

TWO-TEMPERATURE PLASMA COMPOSITION IN SF₆ PLASMA : A KINETIC MODEL

J. B. Belhaouari, R. Girard, J. J. Gonzalez, A. Gleizes
Centre de Physique des Plasmas et de leurs Applications de Toulouse, ESA 5002,
Université Paul Sabatier 118 route de Narbonne, F31062 Toulouse Cedex 4, France
jjg@cpa11.ups-tlse.fr

ABSTRACT

In order to simulate departures from thermodynamic equilibrium occurring in a lot of situations like circuit breaker near current zero or plasma jets, we have developed a two-temperature plasma composition based on a kinetic model of SF₆ plasma. This model takes into account the radiative and collisional mechanisms responsible for the creation and disappearance of atoms and molecules through 19 species linked by sixty-six chemical reactions. The direct reaction rates, which are function of the heavy particles temperature, proceed from literature, whereas the reverse rates, which are function of electronic temperature T_e and heavy particle temperature T_h , were computed by micro-reversibility using the Saha law and are function of the parameter $\theta = T_e/T_h$. A comparison is made on the results obtained with the Saha law given by Potapov and those calculated using the law given by Van de Sanden. The plasma composition is compared with the equilibrium composition obtained by classical laws of dissociation and ionisation. The difficulty on the choice of T_{ex} is pointed out, and several diatomic and atomic species concentrations present big changes on their evolution, following the choice of T_{ex} .

KEY WORDS : Composition, collisional model, departures from equilibrium, SF₆

1. INTRODUCTION

Many numerical models are made on the behaviour of the arc during its decay in a circuit breaker [1-4]. On the other side quantitative analysis of the extinction mechanisms occurring in SF₆ arcs still raises a lot of problems, as can be seen from comparison between experimental trials and theoretical predictions. We can note in particular that, during the extinction, a model based on the hypothesis of thermal equilibrium overestimate the time constant of the decay of conductance [5-6] with respect to experimental values [7]. Models based on the assumptions of equilibrium always predict the existence of a certain current [8-9] which, in most cases, cannot be demonstrated experimentally. The aim of our study was to examine the existence of departures from thermal equilibrium (between the electron temperature and the heavy particles one), and to point out whether such departures could explain certain discrepancies between experimental and theoretical values.

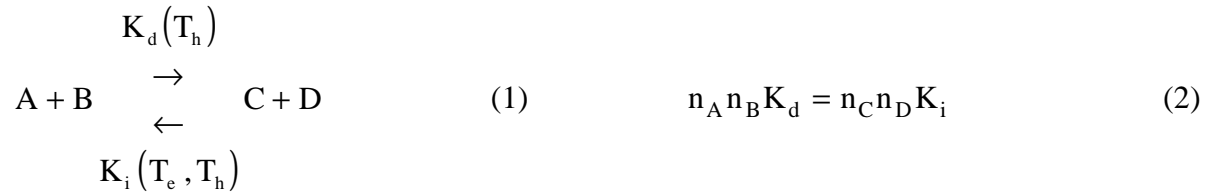
2. COMPOSITION

Here, we present the bases and the assumptions made to calculate the composition with the kinetics model. The energy distribution functions of all species are Maxwellian. The pressure is constant and the results are presented for $P = 10^5$ Pa. The calculated composition will be presented for two values of θ , at the equilibrium $\theta = 1$ and for $\theta = 1.5$.

Species and Chemical reactions

For temperatures between 3000 K and 12000 K, we considered 19 species: (e^- , S, S^- , S^+ , S_2 , S_2^+ , F, F^- , F^+ , F_2 , F_2^+ , SF, SF^- , SF^+ , SF_4 , SF_5 , SF_6 , SF_2 , SF_3). In order to avoid excessive calculation times, the minor species, such as (SF_5^+ , SF_4^+ , SF_3^+ , SF_2^+ , F^{2+} , S^{2+} ...) were ignored. Similarly, the negative ions (F_2^- , S_2^- , SF_6^- , SF_5^- and SF_4^-), which were present in very small amounts over the temperature range considered (3000 K < T < 12000 K) were not taken into account. A preliminary study of the reactions showed that these species are only weakly involved in electron capture processes. Sixty-six chemical reactions were taken into account and have been described previously [10].

The general chemical reaction of dissociation or recombination between atoms and molecules is given by relation (1), where K_d represents the direct rate and K_i the reverse rate. At the equilibrium, the direct reaction rate is equal to the reverse reaction rate per time and volume units (2).



Most of the direct reaction rates proceed from reference [11] and are function of one single temperature, whereas the reverse rates were computed by micro-reversibility requiring the calculation of two temperatures partition functions [12].

