Insights into Air-Carbon Ablation Chemical Kinetics from Spontaneous Raman Scattering Experiments

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Abstract: We provide a framework for the validation and the development of chemical kinetics models for the ablation of heat shield materials. We initially focus on vitreous carbon, for which models based on molecular beam experiments are available. We establish a stagnation flow in presence of preheating and compare the simulated and the experimentally measured chemical boundary layer profiles for key species.

1. Introduction

Testing and developing novel heat shields materials is crucial for future re-entry applications and hypersonic vehicles. Traditionally, this process has been lengthy and required access to expensive and energy-intense arc-jet, shock tube or high power CO_2 laser facilities [1,2].

This work aims at providing a framework for the validation and development of chemical kinetics models to describe the thermal protection shield ablation process. These capabilities are a stepping stone towards the development of evaluation methods based on high energy tabletop pulsed lasers to provide a more economic route to the development and the evaluation of future heat shield materials.

2. Methods

A simplified simulation of a 1D stagnation flow over a reactive carbon surface was carried out using the ACA model [3] for surface reactions and the GRI Mech 3.0 mechanism for gas-phase reactions. The simulation was implemented and executed using Cantera [4].

The experimental setup consists in a conventional Spontaneous Raman Scattering system, comprising a ns Nd:YAG laser, focused right above the surface of interest. The Raman scattering signal is collected with a spectrometer equipped with an intensified camera. From the analysis of the Raman spectra, the temperature and concentrations of N2, O2, O, CO, and CO2 can be determined.

The vitreous carbon surface is heated to the desired temperature by using induction heating and the jet of impinging gas is also pre-heated at the same temperature. The gas composition and flowrate can be adjusted as desired. The sample is placed inside a vessel equipped with a backpressure regulator, allowing for stable pressure control ranging from vacuum to slightly above atmospheric.

3. Results and Discussion

Figure 1 shows a sample simulation of the chemical boundary layer above the carbon surface in case of a jet of air impinging on a preheated vitreous carbon surface. These simulations are also necessary to find conditions beforehand for which the chemical boundary layer has the required size and species concentrations to be resolvable experimentally.

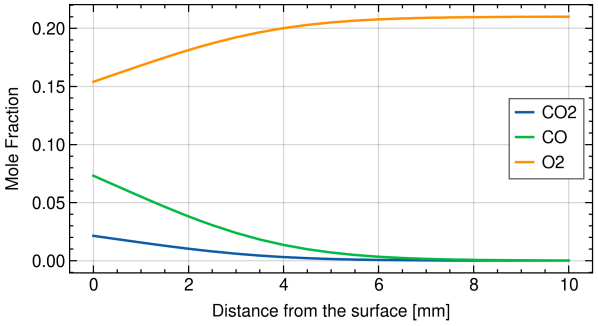

Fig 1: Key species concentration above a vitreous carbon surface in a stagnation flow. In this example, a dry air jet at 30 cm/s impinges on the sample, both surface and sample are preheated to 800 K at 0.4 bar.

According to simulation results, the temperature in the bulk gas faces a minimal increase because of the heat released in the oxidation of CO–this fact simplifies the interpretation of experimental data. By changing surface and gas temperature, gas composition and pressure, specific chemical pathways leading to the carbon ablation will be probed.

4. Conclusion and future work

In the final conference contribution, we will present a comparison between the experimental and simulated chemical profiles.

By focusing on gas-phase products, these results will offer new insights into the ablation processes.

In the future, we plan to extend the study to include intense pulsed laser heating of the surface and test ultrahigh-temperature ceramics.

Acknowledgments

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