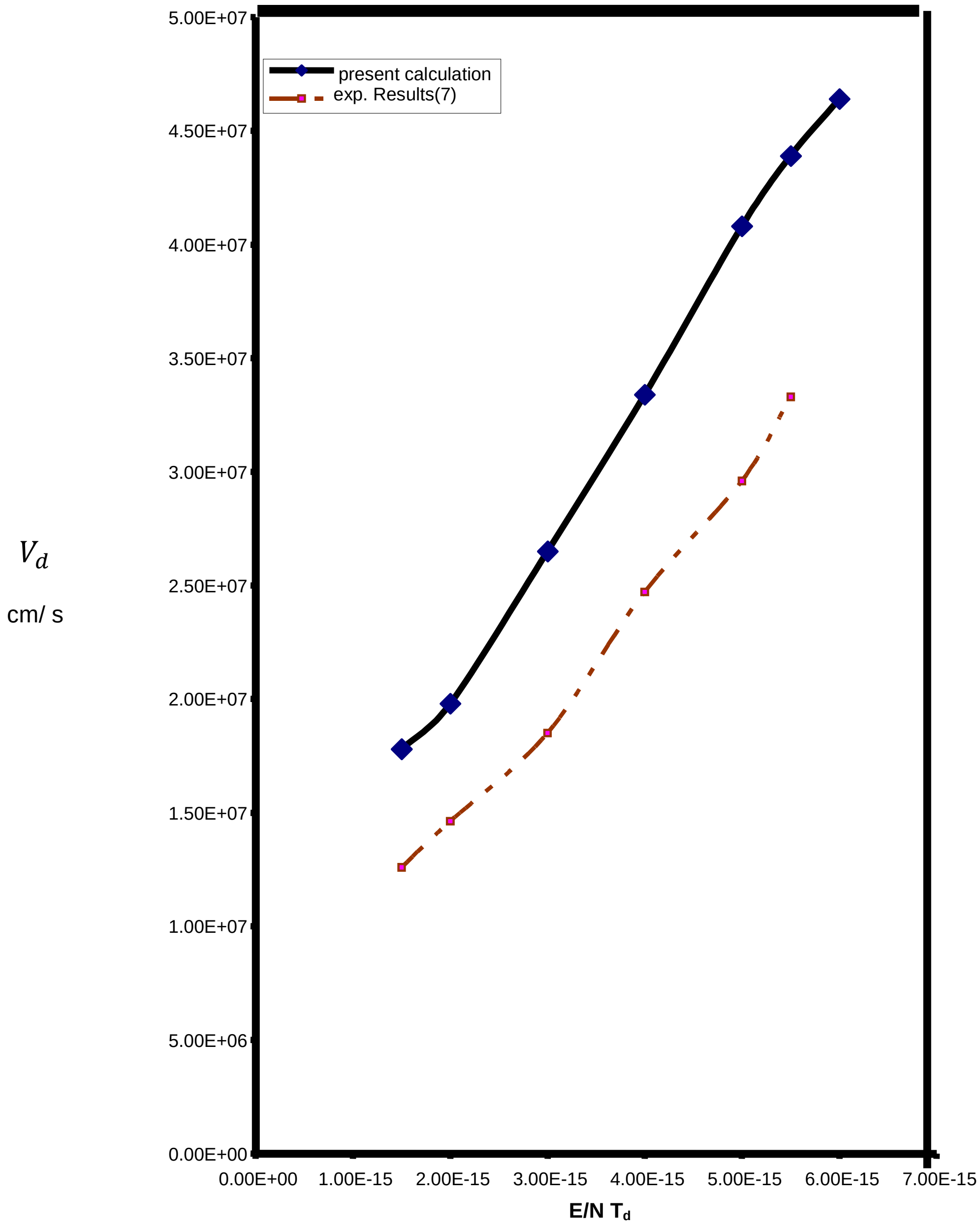

Figure (6): The experimental and calculated electron drift velocities as a function of E/N in SF_6- He (50/50) gas mixture.

Discussion and Conclusion

Sulfur hexafluoride (SF_6), the electric power industry`s presently preferred gaseous dielectric (besides air), has been shown to be a green house gas. in this report we provide information that is useful in identifying possible replacement gases mixture, which deemed a reasonable approach to reduce the use of SF_6in high voltage electrical equipment. An important part of this information is found from the calculations of the electron transport parameters in such gases mixture, which indeed 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.

From Figure (2), it's clearly appear the effect of adding the helium gas to the pure Sulfur hexafluoride, in increasing the electron drift velocity to values approximately lies in the intermediate range of pure helium and pure sulfur hexafluoride, which alter the dielectric properties of the gas mixture.Figure (3), explains the effect of changing the helium concentration on the electron drift velocity for different mixing ratios, and one can directly show the likely linear increase in the electron drift velocity for each mixing ratio. Finally, from Figure (6), which reflects the suitable agreement between our calculated results with the corresponding experimental results, we can focus on the missing of available cross section data for the different types of inelastic collisions (e.g., excitation, electronic, vibration, attachment, ionization, etc.) in getting or producing a more accurate results.

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