UNIFIED NUMERICAL MODELLING OF NEAR-CATHODE PLASMA LAYERS IN HIGH-PRESSURE ARC DISCHARGES

N. A. Almeida(1), M. S. Benilov(1) (*), and G. V. Naidis(2)

(1)Departamento de Física, Universidade da Madeira, Largo do Município, 9000 Funchal, Portugal

(2)Institute for High Temperatures of the Russian Academy of Sciences, Moscow 125412, Russia

(*) **benilov@uma.pt**

It has been realized long ago that an adequate description of the near-cathode plasma layer is a key element of a theory of plasma-cathode interaction in high-pressure arc discharges. A review of early works treating near-cathode plasma layers can be found in [1,2]; further references can be found in the review [3]. However, there is still no universally accepted understanding of the physics involved, neither are there universally employed simulation models. In part, the unsatisfactory state of the theory is due to diversity of physical mechanisms involved and complexity of the overall physical picture. On the other hand, near-cathode layers of high-pressure arc discharges represent an extremely difficult object for experimental investigation due to their very small dimensions and extreme conditions typical for arc discharges; even such basic quantity as a near-cathode voltage drop has been reliably measured relatively recently. Therefore, the experiment cannot provide much guidance for the theory.

Published papers deal with different aspects of near-cathode plasma layers and employ different approaches, however all of them have one point in common: the near-cathode plasma layer is *apriori* divided into a number of sub-layers with different properties (such as a layer of thermal non-equilibrium, an ionization layer, a near-cathode space-charge sheath *etc*), each sub-layer is described by its own set of equations, and solutions in adjacent sub-layers are matched in some way or other at a boundary between the sub-layers. A division of the near-cathode plasma layer into sub-layers with different properties reflects the fact that different physical mechanisms in many cases, although not always, come into play on different length scales. However, a usage of this division as a basis for a calculation model inevitably involves quite a bit of intuitive considerations and therefore is not a proper way to develop commonly accepted physical understanding and/or simulation models. In fact, there is no universally accepted point of view even on such basic question as what sub-layers are the most important and must be necessarily included in a model: while most of the workers believe that a near-cathode space-charge sheath is of primary importance (e.g., [3] and references therein), there are models in which a space-charge sheath is discarded (e.g., [4-6]).

An alternative to the above-described approach, which relies on an a priori introduction of different sub-layers, is to model the whole of a near-cathode layer in the framework of a single set of equations without simplifying assumptions such as thermal equilibrium, ionization (Saha) equilibrium, and quasi-neutrality. After such modelling has been completed, one will be able to identify physical mechanisms dominating different regions and thus to pin down appropriate sub-layers. (In other words, an introduction of sub-layers, while being hardly justifiable as a basis for a numerical model, is natural and legitimate as a tool of analysis of results of calculations in which the near-cathode plasma layer is treated in a unified way.) In spite of being highly desirable, unified numerical modelling of near-cathode plasma layers in high-pressure arc discharges still has not been reported, the likely reason being a considerable computational complexity of the problem. Note that a two-dimensional modelling of high-pressure arc plasmas without assumptions of thermal or ionization equilibrium has already been reported (e.g., [4]), however the assumption of quasi-neutrality is more difficult to relax, given a high density of charged particles and, consequently, a high degree of quasi-neutrality in the bulk plasma. On the other hand, in [7] boundary layers of a high-pressure combustion plasma with an alkali seed were simulated in the framework of a one-dimensional (1D) approach without assumptions of thermal or ionization equilibrium or quasi-neutrality, however only for conditions of low current densities and, consequently, low ionization degree.

In this work, a unified 1D modelling of near-cathode plasma layers is performed in the range of (high) current densities from 10^6 A/m^2 to 10^8 A/m^2, which are typical for cathodes of high-pressure arc discharges. Detailed calculation results are given for (1) an argon arc at atmospheric pressure, which is a kind of a standard high-pressure arc; and (2) a mercury arc at the pressure of 100 bar, which is typical for high-intensity discharge lamps. Sub-layers dominated by different physical mechanisms appear in the course of analysis of calculation results in a natural way.

The results confirm the physical picture described in [3], in particular, a critically important role played by the near-cathode space-charge sheath. It is found, in agreement with conclusions of [8], that the electric power deposited into the near-cathode layer is transported not only to the cathode, but also to the arc column. The latter effect is caused by the electron enthalpy transport, which substantially exceeds thermal conduction by the electrons and heavy particles, and cannot be described by models employing the assumption of thermal equilibrium, $T_e = T_h$. Modelling results for an atmospheric-pressure Ar arc do not differ very much from results given by the modelling technique described in [3] and references therein, however there is a significant difference for a 100 bar Hg arc.

Acknowledgments This work was supported by the projects POCI/FIS/60526/2004 and PPCDT/FIS/60526/2004 *Modes of current transfer to cathodes of high-pressure arc discharges and their stability* of FCT, POCI 2010 and FEDER and by the project *Centro de Ciências Matemáticas* of FCT, POCTI-219 and FEDER.

References

[1] G. Ecker 1961 *Ergeb. Exakten Naturwiss*. **33**, 1.
[2] W. Neumann 1987 *The Mechanism of the Thermoemitting Arc Cathode* (Akademie-Verlag, Berlin)
[3] M. S. Benilov 2008 *J. Phys. D: Appl. Phys.* **41** (submitted).
[4] J. Haidar 1999 *J. Phys. D: Appl. Phys.* **32**, 263.
[5] L. Sansonnens, J. Haidar, and J. J. Lowke 2000 *J. Phys. D: Appl. Phys*. **33**, 148.
[6] P. Flesch and M. Neiger 2005 *J. Phys. D: Appl. Phys*. **38,** 3098.
[7] M. S. Benilov, G. G. Bochkarev, B. V. and Rogov 1995, *IEEE Trans. Plasma Sci.* **23,** 742.
[8] H.-P. Li and M. S. Benilov 2007 *J. Phys. D: Appl. Phys*. **40,** 2010.