ELECTRON DRIFT, DIFFUSION, AND EFFECTIVE IONIZATION COEFFICIENTS IN SF_6-CHF_3 AND SF_6-CF_4 MIXTURES FROM BOLTZMANN ANALYSIS

L. S. WEI*, D. K. YUAN, Y. F. ZHANG, Z. H. TAN

School of Environmental & Chemical Engineering, Nanchang University, 330031, Nanchang, China
*weilinsheng@ncu.edu.cn

ABSTRACT

The electron drift velocity, electron energy distribution function and density-normalized effective ionization coefficient are calculated for SF_6-CHF_3 and SF_6-CF_4 mixtures. Two-term, spherical harmonic expansion approximation is utilized to calculate the swarm parameters in steady-state Townsend form Boltzmann analysis. Results show that the drift velocity v_D varies feebly with SF_6 content. On the other hand, a strong dependence is observed in density-normalized effective ionization coefficient with SF_6 content, the gas mixture becomes more electronegative as the share of SF_6 in gas mixtures increases. The calculated value E/N_{cr} of SF_6-CHF_3 and SF_6-CF_4 mixtures is lower than measured value of SF_6-N_2. The calculated density-normalized effective ionization coefficients obtained in the paper are compared with measured data from pulsed Townsend experiments. The predicted results in the numerical simulation are in agreement with the experimental results.

1. INTRODUCTION

Due to its outstanding electrical, physical and excellent thermal characteristics, Sulfur Hexafluoride has been widely used in the electrical industry. Whereas a major concern have emerged that SF_6 is supposed to be a remarkable greenhouse gas, with a global warming potential 24 000 times greater than that of CO_2 for a 100 year period. In order to decrease the greenhouse impact, SF_6 involved mixtures with less harmful fluorocarbon gases have been therefore investigated as alternatives to be used in electric power engineering.

SF_6-CHF_3 and SF_6-CF_4 have been identified as effective alternatives to pure SF_6. Urquijo has measured of electron drift, diffusion and effective ionization coefficients in SF_6-CHF_3 and SF_6-CF_4 gas mixtures using pulsed Townsend method[1]. The theoretical calculation based on the numerical solutions of Boltzmann equation have been widely investigated in relevant studies for SF_6 involved mixtures[2-4], whereas numerical analysis regarding SF_6-CHF_3 and SF_6-CF_4 are rare.

In this paper, we calculate the electron drift velocity, and density-normalized effective ionization coefficient at various SF_6 content by solving Boltzmann equation with two-term expansion for a steady Townsend discharge. The critical reduced field E/N_{cr} is then determined at which ionization exactly balances attachment. In addition, reliable data of $(\alpha-\eta)/N$ from pulsed Townsend are plotted for the sake of comparison.

2. RESULTS AND DISCUSSION

2.1 Effective ionization coefficients and electron drift velocity of pure SF_6

In the paper, the results from Boltzmann analysis within two-term approximation and the data from direct experimental measurements of the density-reduced effective ionization coefficient in pure SF_6 are compared in Fig. 1. It can be observed that density normalized coefficient $(\alpha-\eta)/N$ increases with increasing reduced field strength. The numerical results are in agreement with previously published values. Thus, the possibility of utilizing a two-term Boltzmann code constitutes a great advantage especially when dealing with a large number of computations.

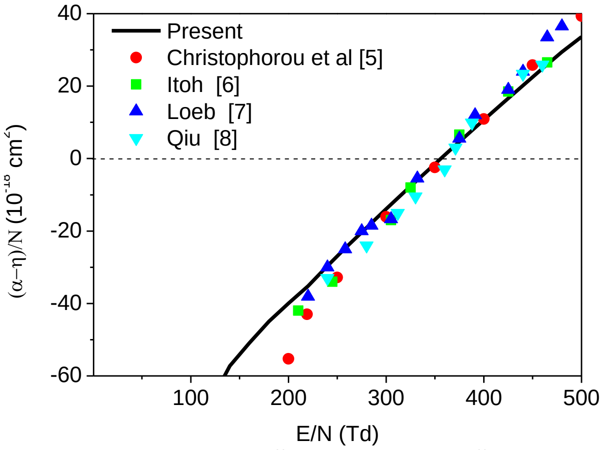

Fig. 1 Density normalized effective ionization coefficient as a function of reduced field strength at different for pure SF_6

2.2 The electron energy distribution functions, EEDF

Fig. 2 excludes the mean electron energy as a function of SF_6 content for SF_6-CHF_3 and SF_6-CF_4 mixtures when $E/N = 200$ Td . It can be observed that mean electron energy of SF_6-CHF_3 mixtures decreases with increasing SF_6 content. Contrarily, as the share of SF_6 in SF_6-CF_4 mixtrues increases, the corresponding mean electron energy of SF_6-CF_4 decreases slightly. Such discrepancies can be attributed to the variation of EEDF.

