DC arcs of short lengths in atmospheric pressure air: properties of the boundary layers and heat loads on the copper electrodes

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The behaviour of electric arcs of short lengths and low current levels generated between copper electrodes in atmospheric-pressure air is important to the understanding of the processes occurring during the contact separation in switching devices. Although a lot of modelling work on switching arcs has been carried out over the years, the processes related to the phase of contact separation have been left out of scope. The main reason can be probably seen in the non-equilibrium conditions that have to be taken into account.

In this work, we present the studies based on a one-dimensional unified chemical and thermal non-equilibrium model of dc electric arcs [1] between copper electrodes of 10 mm length each in atmospheric-pressure air, which from the best of authors' knowledge has not been reported so far. In experiments, the inter-electrode distance is varied from 20 µm up to 1 mm at a constant current of 0.88 A and the arc voltage has been measured. The main focus is set on the computed properties of the near-electrode boundary layers, which are spatially resolved. The plasma chemistry involves the 11-species reaction database by Dunn and Kang [2]. The emission of electrons from the non-refractory cathode is considered as a thermo-field emission and computed applying the TMM (transferred matrix method) [3] and an appropriate field enhancement factor. A description of the model in detail will be given in a forthcoming publication. Results from the model and experiment are summarized in what follows.

Figure 1 shows the arc voltage as a function of the arc length. A near-linear increase of the voltage is observed with the increase of the arc length. A value of about 13 V is found at miniscule arc lengths that indicates the value of the total voltage in the cathode and anode sheaths. The experimental course of the arc voltage was reproduced by the determination of the mean current density to be used in the model for a given arc length. The obtained mean current density decreases with the increase of the arc length that can be related to an increase of the arc attachment area.

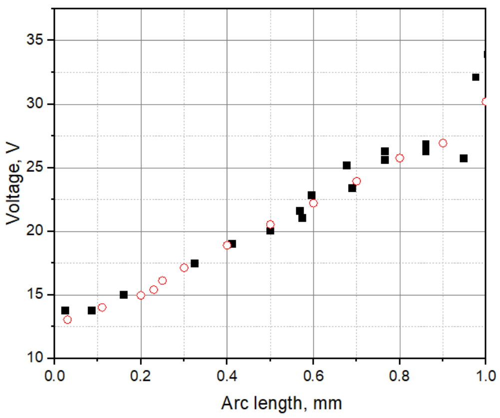

Fig. 1: Measured (solid) and computed (open symbols) arc voltage as function of the arc length.

The temperatures on the electrode boundaries in contact with the plasma and the corresponding heat fluxes from the plasma are shown in Figure 2a (subscripts "c" and "a" denote the cathode and the anode, respectively). Figure 2b shows the distribution of the electric potential along the inter-electrode distance (the position of the cathode is at the value of 0 and the position of the anode varies). The highest value (though still below the melting point) of the anode temperature T_a is reached for the shortest arc length. Notice the change in the T_a, Q_a-behaviour and the reversal of the anode fall for arc lengths beyond 0.2 mm.

Figure 3 shows the distribution of the gas and electron temperature (a), and the species number densities (b) along the inter-electrode distance for arc lengths of 0.03 (curves 1); 0.11(curves 2) and

