ELECTRON SWARM PARAMETERS IN BINARY GAS MIXTURES OF CF_3I WITH Xe, He, N_2 AND CO_2 FROM BOLTZMANN EQUATION ANALYSIS

Y. K. DENG, D. M. XIAO*, J. G. JIANG, S. L. QIN AND L. L. ZHU

Department of Electrical Engineering, Shanghai Jiao Tong University, Shanghai, 200030, China
*email of corresponding author: dmxiao@sjtu.edu.cn

ABSTRACT

The present paper investigated the insulation characteristics of gas mixtures containing CF_3I as an alternative to SF_6 from the point of view of electron swarm parameters. The density-normalized effective ionization coefficients and electron drift velocities are calculated for the gas mixtures of CF_3I with Xe, He, N_2 and CO_2, by solving the Boltzmann equation in the condition of steady-state Townsend (SST) experiment. The overall range of the density-normalized electric field *E*/*N* is from 200 to 800 Td (1 Td = 10^{-17} Vcm^2). From the variation curve of the effective ionization coefficients with the CF_3I mixture ratio, the limiting field strength for which the ionization exactly balances the electron attachment is determined. The calculated results are valid for theoretical analysis of the insulation performance of CF_3I and its gas mixtures as replacement of SF_6. Additionally, the global warming potential (GWP) is also taken into account to evaluate the possibility of applying in gas insulation of power equipment.

1. INTRODUCTION

Because of its high dielectric strength and outstanding interruption performance, sulphur hexafluoride (SF_6) has been widely used as a gaseous insulating medium and an arc quenching medium in the field of high voltage engineering and electrical power applications. However, SF_6 is a strong greenhouse gas with a very high GWP which is 23900 times greater than that of SF_6 over 100-year time period. Consequently, SF_6 has been listed as one of the six principal greenhouse gases of concern according to the Kyoto protocol. In a short term, the gas mixtures of SF_6 with environment friendly gases can reduce the adverse impact on environment, but the lifetime of SF_6 is estimated to be as long as 3200 years because of its chemical inertness and thermal stability, which means that all of the SF_6 that has ever been or will be produced will eventually end up in the atmosphere [2]. The long-term solution to the SF_6 greenhouse problem is to replace SF_6 with an acceptable non-greenhouse gas as the insulating medium.

After decades of exploration and research, there is still no perfect gas to substitute SF_6 with fully consideration of the insulation strength, arcing performance, chemical stability and liquefied temperature. Most of perfluorocarbon (PFC) and hydrofluorocarbons (HFC) which have higher insulation ability than, or comparable to SF_6 also present high GWP or high boiling point, such as c-C_4F_8, n-C_4F_{10}, CF_3SF_5. However, if we use the environment friendly gas such as N_2 and CO_2 to replace SF_6, the size of the insulating equipment would have to be increased since the dielectric strength of these fluorine-free gases is substantially smaller than that of SF_6. Recently, trifluoroiodomethane (CF_3I) has been found to be a potential high voltage insulator.

Relative molecular mass	200.03
Melting point (°C)	-110
Boiling point (°C)	-22.5
Liquid density (g/cm^3)	20°C, 1400
Critical temperature (°C)	122
Critical pressure (MPa)	3.95
C-I bond dissociation energy	226.1 kJ/mol
GWP	≤ 5
ODP	≤ 0.0001
flammability	non

Tab. 1: Mainly physical and environmental properties of CF_3I

As shown in Table 1, CF_3I is colourless and non-flammable. From the environmental point of view, CF_3I presents a weak GWP of 1–5 against approximately 23900 for SF_6. Due to the weak chemical bond C-I, the overall atmospheric lifetime of CF_3I is very short (at most a few days), which greatly limits its transport to the stratosphere when released at the surface. It has been reported in that the steady-state ozone depletion potential (ODP) of CF_3I for surface releases is less than 0.0001. Thus, CF_3I is considered as a low environmental impact gas. However, CF_3I has a high boiling point -22.5°C [3]. The application of CF_3I for insulation inevitably needs it to be mixed with some ordinary gases. The buffer gas composing the greater portion can efficiently decrease the boiling point of the mixture.