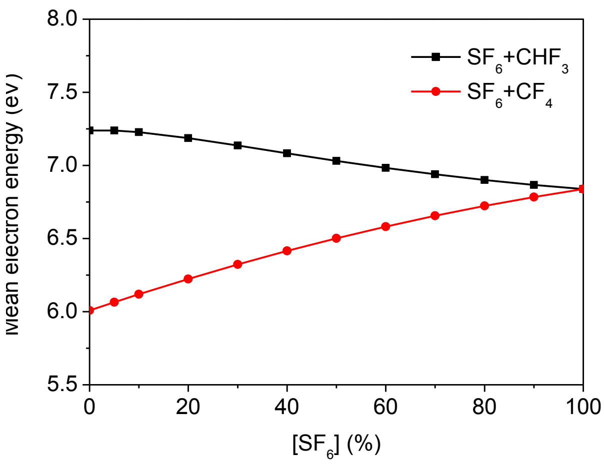

Fig.2 Mean electron energy as a function of SF_6 content for SF_6-CHF_3 and SF_6-CF_4 mixtures

The addition of SF_6 in SF_6-CHF_3 mixtures decreases the electron energy distribution function at the vicinity of the origin of energy space $\varepsilon = 0$ as shown in Fig. 3, which leads to the decrease of mean electron energy. With respect to SF_6-CF_4 mixtures, as the share of SF_6 in gas mixtures increases, electron energy distribution function hardly differs near $\varepsilon = 0$, whereas the electron energy distribution function shifts to the right in the low electron energy region as shown in Fig. 4, which causes the mean electron energy of SF_6-CF_4 mixtures increases with increasing SF_6 content.

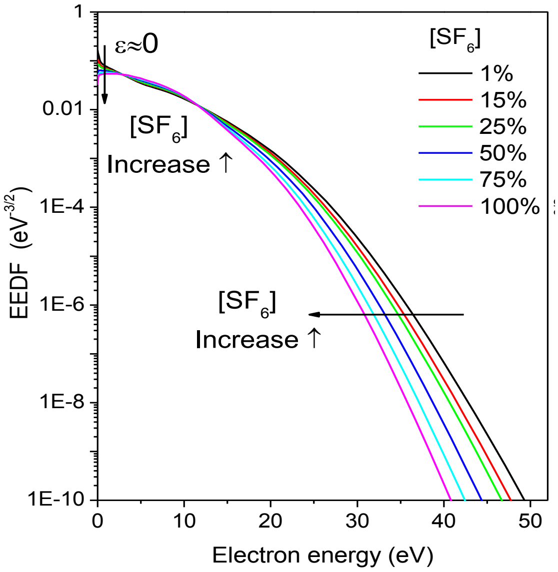

Fig. 3 Electron energy distribution functions of SF_6-CHF_3 mixtures

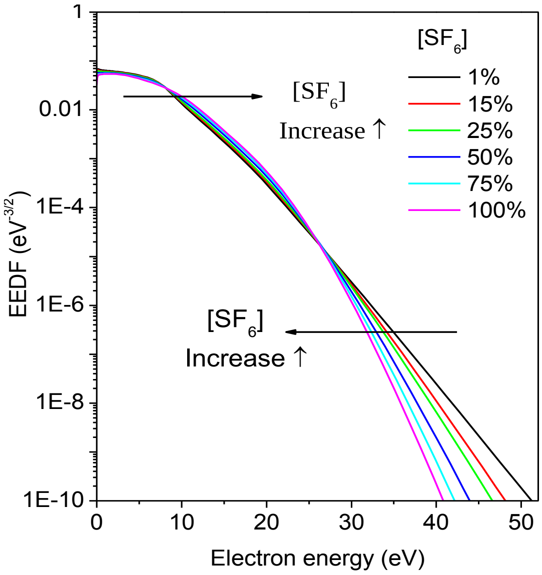

Fig. 4 Electron energy distuibution functions of SF6-CF_4 mixtures

2.3 Drift velocity

Fig. 5 and Fig. 6 describe the calculated electron drift velocity as a function of reduced field strength for SF_6-CHF_3 and SF_6-CF_4 mixtures. As it can seen from the figures, drift velocity V_D increases with increasing reduced field strength and it varies weakly when the share of SF_6 in

