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Hypersonic wind tunnel experiments on chemical reaction around an icy object with ablation using electric discharge

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When an extraterrestrial object enters the planetary atmosphere, a strong shock wave is formed in front of the object, and various gaseous materials including prebiotic ones are produced in the high temperature shock layer flow by the chemical reactions of the atmospheric gas and the ablation gas injected at the surface. Such products are distributed into the atmosphere through the wake flow behind the entry object. We conducted the numerical analyses of the Navier-Stokes equations for the chemically reacting hypersonic flow around an icy object with the ablation injection of H2O in the N2-CO2 atmosphere (Suzuki, AIAA Paper 2011-3756, 2011). The nonequilibrium chemistry of the 28 species (N2, O2, N, O, NO, NO+, e-, N+, O+, N2+, O2+, C, C2, C3, CO2, CO, CN, CO+, C+, H, H2, HCN, HCO, C2H2, C2H, CH, H2O, OH) is considered as well as the thermal nonequilibrium described by the two-temperature (translational and vibrational) model. The computational results show that HCN is produced near the surface in the stagnation region by the chemical reaction of H2, which comes from the decomposition of the ablation gas, and CN, which is produced behind the shock wave in front of the object. HCN is transported into the atmosphere via rapid expansion flow at the shoulder and the wake flow in almost frozen state. In the case of an icy sphere of 0.2 m radius with the uniform ablation rate 0.05 kg/(s m2) over the windward surface at the flight velocity, altitude and atmospheric composition 8 km/s, 60 km (equivalent to the present earth) and CO2:N2=0.93:0.07, respectively, the mass flux of HCN exhausted into the wake flow is in the order of 0.01% relative to the total mass loss rate of H2O.

The hypersonic wind tunnel facility, which is used in the aerospace engineering for research and development of a re-entry vehicle for the space transportation, is also a powerful tool to simulate the high-speed flow around an extraterrestrial entry object and the various phenomena caused by the ablation (Suzuki, et al., JpGU Meeting 2010, PPS004-10, 2011, PPS020-22, Imamura et al., AIAA Paper 2010-4512). Due to the operation limit of the facility, however, it is impossible to make the flow temperature high enough to excite the chemical reactions. Then the thermal energy was added to the flow by the electric discharge at the electrodes put on the surface of the test piece (Watanabe and Suzuki, AIAA Paper 2011-3736). The experiments were conducted at the hypersonic and high-enthalpy wind tunnel of the graduate school of frontier sciences, the University of Tokyo (http://daedalus.k.u-tokyo.ac.jp/wt/wt_index.htm). The figure shows a picture taken at a trial experiment using a flat plate model. In addition to the electrodes, a cavity having ice inside was installed on the plate. The ablation occurred at the surface of the cavity in the hypersonic flow. The image was taken through the narrow band pass filter at 380-384nm, where the emission of CN is observed. The stagnation temperature and the pressure on the surface are about 600K and 300Pa, respectively. The quasi-steady electric discharge was kept for about 1 sec at 5V and 6A. At the center of the discharge region, the vibrational temperature is estimated as about 6000K by the spectroscopy and the fitting technique for N2(1+) band. The high luminous region indicates the presence of CN, which is produced from N in the air and C in the ablation gas of the Bakelite, from which the plate is made.

As seen in the above, the hypersonic wind tunnel experiment using the electric discharge seems promising for simulating the chemical reactions around the atmospheric entry object with ablation.

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Keywords: atmospheric entry, hypersonic flow, wind tunnel, ablation, ice, chemical reaction

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