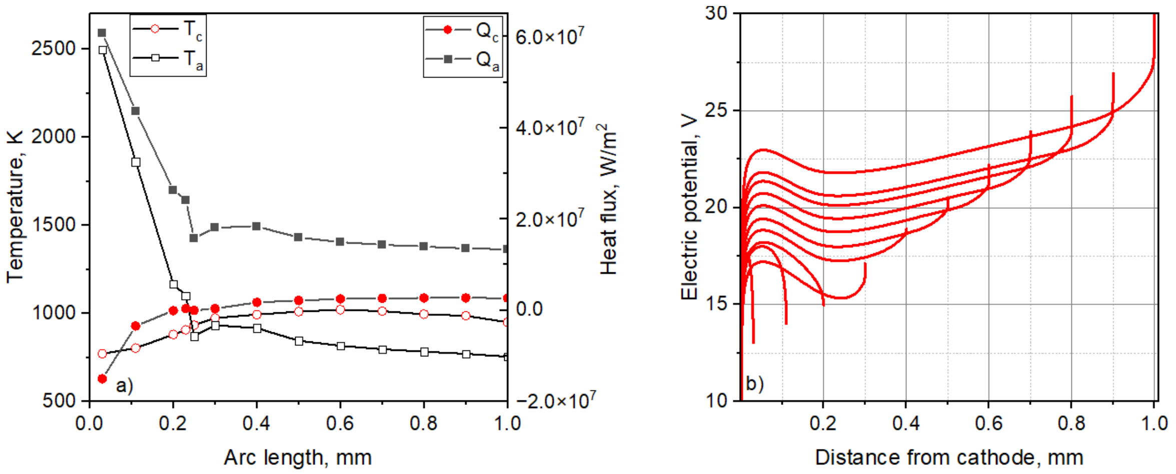

Fig. 2: Temperature and heat flux at the electrodes (a) and distribution of the electric potential between the electrodes (b) for various arc lengths.

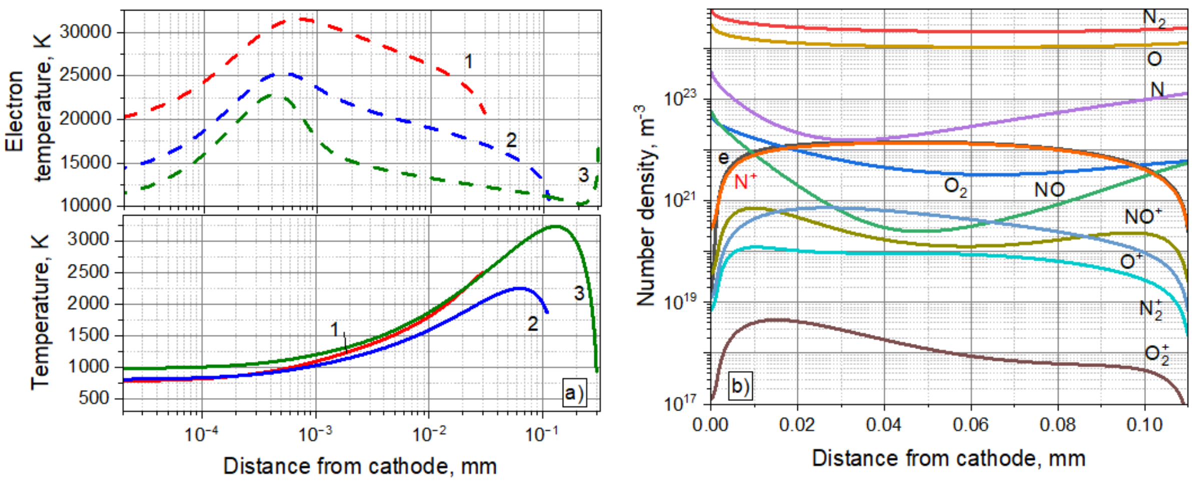

Fig. 3: Distribution of the temperatures of heavy particles and electrons for arc lengths of 0.03, 0.11, and 0.3 mm (a); distribution of species number densities for an arc length of 0.11 mm (b).

0.3 mm (curves 3). Maximum temperature is reached at the anode for the shortest arc length and shifts towards the cathode. The electron temperature reaches a maximum in the cathode sheath and drops towards the plasma bulk due to the processes of ionization and dissociation. With the reversal of the anode fall, an increase of the electron temperature is obtained in front of the anode. The results indicate conditions of a strong thermal non-equilibrium. The computed plasma composition (Figure 3b) shows the that N_2 and O are the dominant neutral species, while N^+ is the dominant ion. The deviation from quasi-neutrality is well pronounced in thin sheaths adjacent to the electrodes.

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