Modeling of Nonequilibrium Effects in a High-Velocity Nitrogen-Hydrogen Plasma Jet

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The high-velocity high-power (HVHP) torch is a newly developed plasma device to generate high-velocity plasma jets with higher enthalpy content. Such torches are typically operated at 400 Amps and 400 Volts with nitrogen-hydrogen mixtures, and produce plasma jets with peak velocities of about 4000 m/s. Due to the high velocity (Ma $\sim$ 1.2), strong departures from chemical equilibrium are expected to occur even at atmospheric pressure.

We report numerical simulations of HVHP plasma jets under the following typical operating conditions: 400 A, 370 V, 65% efficiency, N_2 volume flow rate = 4900 ℓ/min, H_2 volume flow rate = 1600 ℓ/min. Thirteen species and ten chemical reactions are included. The species included are H_2, N_2, O_2, OH, H_2O, and their dissociation and ionization products. The chemical reactions considered are dissociation of molecular species, ionization of atomic species, charge exchange and dissociative recombination of nitrogen, and hydrogen-oxygen reactions. Charge exchange and dissociative recombination of hydrogen and oxygen, and formation of NO_x, are neglected for simplicity.

The inflow at the nozzle exit is assumed to be perfectly expanded and in chemical equilibrium. The calculational results show that strong departures from ionization and dissociation equilibrium nevertheless develop in the downstream region as the chemical reactions freeze out at lower temperatures. In the region near the torch nozzle exit, the calculated behavior of the plasma flow exhibits features similar to the experimental observations, including oblique shock and expansion waves. The calculations show that ionized species are overpopulated throughout the flow, while dissociated species in the core of the jet are underpopulated near the nozzle exit and become overpopulated farther downstream. This initial underpopulation is evidently due to diffusive depletion of dissociated species and enrichment of molecular species in the core.

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