Dependence of electrons distribution function and the swarm parameters on the buffer gas (Xe) concentration in SF6-Xe gas mixture

Raad Hameed Majeed
College of Education-Ibn-AL-Haitham/Department of physics

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Abstract

The effect of concentration varying of the buffer gas Xenon (Xe) in a mixture of Sulphur hexafluoride and Xenon (SF_6-Xe) are considered to study the change in electrons distribution function and therefore the change of the electrons transport or swarm parameters such as the drift velocity , the main energy, characteristics energy, electrons mobility, …etc., in order to choose the suitable optimized calculated set of the electrons transport parameters for the mixture that have realty usage in many high voltage engineering purposes in industrial applications, by comparing with the recently published experimental results.

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Introduction

The motion of particles for gas or plasma considered as pure or as a mixture is completely described by Boltzmann equation or sometimes called transport equation. By solving this equation numerically one can get the normalized distribution function which plays important roles in calculation the electrons swarm parameters.

Since inert gases are monatomic and their atoms are of closed shell structure, the collision of an electron with an inert gas atom is the most typical case of electron-atom collision processes [1]. Pure SF_6 is not poisonous, so that this gas is not dangerous to inhale, provided that the oxygen content is high enough. SF6is about 6 times heavier than air, it means that it may condensed in cable ducts or at the bottom of tanks. Because SF_6 is non flammable gas its used in electrical apparatus and also can be used as a fire extinguishing agent [2,3] .it is necessary to note that SF6 gas is used (pure or mixture) as an insulating medium in substations and as insulating and cooling medium in switchgear for high and intermediate voltage applications, and for these usage it required to cut off the power in case of a fault in order to protect people and equipments [4,5] . In our work, we use the mixture SF_6-Xe gases as a medium gas target.

The method for calculating the sparking potential of gases or gaseous mixtures is basically approach by calculating e the ionization and attachment coefficients from electron energy distribution functions and then applies the breakdown criterion, i.e.,

$\alpha/N = \eta/N$, (α is the ionization coefficient in cm^{-1}, η is the attachment coefficient in Cm^{-1}, N is the number of gas molecules at 0 ^0C= $3.54x10^{16}$ pcm^{-3}, p is the gas pressure in Torr). This approach relies only on the basic physical properties of the industrial gases which are available in some, but not in all, gases from fundamental research studies of the behavior of electron in gases [6].

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 [7,8].

$$\left(\left(\frac{\partial}{\partial t}\right)+v.\nabla_r+\left(\frac{eE}{m}\right).\nabla_v\right)f(\mathrm{r},v,t)=\left(\frac{\partial f}{\partial t}\right)_{collisions} \quad ----(1) \quad \text{Or}$$

$$\left(\frac{\partial f}{\partial t}\right)+v.\nabla_r f+\mathrm{a}.\nabla_v f=\sum\iint[f(v^l,r,t)F_j(V_j^l,r,t)-f(\mathrm{r},v,t)F_j(V_j,r,t)*v_{rj}\sigma_j(\theta,v_{rj})d\Omega_j;dV_j$$

Where v is the velocity of charge particles

a is the acceleration of charges particles

$f(\mathrm{r},v,t)$ is the electrons distribution function

$F_j(V_j,r,t)$ is the neutral species distribution function

$v_{rj}=\mid v-V_j \mid$ is the relative velocity of charges particles

V_j is the velocity of neutral species

$\sigma_j(\theta,v_{rj})$ is the differential microscopic cross section of interaction the charges particles (electron) with neutral gas species j

$d\Omega_{jj}=Sin\,d\theta d\phi$ 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 $f(\mathrm{r},v,t)$ is approximated by $f(v)$, since it is assume that electrons fields is independent of space and time

and the problems of electrons interactions are spatially uniform, so that the velocity dependence distribution function can be written by Legendre series expansion as follow.

$$f(\mathrm{r},v,t) \approx \quad f + \Sigma\ f(\mathrm{v,r,t})\ \mathrm{P}\ (\mathrm{Cos}\ \theta)\text{-------(2)}$$

Or, in terms of the velocity dependence approximation

$$f(\mathrm{v}) \approx f(\mathrm{v}) + \Sigma\ f(\mathrm{v})\ \mathrm{P}\ (\mathrm{Cos}\ \theta)\text{ --------(3)}$$

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 using the relations.