In this paper, the density-normalized effective ionization coefficients and electron drift velocities in mixture compositions CF_3I-xY, with x = 0-100%, and where Y denotes Xe, He, N_2 or CO_2 gas, are investigated by solving the electron Boltzmann equation for a steady-state Townsend discharge. The range of the overall density-normalized electric field strength *E/N* is from 200 to 800 Td. Values of $(E/N)_{lim}$ with which the ionization exactly balances the electron attachment are deduced from the curves of $(\alpha - \eta)/N$.

2. THEORETIC FRAMEWORK

The numerical method used for solving the Boltzmann equation has been described in detail by the present authors in Ref. [4]. The electron collision cross sections for CF_3I are taken from Ref. [5], which have been confirmed to be capable of predicting the experimental limiting *E/N* values of CF_3I-N_2 mixtures accurately. While for the companion gas, we use the collisional data of Xe [6], He [7], N_2 [8] and CO_2 [9] as the initial set.

3. RESULTS AND DISCUSSIONS

Figure 1 shows the density-normalized effective ionization coefficient $(\alpha - \eta)/N$ for different mixture compositions in CF_3I-Xe, as a function of the reduced electric field *E/N*. In present work, the electron energy share between the primary and secondary electrons after an ionizing collision is assumed to be 0.5, which means the newly released electron shares half of the primary electron's energy after the ionization scattering. The results indicate that the values of $(\alpha - \eta)/N$ increase with increasing *E/N* values, moreover, at a given *E/N* value, reduce with increasing CF_3I content in the mixture. Figure 2 gives the electron drift velocities V_e, calculated in this work for CF_3I-Xe mixtures as a function of the *E/N*. It can be clearly observed that the electron drift velocity displays a quick trend to decrease as the CF_3I content increases, especially in the higher *E/N* range.

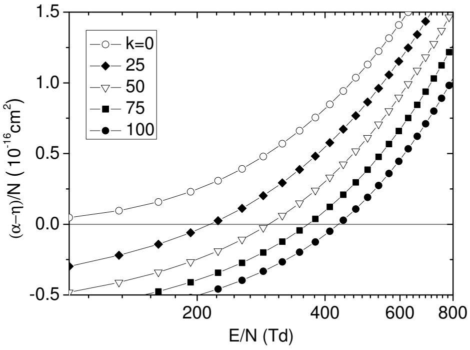

Fig. 1: The density-normalized effective ionization coefficients of CF_3I and Xe mixtures as a function of E/N at different CF_3I gas mixture ratio k(%).

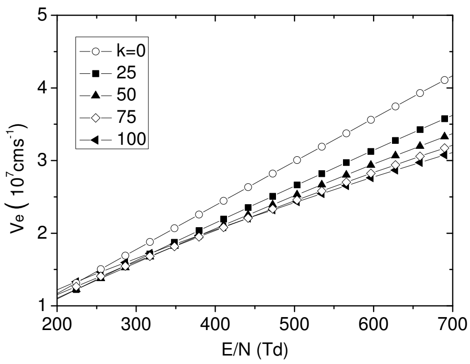

Fig. 2: The electron drift velocities in CF_3I and Xe mixtures as a function of E/N at different CF_3I gas mixture ratio k(%).

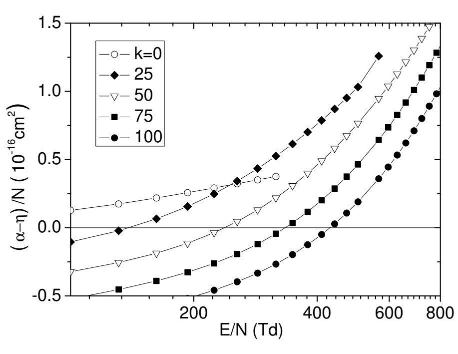

Fig. 3: The density-normalized effective ionization coefficients of CF_3I and He mixtures as a function of E/N at different CF_3I gas mixture ratio k(%).

