Publ. Astron. Obs. Belgrade No. 102 (2022), 33 - 36 *Contributed Paper*

FORMATION AND PROPAGATION OF STREAMERS IN CF_3I-SF_6 GAS MIXTURES

J. ATIĆ[1], D. BOŠNJAKOVIĆ[1], I. SIMONOVIĆ[1],
Z. Lj. PETROVIĆ[2] and S. DUJKO[1]

[1]*Institute of Physics Belgrade, University of Belgrade, Pregrevica 118,*
11080 Belgrade, Serbia
E-mail sasa.dujko@ipb.ac.rs

[2]*Serbian Academy of Science and Arts, Knez Mihailova 35, 11000 Belgrade, Serbia*

Abstract. The formation and propagation of streamers in CF_3I-SF_6 mixtures are studied by the classical fluid model in 1D and 1.5D configurations. We calculate the electron density, electric field, and velocity of streamers as a function of the applied reduced electric fields for various CF_3I-SF_6 mixtures. We found that the transition of an electron avalanche into a negative streamer occurs more slowly with an increasing fraction of CF_3I in the mixture.

1. INTRODUCTION

In high voltage technology, strong electronegative gases are used to prevent the electrical breakdown in power transmission and distribution systems. SF_6 is widely used in these applications because of its extraordinary dielectric characteristics (primarily, high critical electric field and low boiling point). However, SF_6 is a very powerful greenhouse gas with an extremely high global warming potential (22800 on a 100-year horizon) and a very long atmospheric lifetime (3200 years). Research on alternative gases is therefore one of the main activities of researchers worldwide.

The first step in this effort involves reducing the SF_6 concentration using gas mixtures. CF_3I, one of the most promising candidates for replacement of SF_6, is also a strong electronegative gas. Its critical electric field is higher than that of SF_6 and it has a very short atmospheric lifetime (shorter than 2 days), as well as negligible global warming potential (lower than the referent gas CO_2). However, in comparison with SF_6, its boiling point is not sufficiently low. Using these CF_3I characteristics as motivation factors, we investigated the formation and propagation of negative streamers in CF_3I-SF_6 mixtures.

2. METHODS OF CALCULATIONS

The transition from an avalanche to a streamer, and the propagation of streamers were considered by a numerical model based on fluid equations. We use the classical fluid model where the equation of continuity is combined with the drift-diffusion approximation. The resulting equation is coupled to the Poisson equation for space charge electric field calculations. The corresponding system of partial differential equations is solved numerically assuming the local field approximation (Bošnjaković et al. 2016). The calculations are carried out in the 1D and 1.5D configurations where the fixed value of the streamer radius is incorporated into the axial symmetrical model. The streamer velocities are calculated from the modeling performed in 1D and by using the analytical expression (Li et al. 2007) which requires knowledge of electron mobility, longitudinal diffusion coefficient and ionization coefficient as a function of the reduced electric field. The cross-section sets for electron scattering in CF_3I and SF_6 were developed in our laboratory (Mirić et al. 2016), and by Itoh and co-workers (Itoh et al. 1993) respectively.

3. RESULTS AND DISCUSSION

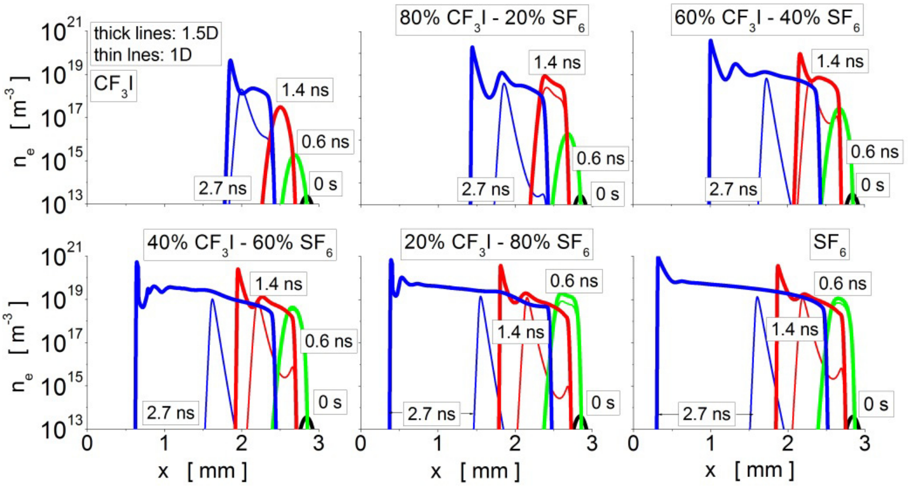

Figure 1: Electron density during streamer formation and propagation in CF_3I-SF_6 mixtures for E_0/n_0 = 480 Td.

Figure 1 shows the electron density during streamer formation and propagation in CF_3I-SF_6 mixtures. The results are obtained from the classical 1D and 1.5D fluid models in which the input data are electron bulk transport coefficients calculated by Monte Carlo simulations. The external electric field is 480 Td, which is larger than the critical electrical fields of the two gases. This requirement permits the development of streamers. Comparing the results in two different configurations for the fixed mixture shows that the electron density is higher in the 1.5D model. The results in the same configuration show that the development of streamers is slower with the decrease of SF_6 in mixture. This behavior is expected based on a greater critical electric field of CF_3I (437 Td) than SF_6 (361 Td). This is one of the indicators that CF_3I is better dielectric than SF_6 because of its capacity to prevent the development of streamers at higher electric fields.