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

$$\mu = \frac{\omega}{E}\text{ --------(5)}$$

$$\bar{\epsilon} = \int_0^{\infty} \epsilon\, F\,(\epsilon) d\epsilon\text{ ----------(6)}$$

$$\frac{\alpha}{N} = \frac{1}{W}\int_{\epsilon_i}^{\infty} Q_i\ \epsilon^{1/2}\ F(\epsilon)d\epsilon - -(7)$$

$$\frac{\eta}{N} = \frac{1}{W}\int_{\epsilon_a}^{\infty} Q_a\ \epsilon^{1/2}\ F(\epsilon)d\epsilon - -(8)$$

Where W is the drift velocity (in 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, ϵ_i the ionization potential. It is important to note that Eqs. (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 at which $\frac{E}{N}$ breakdown occurs in highly electronegative gases.

Calculations and Results

To calculate the drift velocity of electrons and the others swarm parameters, a knowledge of the dependence of the momentum transfer cross section θ on the electron energy is essential. The drift velocity does not depend on electron energy distribution function significantly, particularly when the cross section does not vary rapidly with electron energy. Using the FORTRAN77 international computer code NOMAD, which solved the Boltzmann transport equation numerically by the finite difference techniques, can calculate the electrons distribution and therefore all the swarm parameters.

The gas density for pure gas or the concentration percentage for gases mixture can be calculated by using the following formulas

N =(m.AV)/ Mw for pure gas

N =((ρ 1.V1+ ρ 2.V2+ ρ 3.V3+……).AV)/ Mw for gasous mixture

Where m= ρ .V, is the mass of the gas, AV,is the Avogadro number,

(V1, V2, V3,….) are the volume fraction for the gases mixture, Mw, is the molecular weight for the gas or gases mixture

Our results are tabulated and described pictorially as follow.

Table (1): swarm parameters of electrons in SF_6-Xe gaseous mixture for the case of concentrations percentage 50% SF6, 50% Xe.

	N = 1.310 x 10^{19} cm^{-3}		
Electric field/gas density E/N (Td=10^{-17} V.cm^2)	Drift velocity V_d (cm/sec)	Characteristic energy D/μ (eV)	electron mobility μ (cm^2/V.sec)
150	10.300x10^6	7.200	320.600
200	13.200x10^6	8.85	278.410
300	19.400x10^6	14.20	183.200
400	25.500x10^6	21.50	124.840
500	31.600x10^6	30.80	88.820
600	35.900x10^6	42.00	65.810

The variation of number density of molecules for the gaseous mixture with the mixture concentration percentage is well described in the following table.

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

No.	Mixture concentration percentage (SF_6/Xe)%	Number density N cm^{-3}	No.	Mixture Concentration percentage SF_6/Xe%	Number density N cm^{-3}
1	**90/10**	**1.333 x10^{19}**	**6**	**40/60**	**1.304x10^{19}**
2	**80/20**	**1.327 x10^{19}**	**7**	**30/70**	**1.298 x10^{19}**
3	**70/30**	**1.321 x10^{19}**	**8**	**20/80**	**1.293 x10^{19}**
4	**60/40**	**1.315 x10^{19}**	**9**	**10/90**	**1.287 x10^{19}**
5	**50/50**	**1.310 x10^{19}**			