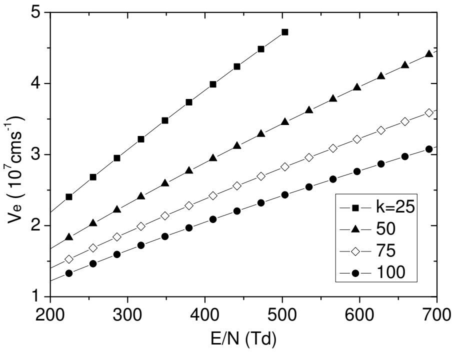

Fig. 4: The electron drift velocities in CF_3I and He mixtures as a function of E/N at different CF_3I gas mixture ratio k(%).

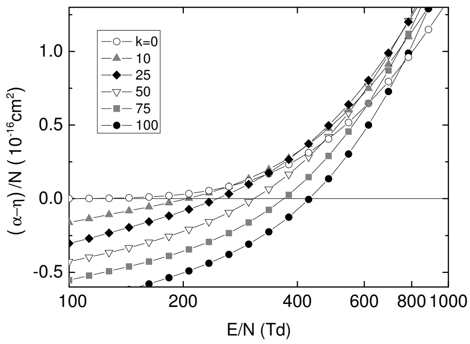

Fig. 5: The density-normalized effective ionization coefficients of CF_3I and N_2 mixtures as a function of E/N at different CF_3I gas mixture ratio k(%).

Figures 3 and 4 show the predicted results for $(\alpha-\eta)/N$ and V_e obtained in CF_3I−He mixtures, calculated for CF_3I percentages between 25% and 100%. The effective ionization coefficients also display the similar variation trend as observed in CF_3I gas mixtures with Xe. Of particular interest is the trend of $(\alpha-\eta)/N$ for higher *E*/*N* with respect to the values of α/N for pure He, where the effective ionization coefficients of gas mixtures are still higher than that of pure He even the severe process of attachment occurred with the composing of CF_3I. This phenomenon has also been observed in CF_3I and N_2 gas mixture and may be ascribed to the fact that the ionization potential of CF_3I is far more lower (10.23 eV) than that of He (24.6 eV) [10]. The electron drift velocity decrease dramatically as the CF_3I content increases.

As regards the electron swarm parameters of CF_3I gas mixtures with N_2 and CO_2, the present authors have detailed discussed in Ref. [11], hence we directly display the results in this section. Figures 5 to 8 show our calculated results obtained in CF_3I-N_2 and CF_3I-CO_2 gas mixtures for $(\alpha-\eta)/N$ and V_e, respectively.

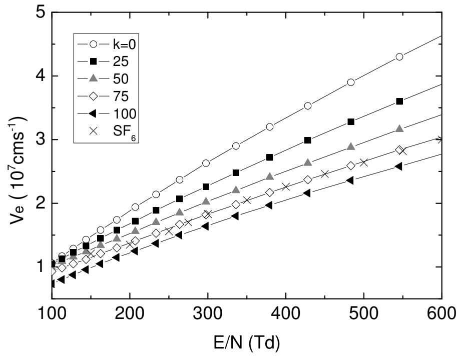

Fig. 6: The electron drift velocities in CF_3I and N_2 mixtures as a function of E/N at different CF_3I gas mixture ratio k(%).