SF_6-CHF_3 and SF_6-CF_4 mixtures varies form 1% to 100%, especially in the relatively high reduced field region. At a fixed reduced field strength, the drift velocity decreases gradually with increasing SF_6 content for SF_6-CHF_3 and SF_6-CF_4 mixtures. The reasons for the changes in drift velocity V_D are twofold. Primarily, the effective collision frequencies for momentum transfer in SF_6 and CHF_3/CF_4 weigh differently as the share of SF_6 in gas mixtures varies. In addition, the most important changes arise from the modifications on the EEDF as the SF_6 content increases. It can be also noted the interaction of electrons within the gas mixtures is strongly dominated by CHF_3 and CF_4, especially for CHF_3 in SF_6-CHF_3 mixtures, in which the electron drift velocity V_D decreases very feebly with SF_6 content even in the low reduced field strength E/N region due to the fact that CHF_3 is a highly polar molecule[5].

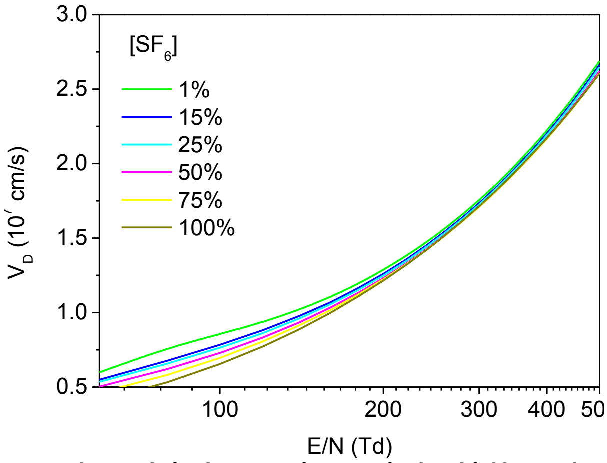

Fig. 5 Electron drift velocity as a function of reduced field strength for SF_6-CHF_3 mixtures

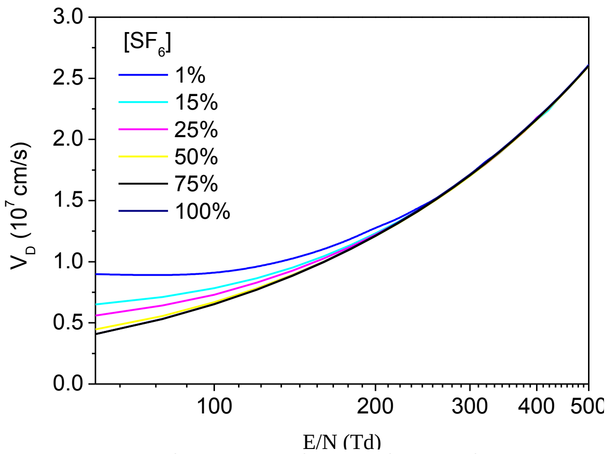

Fig. 6 Electron drift velocity as a function of reduced field strength for SF_6-CF_4 mixtures

3.4 Density-normalized effective ionization coefficient and critical field strength.

The density-normalized effective ionization coefficients $(\alpha-\eta)/N$ calculated in the paper for and SF_6-CHF_3 and SF_6-CF_4 gas mixtures with 1%, 15%, 25%, 50%, 75% and 100% as a function of reduced field strength are displayed in Fig. 7 and Fig. 8. It indicates that density-normalized effective ionization coefficient $(\alpha-\eta)/N$ increases with increasing reduced field E/N. For a given value, it decreases as the share of CHF_3/CF_4 content in gas mixtures decreases. This is a consequence of the increasingly electronegative character of the SF_6-CHF_3 and SF_6-CF_4 gas mixtures. For the sake of comparison with published, reliable data are displayed as well.