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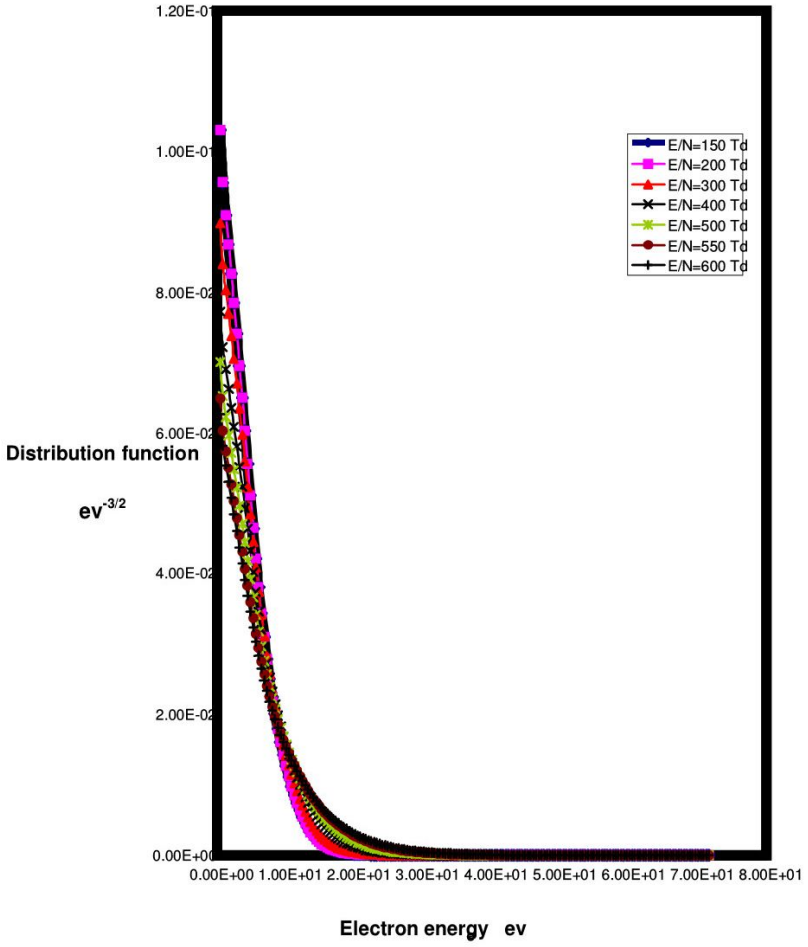

Fig.(1) The electron distribution function versus the electron energy in SF_6-Xe(50/50%) gaseous mixture

