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Non-equilibrium synergistic transport processes in an atmospheric-pressure thermal plasma system

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Atmospheric-pressure low-temperature plasma (AP-LTP) operates in a non-equilibrium state where the characteristic electron energy ranges from a few eV to 10 eV, while the heavy-particle temperature varies from around the room temperature to comparable to but usually lower than the electron temperature under most operating conditions [1,2]. Three types of non-equilibria may exist in an AP-LTP system: non-electrical-equilibrium (NEQ), non-local-thermodynamic-equilibrium (NLTE) and non-local-chemical-equilibrium (NLCE). As a storage for both particles and energies, such non-equilibrium characteristics are of great importance for various applications of the AP-LTP sources because the input energy into plasmas can be transported and re-distributed to other types of energies at various freedoms [3-6]. Therefore, it is indispensable to investigate the complicated fundamental processes in a non-equilibrium plasma system so as to optimize the operating parameters of the AP-LTPs.

The atmospheric free-burning argon arc is a typical model system for studying the non-equilibrium characteristics of the AP-LTPs. This is because that both the electrical-thermal-chemical equilibrium and non-equilibrium regions are involved simultaneously in this arc plasma system; and in particular, a steep spatial gradient of the temperature ratio, θ ($=T_e/T_h$, where T_e and T_h are the electron and heavy-particle temperatures, respectively), exists in the atmospheric arc plasmas. In the first part of this study, discussions on the development of the complete non-equilibrium model for revealing the non-equilibrium synergistic effects, the self-consistent prediction on the transition between the "hot" and "cold" equilibrium regions of an arc plasma system, the local and non-local energy transfer processes [6-9], as well as the dimensional analysis [10], are provided based on the numerical simulations. The modeling results and the dimensional analysis show that: (i) the collisions between electrons and heavy particles influence directly the energy and mass transfer processes between these two sub-systems; meanwhile, there exists an interaction between the non-uniform spatial temperature distributions of electrons and heavy particles; and (ii) a new dimensionless parameter, non-equilibrium thermal diffusion number ($N_{\lambda\theta}$), is defined which represents physically the ratio of the energy transfer related to the spatial gradient of θ to that of the Joule heating, as shown in Fig. 1. In the second part of this paper, the preliminary experimental measurements on the non-equilibrium features in a free-burning argon arc are conducted based on our newly-developed arc plasma experimental platform (FPX-2017). The comparisons between the calculated and measured results under the same operating conditions are also provided to valid our modeling results. The preceding results would be helpful for deeply understanding to the particle and energy transport mechanisms in the AP-LTPs, for tuning, to some extent, the key parameters of the non-equilibrium plasmas, and even for further development of new plasma sources with specific applications in the fields of plasma medicine, advanced materials processing, ground simulation of space plasmas, etc.

References

[1] S. Samukawa, et al. J. Phys. D: Appl. Phys., 2012, 45: 253001.
[2] I. Adamovich, et al. J. Phys. D: Appl. Phys., 2017, 50: 323001.
[3] Y.-W. Yeh, Y. Raitses, N. Yao, Carbon, 2016, 105: 490-495.
[4] Y. Ju, W. Sun, Prog. Energy Combust. Sci., 2015, 48: 21-83.
[5] J.-J.Wang, K.-S. Choi, L.-H. Feng, T. N. Jukes, R. D. Whalley, Prog. Aeosp. Sci., 2013, 62: 52-78.
[6] H. Guo, X.-N. Zhang, J. Chen, H.-P. Li, K. Ostrikov, Sci. Rep., 2018, 8: 4783.
[7] X.-N. Zhang, H.-P. Li, A. B. Murphy, W.-D. Xia, Phys. Plasmas, 2013, 20: 033508.
[8] H.-P. Li, X.-N. Zhang, W.-D. Xia, Phys. Plasmas, 2013, 20: 033509.
[9] X.-N. Zhang, H.-P. Li, A. B. Murphy, W.-D. Xia, Plasma Sources Sci. Technol., 2015, 24: 035011
[10] W. D. Curtis, J. D. Logan, W. A. Parker, Linear Alg. Appl., 1982, 47: 117-126.

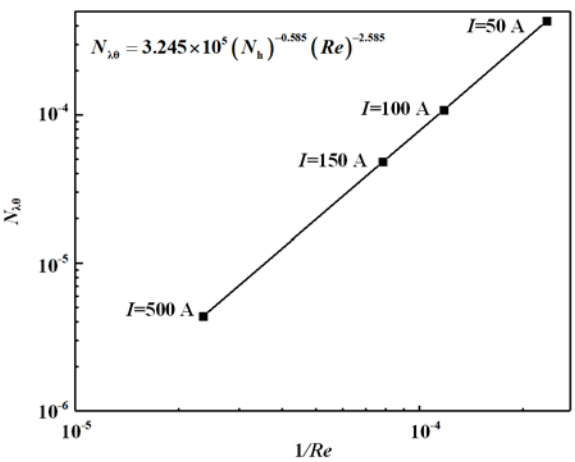

Figure 1. Variation of $N_{\lambda\theta}$ with Re at different arc currents.

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