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# COMPLETE DATABANK OF SF<sub>6</sub>-C<sub>2</sub>F<sub>4</sub> PLASMA FOR HVCB MODELLING

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## ABSTRACT

We propose a complete databank built with the composition of several SF<sub>6</sub>-C<sub>2</sub>F<sub>4</sub> mixtures (step of 10%), the thermodynamic properties (specific heats, mass densities, enthalpies), the transport coefficients (viscosities, electrical and thermal conductivities, diffusion coefficients), and the radiative properties (Net Emission Coefficients (NEC) and Mean Absorption Coefficients (MAC)). The pressures go from 1 to 250 bar and the temperatures from 300K to 50000K (step of 10K). The method used to obtain these data will be briefly given, some results will be presented. This databank has been implemented in a CFD arc simulation tool for High Voltage Circuit-Breaker (HVCB) developed by SIEMENS ENERGY. A validation of the complete databank is proposed by the comparison of the pressure build-up measurements with the results given by the CFD simulation approach.

## 1. INTRODUCTION

The simulation of an electrical arc in HVCB from its ignition to its extinction requires the thermophysical properties of the plasma such as the thermodynamic properties ( $\rho$ ,  $H$ ,  $C_p$ ), the transport coefficients ( $\mu$ ,  $\kappa$ ,  $D$ , and diffusion coefficients) and the radiative losses (divergence of the radiative flux from the NEC or the MACs). Many studies have been developed, a review and some perspectives are reported in the paper from Seeger [1]. Unfortunately, few confrontations between experimental and theoretical works are available, often based on the comparison of the arc voltage, the heating volume, the critical field, or the temperature profiles. The team ScIPRA of the LAPLACE laboratory developed this database for SF<sub>6</sub>-C<sub>2</sub>F<sub>4</sub> mixtures in 2014 [2], improved for this work for pressures from 1 to 250 bar, and temperatures in the range 300-50000K. Implemented in the SIEMENS ENERGY CFD arc simulation tool, it allowed to simulate the evolution of the arc and the rise of pressure in the HVCB by a detailed study of the radiative losses via MACs (for absorption regions) coefficients.

## 2. COMPOSITION AND THERMODYNAMIC PROPERTIES

The method of Godin and Trepanier [3] was used to obtain the evolution of the different species existing in the plasma: e<sup>-</sup>, 19 atomic species (C, C<sup>+</sup>, C<sup>2+</sup>, C<sup>3+</sup>, C<sup>4+</sup>, C<sup>-</sup>, S, S<sup>+</sup>, S<sup>2+</sup>, S<sup>3+</sup>, S<sup>4+</sup>, S<sup>5+</sup>, S<sup>-</sup>, F, F<sup>+</sup>, F<sup>2+</sup>, F<sup>3+</sup>, F<sup>4+</sup>, F<sup>-</sup>), 17 diatomic molecules (S<sub>2</sub>, S<sub>2</sub><sup>+</sup>, S<sub>2</sub><sup>-</sup>, C<sub>2</sub>, C<sub>2</sub><sup>+</sup>, C<sub>2</sub><sup>-</sup>, F<sub>2</sub>, F<sub>2</sub><sup>+</sup>, F<sub>2</sub><sup>-</sup>, SF, SF<sup>+</sup>, SF<sup>-</sup>, CF, CF<sup>+</sup>, CF<sup>-</sup>, CS, CS<sup>+</sup>), 8 triatomic molecules (C<sub>3</sub>, CF<sub>2</sub>, CS<sub>2</sub>, SF<sub>2</sub>, S<sub>3</sub>, SF<sub>2</sub><sup>-</sup>, SF<sub>2</sub><sup>+</sup>, CF<sub>2</sub><sup>+</sup>) and 28 polyatomic molecules (C<sub>2</sub>F<sub>2</sub>, CF<sub>3</sub>, C<sub>4</sub>, SF<sub>3</sub>, S<sub>4</sub>, S<sub>2</sub>F<sub>2</sub>, FS<sub>2</sub>F, SF<sub>3</sub><sup>-</sup>, SF<sub>3</sub><sup>+</sup>, CF<sub>3</sub><sup>+</sup>, CF<sub>4</sub>, SF<sub>4</sub>, S<sub>5</sub>, SF<sub>4</sub><sup>-</sup>, SF<sub>4</sub><sup>+</sup>, C<sub>5</sub>, C<sub>2</sub>F<sub>4</sub>, SF<sub>5</sub>, S<sub>6</sub>, SF<sub>5</sub><sup>-</sup>, SF<sub>5</sub><sup>+</sup>, S<sub>7</sub>, SF<sub>6</sub>, SF<sub>6</sub><sup>-</sup>, CF<sub>3</sub>SF<sub>5</sub>, S<sub>2</sub>F<sub>10</sub>, C<sub>2</sub>F<sub>6</sub>, S<sub>8</sub>).

