1st Asia-Pacific Conference on Plasma Physics, 18-22, 09.2017, Chengdu, China

Nonequilibrium species diffusion in a low-power nitrogen–hydrogen arcjet thruster

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The arcjet thruster can be considered as fundamentally an energy conversion device in which electric energy is first converted into the undirected thermal energy of the working gas, and then converted into directed kinetic energy during the expansion process inside Laval nozzle. In arcjet thruster, chemical kinetic processes and species diffusion play important roles in the energy conversion processes and in determining the performance of arcjet thrusters. Extremely-high gas flow velocities, extremely-short gas residence times, and the extremely small thruster size lead to large parameters gradients in the thruster, which further lead to departures from both chemical and thermal equilibrium. Therefore, species diffusion in arcjet thruster is closely related to nonequilibrium chemical kinetic processes and parameter gradients. In this article, we mainly focus on the analysis of species diffusion processes in the chemical nonequilibrium plasma flow in an arcjet thruster.

In this paper, in order to obtain a detailed understanding of species diffusion in the arcjet thruster, the SCEBDC approximation is used to treat the species diffusion in a low power nitrogen–hydrogen arcjet. The diffusion fluxes due to concentration, temperature and pressure gradients are taken into account. Since nitrogen–hydrogen mixtures are used as working gas, both dissociation and ionization of gases will take place as the temperature increases. This requires a chemical kinetic description of the chemical reactions to be developed and implemented. Seven species taken into account: electrons, N_2, H_2, N, H, N^+ and H^+. In this study, doubly-ionized nitrogen ions and molecular ions have been neglected.

The numerical results show that there is significant species separation throughout the flow field of the arcjet thruster. As shown in Fig.1, three distinct features are apparent in these figures. First, the concentration of hydrogen species in the hottest regions of the nozzle centre is much higher than that of nitrogen species. Second, the concentration of hydrogen species is depleted at a radius of around 1 or 2 mm. Finally, near the inner wall of the thruster nozzle, the concentration of hydrogen species is much larger than nitrogen species in all three cases; the mole fraction of hydrogen species is higher than 0.8 while the mole fraction of nitrogen species is lower than 0.2 in most part of nozzle wall region. Since hydrogen molecules have a much lower dissociation energy (4.48 eV) than those of nitrogen (9.61 eV), and are 50% dissociated at around 3500 K, compared to 7000 K for nitrogen. The dissociation of hydrogen molecules in the low temperature region leads to a concentration gradient of hydrogen atoms, which drives diffusion of hydrogen towards the edge.

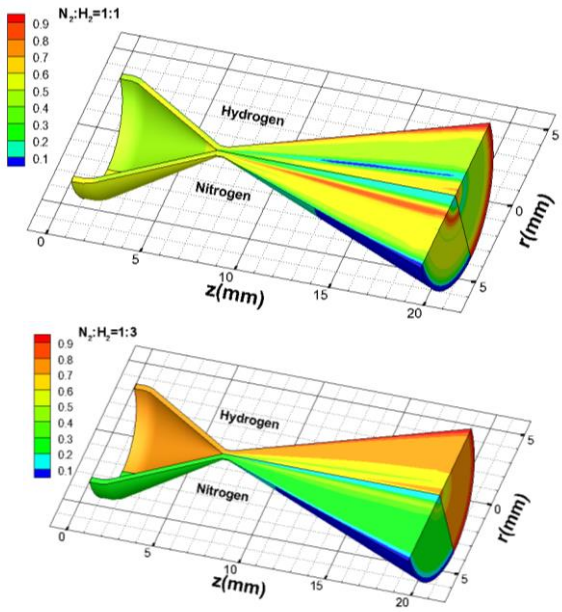

Figure 1 Calculated species contours of hydrogen and nitrogen mole fractions within the arcjet thruster, calculated for 50 mg/s, 10 A, and inlet flow with nitrogen–hydrogen mixture ratios of (a) 1:1, (b) 1:3 by mole

The radial profiles of nitrogen and hydrogen species have been compared at the constrictor exit and thruster exist. It is found that compared to the constrictor exit, the mole fraction of hydrogen ions decreases while the concentrations of hydrogen atoms and molecules increase at the exit of the nozzle. However, the radial distributions of nitrogen species concentration maintain similar profiles, which imply that the kinetic processes have been almost frozen in the plasma flow.

The effects of temperature and pressure gradients on the species diffusion inside the arcjet thruster were also investigated. It is found that the diffusion due to pressure gradients has only minor effects on species distribution, which is because that the axial convection transport of species dominates in the expansion part of the thruster nozzle. The effects of diffusion driven by temperature gradients along the thruster axis differ depending on the species, with the lighter species driven towards regions of lower temperature.

References

[1] Wang HX, Sun SR, Sun WP (2015) Status and prospects on nonequilibrium modeling of high velocity plasma flow in an arcjet thruster. Plasma Chem Plasma Process, **35**:543–564