

MATHEMATICAL MODELLING OF CERTAIN EFFECTS AND CHEMICAL REACTIONS IN AN ELECTRIC ARC IN SF₆ UPON THE DECAY OF THE ARC¹⁾

ADAMEC, L.,²⁾ Brno

In this paper, a mathematical model of reaction kinetics of SF₆ in an electric arc from the moment of its decay is presented. The model is solved numerically, and the obtained results are compared with those obtained by other authors by calculation of the balanced composition of SF₆.

1. INTRODUCTION

Certain properties of SF₆, particularly its high thermal conductivity and capacity of a fast electrical strength restoration predetermine this substance for the application as an optimum extinction medium in breakers and further devices, in which it is necessary to break effectively an electric arc.

In order to make the best use of these properties, it is necessary to study and to describe them most thoroughly. The presented paper attempts to describe at least qualitatively the behaviour of the SF₆ system upon the decay of the arc, or more precisely, to determine the time or temperature dependence, respectively, of the composition of the system, arising by the dissociation and the ionization of SF₆ during the fast temperature drop in the system.

Similar problems have already been investigated in several papers — e.g. [1], [2], [3], which can be divided, according to their approach, into two groups. The first group is based on the presumption that the temperature change is slow in view of the speed of the composition change in the system. It follows therefrom that at each considered instant of time (i.e. also for each temperature considered), the system is in equilibrium. Thus, the problem is transferred to the calculation of chemical equilibria. However, a model considered in this way does not express the kinetics of the effects in progress. The presumption of the relation of the speed of the temperature change and the speed of the system

¹⁾ Contribution presented at the 7th Symposium on Elementary Processes and Chemical Reaction in Low Temperature Plasma, STARÁ TURÁ-DUBNÍK, June 13—17, 1988

²⁾ ÚSPE. Božetěchova 2, 61266 BRNO, Czechoslovakia

composition change is not quite correct. Probably, the system is not capable to attain for certain temperatures an equilibrium state.

This neglect can cause relevant errors. Therefore, the second group of papers deals directly with the kinetics of the given effect. The present paper belongs to that group.

II. METHOD

It is well known that in a gaseous mixture the most probable reactions are bimolecular and trimolecular. The probability of the occurrence of other reactions is negligible. Generally, a reaction of the type



corresponds [4] to an ordinary differential equation of the type

$$\frac{dn_{A_i}}{dt} = (c_i' - c_i'') r \prod_{i=1}^n n_{A_i}^{a_i} + (c_i' - c_i'') d \prod_{i=1}^n n_{A_i}^{b_i} \quad (1)$$

If we have a system of m -components in which n reactions occur, then — when we denote the time variation of concentration of the i th component in the j th reaction as G_{ij} ($i = \frac{dn_{A_i}}{dt}$) — it follows [2] that

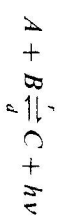
$$\frac{dn_i}{dt} = \sum_{j=1}^n G_{ij} - n_i \left(V + T^{-1} \frac{dT}{dt} \right), \quad i = 1, 2, \dots, m \quad (2)$$

$$V = \frac{RT}{p} \sum_{i=1}^m \sum_{j=1}^n G_{ij},$$

where the term V records isobaric conditions, and the term $T^{-1} \frac{dT}{dt}$ describes the influence of changing temperature. (R -gas constant, p -pressure.)

One of the main difficulties of the applied method consists in the necessity of determining the most important reactions in the system at the given temperatures and pressures, and mainly the corresponding reaction velocities r , d of these important reactions. On the basis of the information from [5], the components SF , S_2 , F_2 , S , S^+ , F , F^+ , e^- were introduced into the examined system. Further components are negligible at the considered temperatures and pressure values under the presumption that the equilibrium state was taken as the zero approximation of the problem.

To simplify the calculations, it was further presumed that the reaction



in which the component hV decreases the excessive energy and the momentum, corresponds to the equation of the type

$$\frac{dn_A}{dt} = -r n_A n_B.$$

As it follows from [2], this simplification does not substantially influence the behaviour of the model.

A part of the r , d values was from [2] where, however, for each reaction either only the value r , or only the value d is given. The remaining values were obtained from [3], [5] on the basis of the following consideration:

When presuming the validity of (2), then there applies for the equilibrium status

$$r \prod_{i=1}^n n_{A_i}^{a_i} = d \prod_{i=1}^n n_{A_i}^{b_i},$$

wherefrom it is possible, under the presumption of the knowledge of the value r or d , respectively, at the given temperature and pressure, to determine the value d or r , respectively, at the given temperature and pressure. In view of the isobaric conditions, this relation depends only on temperature, and the first approximation of r and d can be written in the form

$$a \cdot \exp(-b/T) \quad a, b \in \mathcal{R}.$$

Therefrom the coefficients a , b are easily determined.