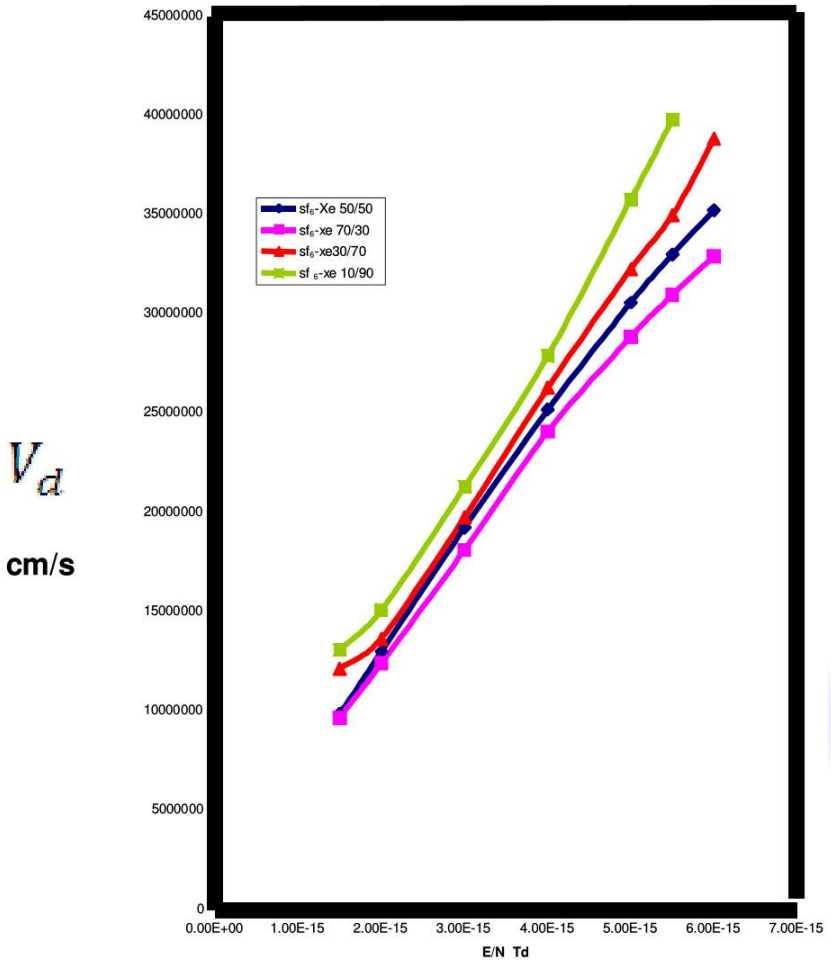

Fig.(2) The electrons drift velocity versus E/N in SF_6-Xe gaseous mixture various percentage

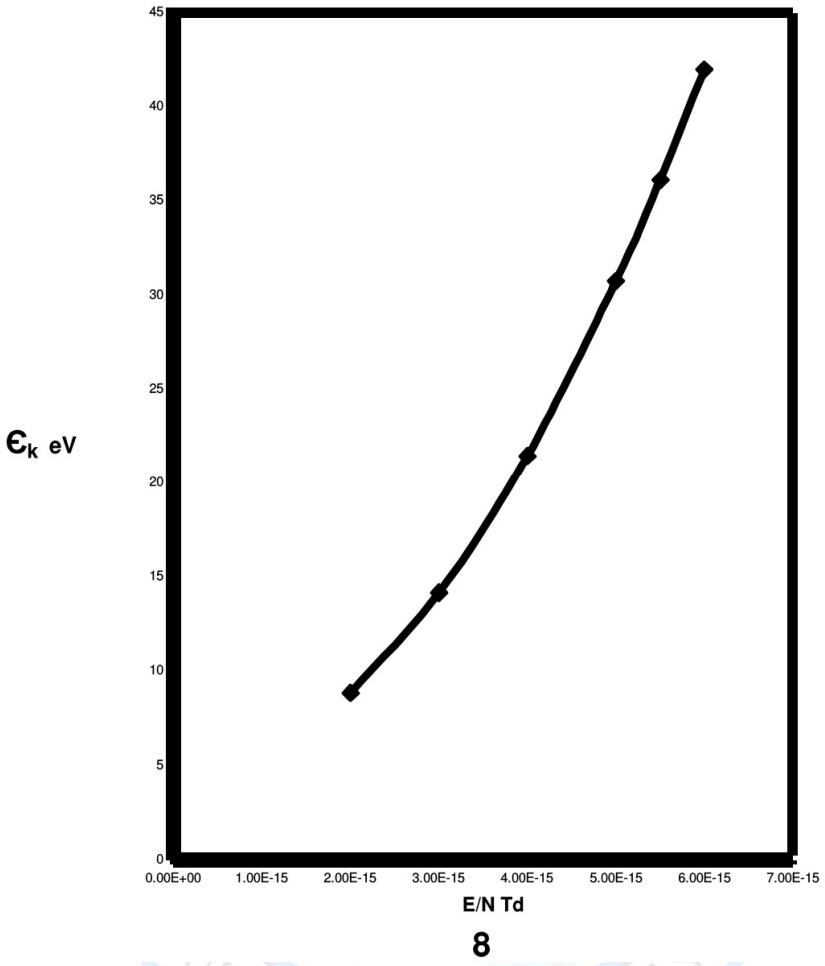

Fig.(3) The characteristic energy of electron as a function of E/N in SF_6 -Xe (50/50)% gaseous mixture