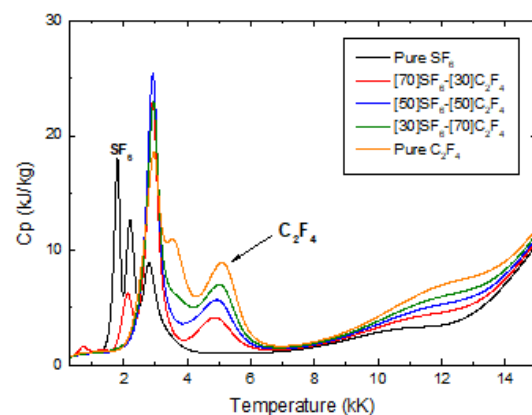


Fig. 1  $C_p$  for several SF<sub>6</sub>-C<sub>2</sub>F<sub>4</sub> mixtures at 1bar and low temperatures.

The calculation of the internal partition functions and the thermodynamic properties (mass density, enthalpy, entropy, specific heat at constant pressure and sound velocity) are detailed in [4]. An example of the specific heat at constant pressure (1bar) for several SF<sub>6</sub>-C<sub>2</sub>F<sub>4</sub> mixtures (in mass proportions) is proposed in figure 1 at low temperature (300-15000K).

### 3. TRANSPORT COEFFICIENTS

The calculation of the transport coefficients is based on the Chapman-Enskog method which requires the knowledge of particle number densities and collision integrals. See [4-6] to read more details about the methods used to calculate the collision integrals. As example for thermal conductivity, figure 2 shows this transport coefficient for several SF<sub>6</sub>-C<sub>2</sub>F<sub>4</sub> mixtures at 1 bar.

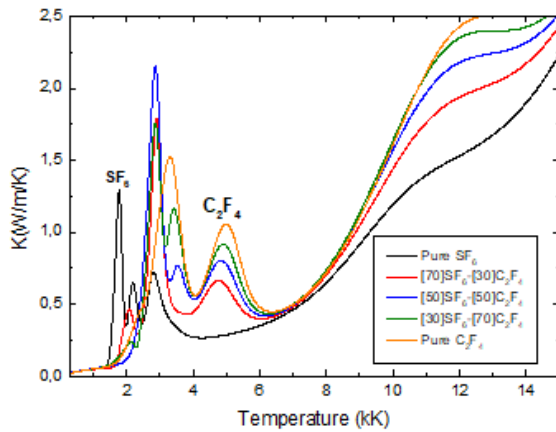


Fig. 2 Thermal conductivity for several SF<sub>6</sub>-C<sub>2</sub>F<sub>4</sub> mixtures at 1bar

The combined diffusion coefficients were calculated according to the Murphy's theory [7]. The method being only valid for binary mixtures and for homonuclear and non-reactive gases, we adopted some assumptions reported in [6].

### 4. RADIATIVES PROPERTIES

Concerning the calculation of plasma properties, many papers and methods are devoted to the radiative transfer such as the Net Emission Coefficient proposed by Lowke [8] or the P1 model using the Mean Absorption Coefficients for which the number of spectral intervals, the influence of the plasma size R<sub>p</sub> or the mean functions were already discussed in [2,4]. The main difficulties of these methods consist not only of the calculation of the spectral absorption

coefficient  $K'_\lambda(T)$  which strongly varies according to the wavelength, temperature and pressure, but also of the calculation of the radiation lines including their absorption. Therefore, various physical phenomena must be considered: the radiation of the atomic continuum (radiative recombination, Bremsstrahlung and radiative attachment), the radiation of molecular continuum (photo-dissociation, photo-ionization and photo-attachment) that we have meticulously studied in [2], the radiation of the atomic lines (by taking into account the absorption phenomena), and the radiation of molecular bands [9] that we have added in this work compared to works done in [2]. For the calculation of the radiative spectra, we used the 'line-by-line' method. As an example, the total absorption coefficient of the [70%]SF<sub>6</sub>-[30%]C<sub>2</sub>F<sub>4</sub> mixture at 1 bar and 10000K is given in figure 3.