III. RESULTS AND DISCUSSION

The calculations were performed for the pressure value of 1 MPa. The dependence of temperature on time was presumed in the form

$$T(t) = 2500 + 7500 \exp(-22.350 \cdot t).$$

this being in very good agreement with the temperature drop upon the decay of the arc. System (2) was solved numerically. Considering that the moduli of the characteristic numbers of the pertinent linearized system are relatively high, it seems suitable to use, for the integration of the system, algorithms for the solution of "stiff" systems.

The balanced composition of the system [3], [5] was used as initial value. The obtained results are given in Fig. 1.

For comparison of the two possible approaches to the problem, in Fig. 2 are given the quotients of the system determined from the kinetic properties of the system (numerator), as well as by calculation from the balanced composition (denominator). Table 1 compares the composition of the system at the temperature of 6000 K and the pressure of 1 MPa, determined by the solution (2), as well as by the method of determining the composition on the basis of the calculation of the chemical equilibrium.

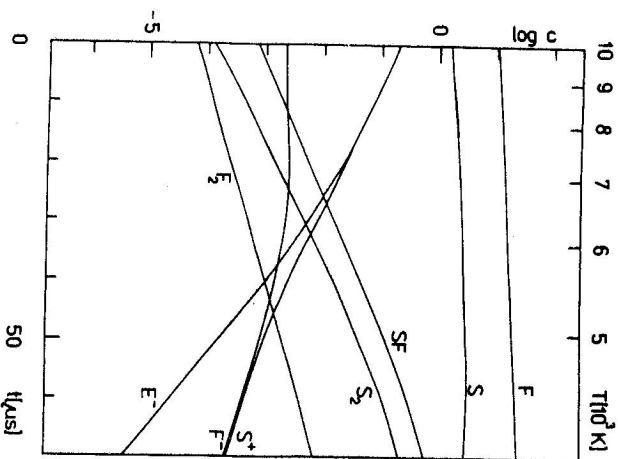


Fig. 1. Time dependence of molar concentrations of the SF_6 system components.

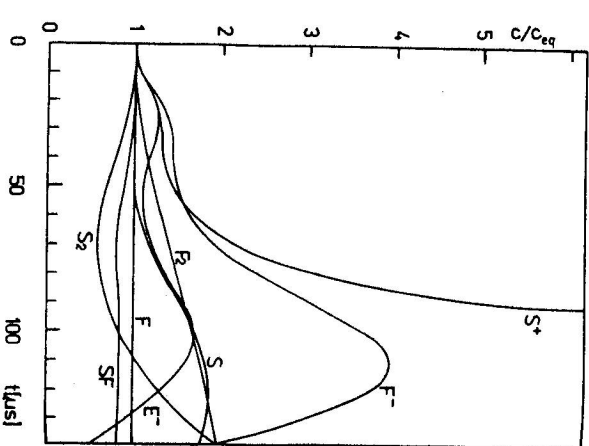


Fig. 2. Deviations from the balanced composition of the system. In the denominator, the molar concentration of the component is given in the equilibrium state.

Finally, it can be stated that also this model, which is considerably simplified as to its number of components and reactions, describes correctly, the qualitative behaviour of the SF_6 system upon the decay of the arc, within the temperature range from 6000 to 10000 K.

Table 1

The composition of the SF_6 system at the temperature of 6000 K and the pressure of 1 MPa.

component	n_k	n_{eq}
SF_6	8.8634 - 3	9.2147 - 3
S_2	2.7296 - 4	3.2268 - 3
F_2	2.400 - 4	2.1912 - 4
S	9.8389 - 1	9.8296 - 1
S^+	1.7943 - 3	1.3671 - 3
F	5.9899 + 0	5.9899 + 0
F^-	7.0886 - 4	4.9545 - 4
E^-	1.0784 - 3	8.7169 - 4

n_k — values determined by the solution of system (2)

n_{eq} — values determined by the calculation of the balanced composition
 $a \pm b$ denotes $a \cdot 10^{\pm b}$

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Received July 13th, 1988

Accepted for publication July 28th, 1989

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ НЕКОТОРЫХ ЯВЛЕНИЙ И ХИМИЧЕСКИХ ПРОЦЕССОВ В ЭЛЕКТРИЧЕСКОЙ ДУГЕ В SF_6 . ПОСЛЕ ИСЧЕЗНОВЕНИЯ ДУГИ

В работе предложена математическая модель реакционной кинетики SF_6 в электрической дуге в момент ее исчезновения. Модель решена численно и полученные результаты сравнены с результатами других авторов, которые были получены на основе расчетов равновесного состава SF_6 .