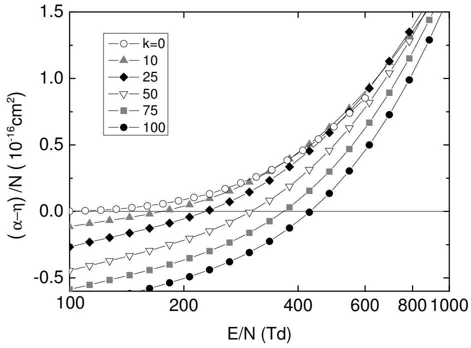

Fig. 7: The density-normalized effective ionization coefficients of CF_3I and CO_2 mixtures as a function of E/N at different CF_3I gas mixture ratio k(%).

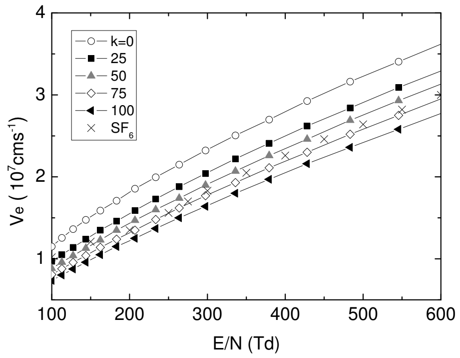

Fig. 8: The electron drift velocities in CF_3I and CO_2 mixtures as a function of E/N at different CF_3I gas mixture ratio k(%).

From the variation of the effective ionization coefficients curves, we can deduce the values of the limiting field strength $(E/N)_{lim}$, i.e. $(\alpha-\eta)/N$=0, for gas mixtures of CF_3I with Xe, He, N_2 and CO_2 at different gas content. Figure 9 shows the $(E/N)_{lim}$ as a function of the CF_3I gas percentage. It is seen that the values of $(E/N)_{lim}$ are larger in CF_3I-N_2 than in the rest gas combination for the CF_3I gas content variation from 20% to 90%, especially for small concentrations of CF_3I in the mixtures. However, the increase of CF_3I percentage leads to the difference among the four decreases gradually. The main reason for this behavior may stem on the dominated influence of CF_3I on the values for the effective ionization coefficients in the gas mixtures. It reveals that for CF_3I concentrations in the gas mixtures of CF_3I with N_2, CO_2 and Xe lower than 70%, the insulation strength of SF_6 is superior, but for above this limit, the positions are reversed. Likewise, as judged from these swarm properties, the gas mixtures of CF_3I with He can also achieve the same insulation level to that of pure SF_6 when the gas content is larger than a certain value.

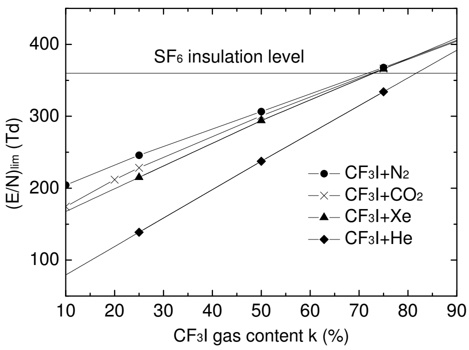

Fig. 9: The limiting fields $(E/N)_{lim}$ as a function of CF_3I gas content k.

4. CONCLUSIONS

In this paper, we use the Boltzmann equation method to calculate the density-normalized effective ionization coefficients and electron drift velocities in CF_3I gas mixtures with Xe, He, N_2 and CO_2 for the range of *E*/*N* from 200 to 800 Td. It is shown that the two-term expansion of the Boltzmann equation is valid for deducing the electron swarm parameters of CF_3I and its gas mixtures. Gas mixtures with 70% CF_3I present a very similar dielectric strength to that of SF_6 and might be a good candidate to replace SF_6 with the advantages of comparable insulation strength and non-environmental destruction. Owing to the scarce number of theoretical analyses in mixtures of CF_3I with a buffer gas the present data is justified for the purposes of discharge modeling. Future, more research works should be carried out on the discharge performance of the gas mixtures under different electric field and by-products produced after dielectric breakdown.

5. ACKNOWLEDGEMENT

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