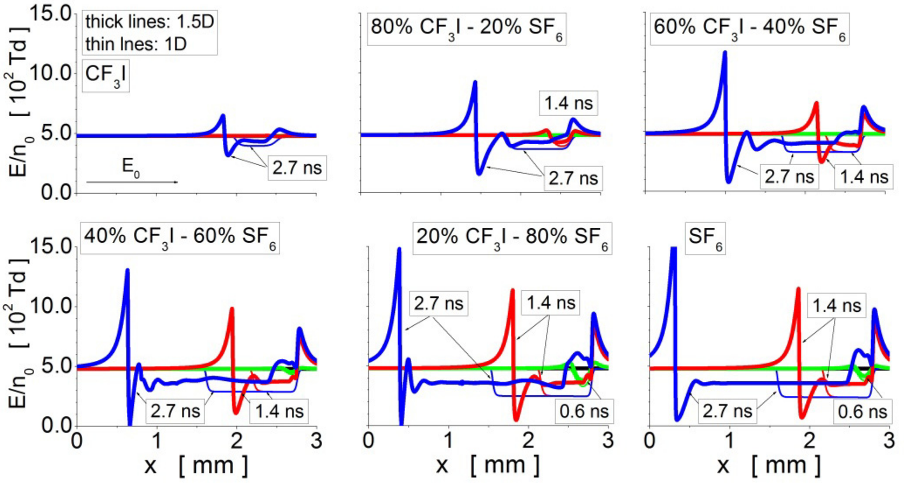

Figure 2: Electric field during streamer formation and propagation in CF_3I-SF_6 mixtures for E_0/n_0 = 480 Td. The calculation is performed using the 1.5D and 1D setups and balk transport coefficients as input to the classical fluid model.

Figure 2 shows the temporal development of the electrical field of the streamers in the CF_3I-SF_6 mixtures according to the same conditions as in Figure 1. The results of the 1.5D configuration show that the electric field in the streamer channel is equal to the critical electric field of the studied gas mixture. Field amplification in the region ahead of the streamer front starts from 40 % (pure CF_3I) up to 200 % (pure SF_6). By comparing the 1D and 1.5D configurations, we observe that the electrical field in the streamer channel descends to the lower level in the 1.5D configuration. In the 1D configuration, the electrical field in the region ahead of the streamer front is equal to the external field, independently of the gas mixture.

Figure 3 shows the streamer velocity and drift velocity of the electrons for various CF_3I-SF_6 mixtures. As the development of streamers is possible in electrical fields above the critical electrical field, the streamer velocity of gas mixtures can be calculated by the fluid model (left panel) starting from different electrical fields. The increase in streamer velocity with increasing concentration of SF_6 is a consequence of the evolution of streamers (Figures 1 and 2). Although it seems unexpected, the streamer velocity in the pure SF_6 is lower than that in the mixture 20% CF_3I - 80% SF_6 because of the behavior of the drift velocity of electrons (right panel). The comparison of these two sets of results shows that the streamer velocity is higher than the drift velocity of electrons regardless of the gas mixture and the electric field. This follows from the fact that the streamer velocity is a combination of the electron drift velocity, the velocity induced by the strong diffusive flux at the streamer front and the creation of the electrons by electron-impact ionization. A comparison of the streamer velocities computed from the fluid model (left panel) and the analytical expression (middle panel) shows that these two sets of results differ from each other. This figure clearly illustrates the limits of the analytical formula that is often used for calculating streamer velocity.

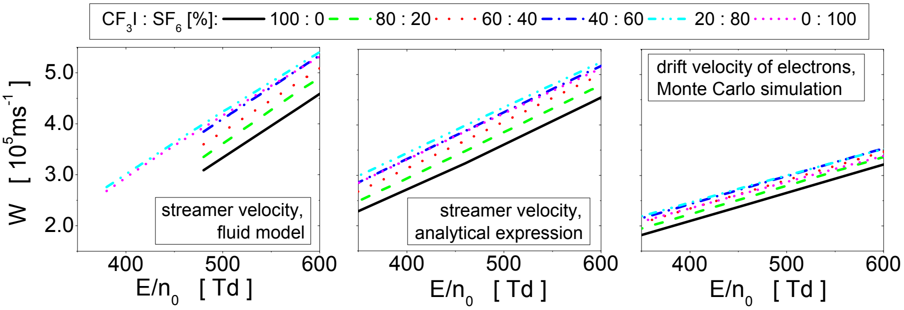

Figure 3: Streamer velocity calculated by the fluid model (left panel) and analytical expression (middle panel) and the drift velocity of electrons (right panel). Results in the CF_3I-SF_6 mixtures are given as a function of the reduced electric field.

Acknowledgment

This research was supported by the Institute of Physics Belgrade, and the Science Fund of the Republic of Serbia [Grant No. 7749560, EGWIn].

References

Bošnjaković, D., Petrović, Z.Lj., Dujko, S.: 2016, *J. Phys. D: Appl. Phys.* **49**, 405201.

Li, C., Brok, W.J.M., Ebert, U., van der Mullen, J.J.A.M.J.: 2007, *Appl. Phys.* **101**, 123305.

Mirić, J., Bošnjaković, D., Simonović, I., Petrović Z.Lj., Dujko, S.: 2016, *Plasma Source Sci. Technol.* **25**, 065010.

Itoh, H., Matsumura, T., Satoh, K., Date, H., Nakano, Y., Tagashira, H.: 1993, *J. Phys. D: Appl. Phys.* **26**, 1975.