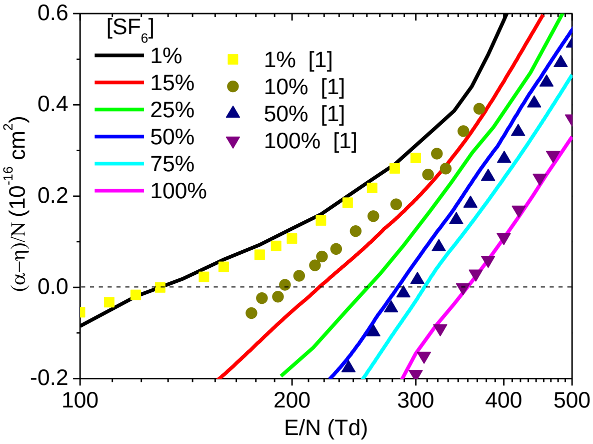

Fig. 7 The density-normalized ionization coefficient for SF_6-CHF_3 mixtures

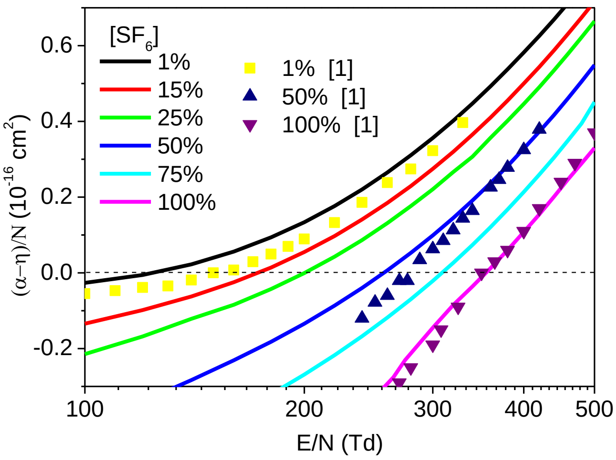

Fig. 8 The density-normalized ionization coefficient for SF_6-CF_4 mixtures

In what concerns now the E/N_{cr}, the critical values at which ionization exactly balances attachment when $(\alpha-\eta)/N=0$, as a function of

SF_6 content in SF_6-CHF_3 and SF_6-CF_4 gas mixtures are plotted in Fig. 9, together with the Urquijo's experimental data and those for SF_6-N_2 mixture for the sake of comparison, since the SF_6-N_2 have been widely studied in relevant studies. It can be seen the critical reduced strength E/N_{cr} increases with increasing SF_6 content, yet the value of E/N_{cr} varies weakly between SF_6-CHF_3 and SF_6-CF_4 gas mixtures as SF_6 content increases. Moreover the agreement between theory and experiment is acceptable in SF_6-CHF_3 and fair in SF_6-CF_4 although some discrepancies are observed as the share of SF_6 in gas mixtures increases. The overall calculated values E/N_{cr} in SF_6-CHF_3 are higher than the measured data while the critical values are lower than the measured data in SF_6-CF_4 mixtures with SF_6 content variation. Now that the E/N_{cr} values in SF_6-N_2 are consistently higher than those in SF_6-CHF_3 and SF_6-CF_4 gas mixtures as indicated by [9], the critical values are by far larger in SF_6-N_2 than in other SF_6 involved gas mixtures, due to the relatively low ionization rate coefficients in N_2 and the influence of N_2 as a good electron scattered that performs in the overall attachment process.

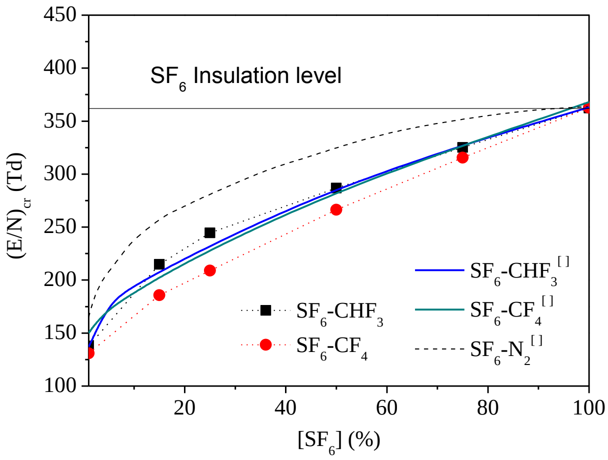

Fig. 9 The critical reduced field strength as a function of SF6 content

3. CONCLUSION

In this paper, density normalized effective ionization coefficients, electron energy distribution function and electron drift velocity for are all calculated using Boltzmann equation along with two-term approximation for SF_6-CHF_3 and SF_6-CF_4 mixtures. The critical electric field strength E/N_{cr} , at which the ionization and attachment rate are exactly balanced, is determined for SF_6-CHF_3 and SF_6-CF_4 mixtures as a function of SF_6 content. By comparing with the previous published values, two-term expansion is confirmed to be a valid approach.

ACKNOWLEDGEMENT

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