COMPUTATION OF SURFACE CATALYSIS FOR GRAPHITE EXPOSED TO HIGH-ENTHALPY NITROGEN FLOW

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The high temperatures on a hypersonic vehicle surface caused by heat loads encountered during (re-)entry through a planetary atmosphere require a reliable Thermal Protection System (TPS) that makes a good understanding of the physical and chemical processes essential for its design. Surface catalysis is a crucial chemical process that directly impacts aerothermal heating of the vehicle TPS. The effects of surface catalysis for graphite exposed to high-enthalpy nitrogen flow are examined in this study.

The objective of this study is to investigate and implement surface chemistry models to describe dominant gas-surface processes. As a first step, a binary catalytic atom recombination model is implemented in the Michigan Aerothermodynamics Navier-Stokes computational fluid dynamics (CFD) code LeMANS, developed at the University of Michigan. It is a general purpose, parallel, three-dimensional code that solves the laminar Navier Stokes equations including chemical and thermal nonequilibrium effects on unstructured computational grids. In LeMANS, prior to the present work, wall catalycity effects were accounted for by choosing a non-catalytic or a super-catalytic surface as the species boundary condition. The full range of catalycity regimes, from a non-catalytic wall to a fully- catalytic wall can be simulated by using the binary catalytic atom recombination model. The entry flight environment considered is the post shock subsonic high enthalpy gas flow. Assessment of the computations is performed using experimental tests that were conducted in the 30 kW Inductively Coupled Plasma (ICP) Torch Facility at the University of Vermont. It is designed to test scaled material samples in high enthalpy gas flows for simulation of planetary entry and Earth atmosphere re-entry trajectory heating conditions. The comparative analysis of the computed profiles of gas temperature and relative nitrogen atom density with the experimental results is performed. The free stream conditions and wall temperature used are based on the experimental set up and are provided in Table 1.

Table 1: Freestream and wall boundary conditions

Mach Number	Temperature	Density	N_2 Density	N Density	Wall Temperature
M_∞	T_∞ [K]	ρ_∞ [kg/m^3]	$\rho_{N_2\infty}$ [kg/m^3]	ρ_{N_∞} [kg/m^3]	T_w [K]
0.11	7000	3.36×10^{-3}	0.35×10^{-3}	3.01×10^{-3}	1590

The equilibrium composition of nitrogen gas mixture at the inlet for the given temperature and pressure are calculated using the NASA program Chemical Equilibrium with Applications (CEA). The influence of different flow physics assumptions viz. thermal equilibrium, thermal nonequilibrium and thermochemical nonequilibrium and surface catalysis (non-catalytic and fully-catalytic surface) on the numerical solution is studied. The main calculated parameters analyzed are translational temperature, relative nitrogen atom density, and surface heat flux. The results from simulations showed that thermal nonequilibrium effects are negligible and that the flow studied is in a state of weak thermochemical nonequilibrium. Strong surface catalysis effects on the boundary layer gradients of temperature and species concentration, and heat transfer to the surface are observed. A fully catalytic surface caused the heat flux to increase by a factor of approximately 3.5 as opposed to a non-catalytic surface for thermochemical nonequilibrium.