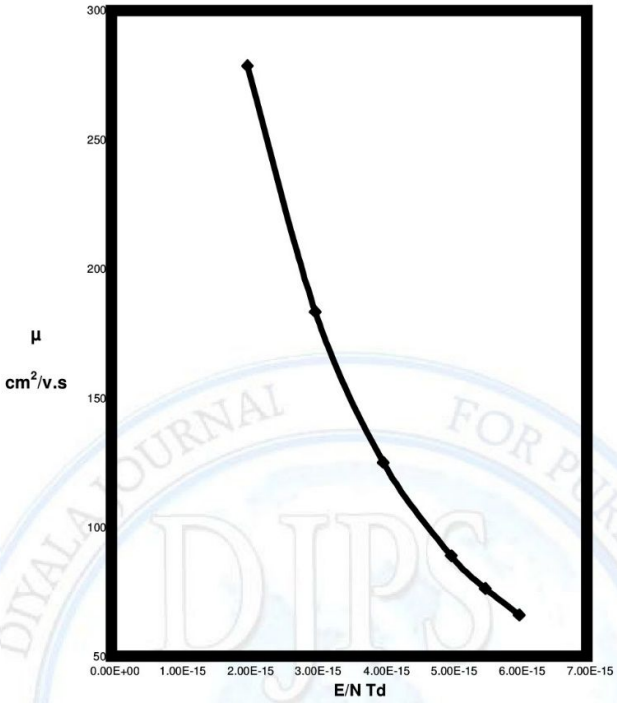

Fig.(4)The mobility of electrons as a function of E/N in SF_6 –Xe (50/50)% gaseous mixture

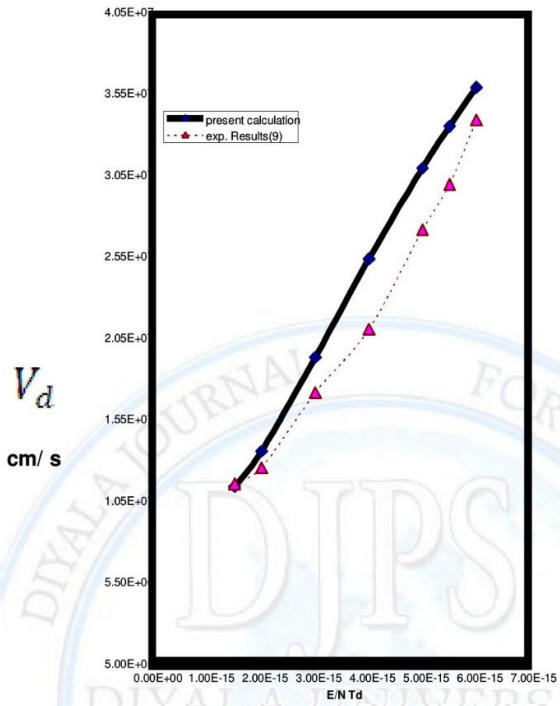

Fig.(5) The electron drift velocity as a function of E/N in SF_6-Xe (50/50) gaseous mixture

Discussion and conculsion

In our work, the present calculation were focused on the concentration percentage value 50% for sulphur hexafluoride and xenon gaseous mixture, so for their measurement distinguished of the transport or swarm parameters in the applied research, and this case are more suitable for comparison with the published measured results.

Figure (1) show the behavior of the electrons energy dependence distribution function for different cases of the factor (E/N), which reflect the fact of the steady state form, and this can be explained theoretically that there are no mistake in the results. After avoiding the above point, figure (2) show the variety in the drift velocity of electrons and it is clearly appear the

effect of adding the buffer gas xenon to the sulphur hexafluoride electronegative gas in increasing their drift velocity due to the change in the different types of collision processes.

It is necessary to note that from figure (5), which explain a brief comparison between our calculated results and a published experimental results [9] for the electrons drift velocity, that there are an increasing beehives in both values and one can explain the relation between the electrons drift velocity and the factor (E/N) as a linear function. In addition there exists a small shift between the two results for a given value of the factor (E/N), and this can be interpret that practically no one of the collision processes are neglected and also all the energy range are involved. In addition, theoretically we need to use a many set of published tables for the different types of cross sections, i.e., the momentum transfer, electronic excitations, electronic vibrations, electronic attachments, etc…in order to reduce the shift or the difference between the two values.

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