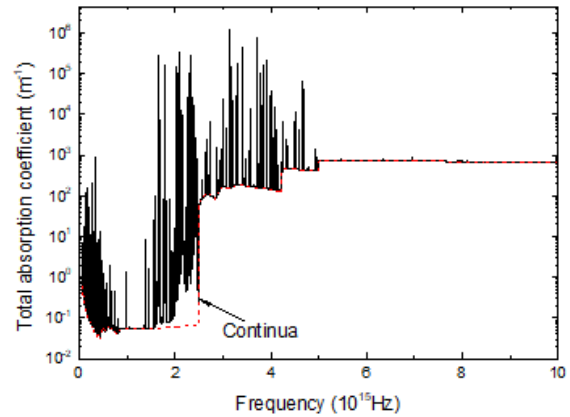


Fig. 3 Total absorption coefficient for [70%]SF<sub>6</sub>-[30%]C<sub>2</sub>F<sub>4</sub> mixture at 1bar and 10000K.

From these total absorption coefficients, we have calculated the NECs and the MACs to consider emission and absorption in order to simulate the pressure rise in the HVCB. As explained in [2] for the MACs, the most difficult step is to well define the spectral intervals, their number, and the mean function. Several tests have been done between 4 and 10 spectral intervals with several mean functions [2]. For this work, 7 spectral intervals have been taken into account, MACs were obtained by mixing Planck, Classic and Planck Modified Mean (with R<sub>p</sub>=0.5mm) functions to obtain a good agreement concerning arc voltage and pressure rise in the HVCB. Figure 4 gives an example of the MACs obtained for a [30%]SF<sub>6</sub>-[70%]C<sub>2</sub>F<sub>4</sub> mixture at 1bar and R<sub>p</sub>=0.5mm.

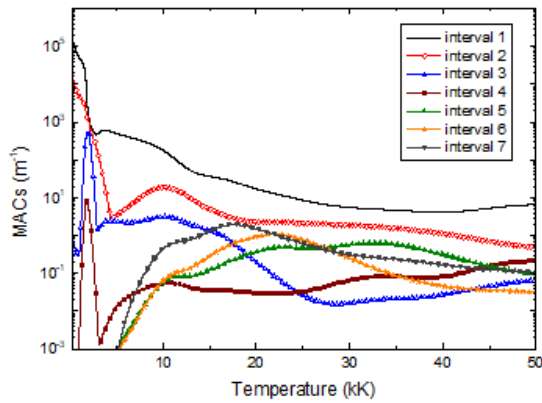


Fig. 4 MACs for a [30%] $SF_6$ -[70%] $C_2F_4$  mixture at 1bar and  $R_P=0.5mm$ .

From the NEC or the MACs, and according to a plasma temperature profile, the divergence of the radiative flux can be deduced from the radiative transfer equation.

## 5. UTILIZATION OF DATABANK

The  $SF_6$ - $C_2F_4$  databank has been integrated into the existing CFD arc simulation tool. Using the tool the switching-off process in the interrupter unit of a HVCB has been simulated. As an example for the simulation results, figure 5 shows the pressure build-up in the heating volume of the HVCB for two different currents in comparison to the measurements [10]. The simulation results demonstrate a very good agreement to the measurements validating the CFD arc simulation tool and the  $SF_6$ - $C_2F_4$  databank as well.

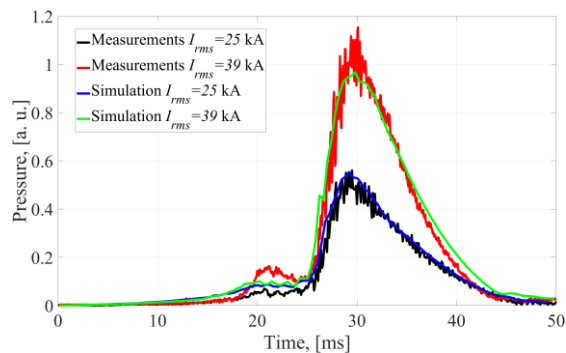


Fig. 5 Pressure build-up in the heating volume.

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