Equations

In order to determine the reverse rate, two Saha laws were used to compute the plasma composition : the first one was given by Potapov [13] (equation 3), the second one was proposed by Van de Sanden [14] and is a function of T_e and T_{ex} (4). Expression (3) was written for atomic ions, for molecular ions the partitions functions should be raised to the power of $1/\theta$. The choice of the excitation temperature T_{ex} in equation (4) is difficult [12], because T_{ex} is equal to T_e or T_h depending on the reaction and on the relative electron concentration.

$$n_e \left(\frac{n_A^+}{n_A} \right)^{\frac{1}{\theta}} = \frac{2Z_{A^+}}{Z_A} \left(\frac{2\pi m_e k T_e}{h^2} \right)^{3/2} \exp \left(- \frac{E_i}{k T_e} \right) \quad (3)$$

$$\left(\frac{n_e n_A^+}{n_A} \right) = \frac{2Z_{A^+}}{Z_A} \left(\frac{2\pi m_e k T_e}{h^2} \right)^{3/2} \exp \left(- \frac{E_i}{k T_{ex}} \right) \quad (4)$$

The conservation equation for species i is given by:

$$\frac{\partial n_i}{\partial t} + \vec{\nabla} \cdot (n_i \vec{V}) = Ca_i - n_i Da_i \quad (5)$$

The terms Ca_i and Da_i describe the global reaction rates of species i and are functions of the direct and reverse rates (K_d and K_i) of all the chemical reactions on species i. In stationary state, the creation term is equal to the loss term and the SF_6 plasma composition is calculated by equation (5) which is reduced to:

$$n_i = \frac{Ca_i}{Da_i} \quad (6)$$

The model is composed of 19 reaction rate equations [10]. These equations are not linearly independent and other relations exist to link the particle densities, like the perfect gas law, electrical neutrality and stoichiometric equilibrium between S and F in the plasma.

3. RESULTS

Equilibrium composition

Figure 1 gives the equilibrium composition $\theta=1$ and shows the variations of the equilibrium particle densities versus the temperature at atmospheric pressure (10^5 Pa). In order to validate our kinetic model, we compared our equilibrium composition with the one calculated using a thermodynamic model [15]. We found good agreement between the two series of results and with the results in the literature.

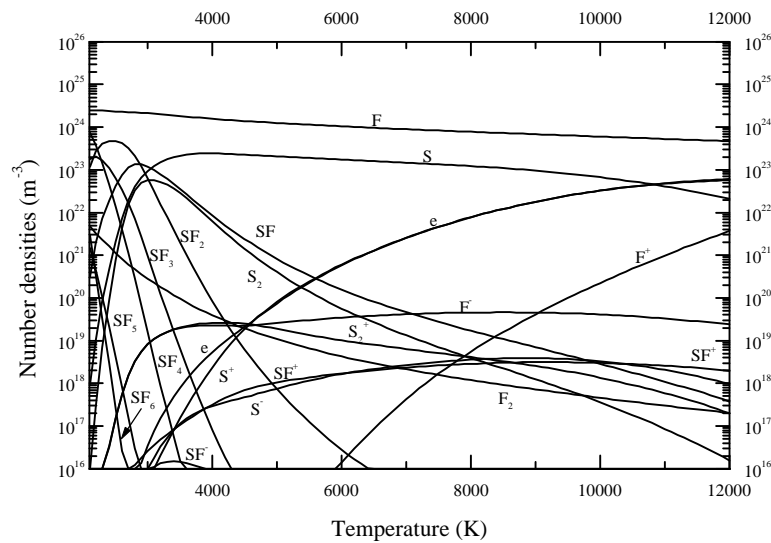


Figure 1: Equilibrium composition of SF_6 plasma.

Two temperature composition

For the determination of the reverse rates, we used Guldberg Waage and Saha laws. In the Saha law given by Van de Sanden we used the heavy particles temperature for T_{ex} , as in the Guldberg Waage law, whereas we considered the electronic temperature in the Potapov expression of Saha law. Other calculations were made using T_e for T_{ex} and using T_e or T_h depending on the reactions, but the obtained densities were not physically realistic. This point is discussed in paper [12].

The main difference between the two temperature compositions using Potapov or Van de Sanden expressions of the Saha law (figures 2 and 3) is the relative difference between the composition of outstanding charged particles, i.e. between F^- and e^- and between S^+ and S_2^+ . This can affect the breaking power of the circuit breaker (directly for F^- and e^- because this power depends on the capacity of the plasma to capture the conducting electrons, and through the energy exchange for S^+ and S_2^+). Thus, electrons loose their energy mainly through elastic collisions with positive ions, and departure from thermal equilibrium appear for electronic temperatures between 6000 to 9000 K.

We have recently shown that the composition obtained with Van de Sanden expression led to better results when calculating energy exchange. Thus, computation with Potapov expression gave a overestimation of S_2^+ density between 6000 to 9000 K, leading to an overestimation of energy exchange on the discharge border.

