SIMULATION OF A DECAYING SF_6 ARC PLASMA

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1. Introduction

During the arc extinction in H.V. circuit breakers there is a strong blowing leading to phenomena of turbulence. These mechanisms are responsible for the energy transfer necessary to the recovery of the dielectric rigidity. So a modelling based only on thermal phenomena cannot explain the behaviour of the plasma where it exists chemical non-equilibrium resulting from turbulence or strong cooling (-10^8 K.s^{-1}). All the models based on the hypothesis of the local thermodynamic equilibrium (LTE) lead to a post-arc current, contrary to the experimental results where the post-arc current is often non-existent after the zero of the alternative current. To interpret this difference, we have to consider that molecular species may be present in the hot regions. So the plasma column should be cut by a portion of gas with a small electrical conductivity unlucky to the circulation of the electric current.

The general aim of this work is to simulate the decaying arc behaviour taking non equilibrium effects into account. So we have built a mathematical model coupling a hydrodynamic and kinetic study for an SF_6 gas in a two dimensions flow in a transient state. The coupling between hydrodynamics kinetics is made through the pressure and the mass density.

2. Mathematical model

The model treats a two dimensional SF_6 arc in transient state. It is based on the following main assumptions: the plasma has a cylindrical symmetry; we consider that the transport coefficients: electrical conductivity σ, thermal conductivity κ, specific heat C_P, viscosity μ [2], net emission coefficient ε_N [3] are only functions of temperature. For the net emission we assume an isothermal and homogeneous cylindrical plasma of radius Rp (Rp = 2 mm). Diffusion of particles is neglected. The calculation domain and boundary conditions are given in figure 1 and table 1. The dimensions of the calculation domain are respectively 2 cm and 0.5 cm on the axial and radial directions for a grid of 40 x 40 points. On the electrode (line EF) we made a preliminary study, resolving in a one dimension the equations (1) and (2) in order to give the boundary condition for the resolution of the 2D stationary model and to give the temperature and radial velocity components for the transient state. The conservation equation that we use in stationary and transient state are the following.

on the electrode (line EF)

$$\frac{\partial \rho}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(r \rho v) = 0 \quad (1)$$

$$\rho C p \frac{\partial T}{\partial t} + \rho v C p \frac{\partial T}{\partial r} = \frac{1}{r}\frac{\partial}{\partial r}\left(r K \frac{\partial T}{\partial r} \right) + \sigma E^2 - 4\pi\varepsilon_N \quad (2)$$

species $$\frac{\partial n_i}{\partial t} + \vec{\nabla}\cdot\left(n_i \vec{V}\right) = Ca_i - n_i Da_i \quad (3)$$

momentum $$\rho \frac{\partial \vec{V}}{\partial t} + \vec{\nabla}\cdot\left(\rho \vec{V} \vec{V}\right) = -\vec{\nabla} P + \vec{\nabla}\cdot\left(\mu \vec{\nabla} \vec{V}\right) \quad (4)$$

energy

$$\rho \frac{\partial h}{\partial t} + \vec{\nabla}\cdot\left(\rho \vec{V} h\right) = \vec{\nabla}\cdot\left(\frac{K}{C_P} \nabla h\right) + \sigma E^2 - 4\pi\varepsilon_N + \vec{V}\cdot\vec{\nabla} P \quad (5)$$

Coupling $$P = \sum_i n_i k_b T \qquad \rho = \sum_i m_i n_i \quad (6)$$

where $\vec{V}$ is the vector velocity (u an v are the axial and the radial components of the velocity), P is the pressure, h the specific enthalpy, n_i represents the particle density of species 'i', Ca_i the number of particles created, n_i Da_i the number of particles 'i' destroyed by unit of time and volume. The terms Ca_i and Da_i are functions of chemical reaction rates, calculated by Borge [4]. The resolution of these equations is based on the algorithms of Patankar [5].

3. Calculation

In stationary state the calculation is made for current intensity I equal to 50 A and mass flow rate D_0 equal to 0.2 g.s^{-1}. The electric field E is constant and uniform. The gas entry is situated on the line DE where the axial velocity profile u(r) of the inlet flow is parabolic. In order to limit the axis temperature in stationary state (the reaction rates were computed for T ≤ 12000 K) and to have a rather strong blowing during the extinction, we have imposed an increase of the inlet flow in transient state given by: $D = D_0\,(1+29\ t/2.10^{-5})$ g.s^{-1}. The initial SF_6 plasma composition is calculated by a kinetic model given in [6].

After the current zero the electric field E = 0. We have 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). More than 66 chemical reactions between these species have been taken into account and have been described in

[4]. The direct reaction rates and the reverse rates are given in [6]. The initial profiles of temperature, velocities and the 19 species densities are given by the stationary model. The models (hydrodynamic and chemical) are coupled with the mass density (7) and the pressure (6). The time step, Δt is chosen using a chemical criterion: $\Delta t = \left[(Da)_{Max}\right]^{-1}$, where $(Da)_{Max}$ represents the maximum destruction rate of any species.

4. Results

The results are presented for a time equal to 20 µs. The temperature field is plotted in figure 2. We can note a pinching on the entrance resulting of the strong convection. The maximal velocity on the entrance is 1622 $m.s^{-1}$. In figure 3 we have plotted the relative electron density field (the relative density is defined as the ratio of the calculated density on the equilibrium value $n_{LTE}(T,P)$). Our results show mainly an under-population of electron density in the edges of the arc that means in the temperature range 5000 K < T < 7000 K. In figure 4 we have plotted the relative density of S_2^+. We can note an overpopulation of S_2^+ density in the edges of the arc. The under-population of electron density is explained by the electron recombination on the molecules S_2^+, this effect is strengthened by the convection of the cold gas.

These results on the influence of the convection are in good agreement with the expected behaviour. In effect an higher convection or phenomena of turbulence can lead to an under-population of electron density in a critical temperature range for the post-arc phase.

6. References

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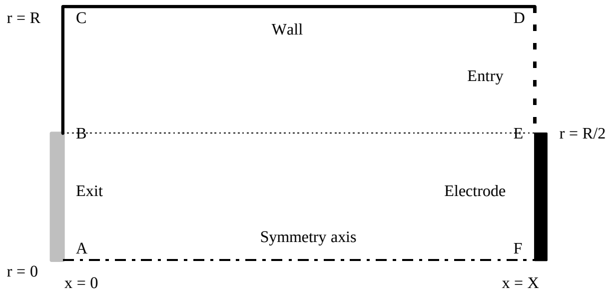

Figure 1: Calculation domain

	AB	BCD	DE	EF	FA
u	$\frac{\partial u}{\partial x} = 0$	0	u (r,t)	0	$\frac{\partial u}{\partial r} = 0$
v	0	0	0	Electrode model	0
T	$\frac{\partial T}{\partial x} = 0$	3000 K	3000 K		$\frac{\partial T}{\partial r} = 0$
n	$\frac{\partial n}{\partial x} = 0$	$\frac{\partial n}{\partial r} = 0$	n_{LTE}	n_{LTE}	$\frac{\partial n}{\partial r} = 0$

Table 1: Boundary conditions

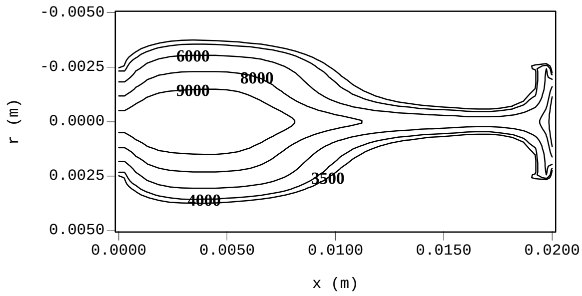

Figure 2: Plasma temperature field

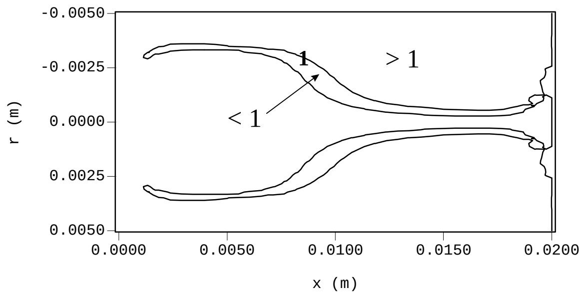

Figure 3: Relative density field (electron)

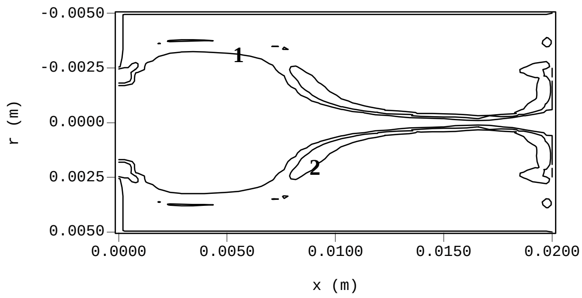

Figure 4: Relative density field (S_2^+)