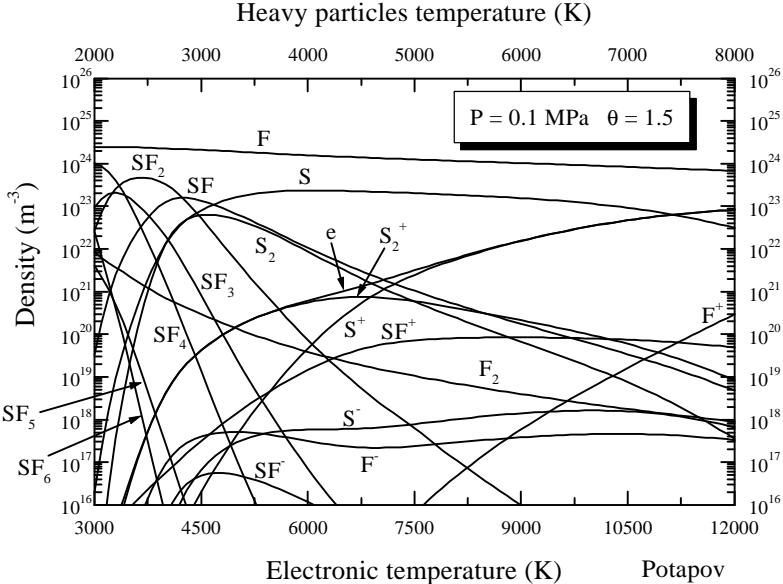


Figure 2: Two temperature composition calculated by a kinetic model using Potapov expression for micro reversibility , $\theta=1.5$.

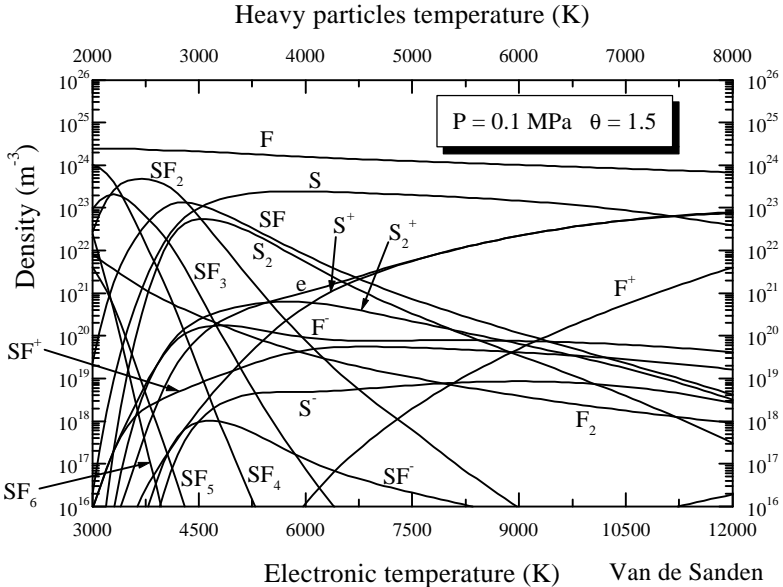


Figure 3: Two temperature composition calculated by a kinetic model using Van de Sanden expression for micro reversibility, $\theta=1.5$.

ACKNOWLEDGMENTS

This work was partly financed by a contract with Electricité de France (EDF) and GEC-Alsthom.

BIBLIOGRAPHIE

- [1] Gleizes A, Robert T., Gonzalez J.J. and Pons A., 1993, *J. Phys. D. : Appl. Phys*, **26**, 1439.
- [2] Gonzalez J.J., Gleizes A. and Krenek P., 1987, *J. Phys. D. : Appl. Phys.*, **27**, 985.
- [3] Robin Jouan P., Rathoin S., Serres E., Chevrier P., Barrauld M, Fievet C., Comte A., Boucher T. and Vérité J.C., 1997, *Proc. Gas Discharges and Their Applications*, **2**, ed G. Babucke, 578
- [4] Fang M.T. C., Zhuang Q and Guo X. J., 1994, *J. Phys. D. : Appl. Phys*, **27**, 74.
- [5] Lowke J.J., Voshall R. E. and Ludwig H. C., 1973, *J. Phys. D. : Appl. Phys*, **44**, 3513.
- [6] Gleizes A., Sakalis I., Razafinimanana M., and Vacquié S., 1987, *J. Phys. D. : Appl. Phys*, **61**, 50.
- [7] Hertz W., 1971, *Z. Phys.*, **245** , 105
- [8] Gleizes A., Robert T. and Pons A., 1992, 10th Int. Conf. Gas Discharges and their Applications ed W T Williams, **1**, 2.
- [9] Park K Y and Fang M T C, 1992, 10th Int. Conf. Gas Discharges and their Applications ed W T Williams, **2**, 940.
- [10] Belhaouari J.B., Gonzalez J.J. and Gleizes A., *J. Phys. D. : Appl. Phys*, **31**, 1998, to be printed.
- [11] Brand K P and Kopainsky J, 1978, *Appl. Phys*, **16**, 245.
- [12] Gleizes A., Chervy B., Gonzalez J.J. and Krenek P., TPP5, S^t Petersburg, 13-16 July 1998
- [13] Potapov A.V., 1966, *High Temp.*, **4**, 48.
- [14] Van de Sanden M.C.M. et al, 1989, *Phys. Rev.*, **A40**, 5273.
- [15] Chervy B., Gleizes A. and Razafinimanana M., 1994, *J. Phys. D. : Appl. Phys*, **27**, 1193.