Comparison of Surface Oxidation Model with Different Site Densities for Carbon Composites Relevant to Hypersonic Environments

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Introduction

Ablative heat shields are commonly used on re-entry vehicles to prevent failure. Oxidation is a key physical mechanism that dictates not just the heat flux to the surface, but also the recession of the heat shield material. Therefore, understanding the underlying mechanisms and capturing the oxidation processes in computational fluid dynamics / material response solvers is important for TPS sizing. New finite-rate oxidation models have been developed from fundamental physical insights [1] that has shown to capture surface oxidation accurately under non-equilibrium conditions [2]. It has been observed that oxidation occurs over specific reactive sites on the material and consequently, the oxidation model relies on the density of reaction sites available on the surface to compute the production of oxidized species. However, it is not trivial, if not impossible, to obtain the density of reactive sites for a given material. Instead of attempting to obtain the site density, this study focuses on a sensitivity analysis to analyze the effect of reaction site density on the production rates of oxidized species and heat flux on the surface.

Method

The flow over a 8° sphere-cone with a 10 cm radius in a 40 km environment is simulated using KATS [3]. Initially, a surface temperature profile is obtained using radiation equilibrium boundary condition for each time step. The species production rates are then derived by applying the MURI model and solving the surface mass balance iteratively. The numerical computations are performed for different surface site densities. The results from these simulations are then compared to understand the effects of surface site density.

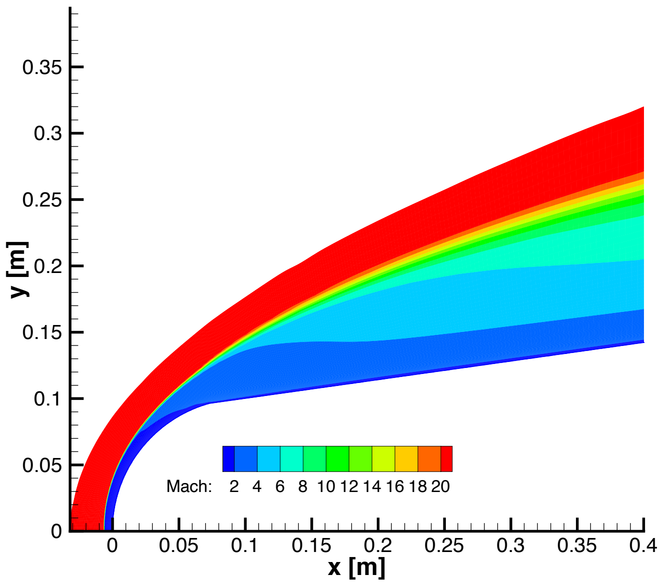

Figure 1: Mach profile for flow over nose cone

Current Work

Figure 1 illustrates the base flow field solution. Surface temperatures are left unshifted when compared to studies using similar methodology [4]. Preliminary results show negligible difference using site densities (B) of 1×10^{-5} and 1×10^{-7}. However, when the results are compared to $B = 1\times10^{-3}$, small changes in the heat flux, temperature, and mass fractions along the surface are observed. This behavior likely occurs because of O-atom desorption being the dominating mechanism when surface temperatures are high.

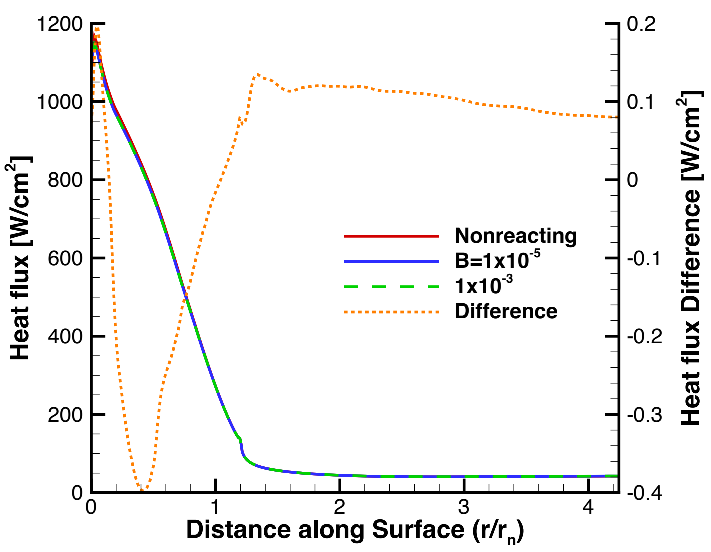

Figure 2: Comparison of heat flux along surface between different site densities

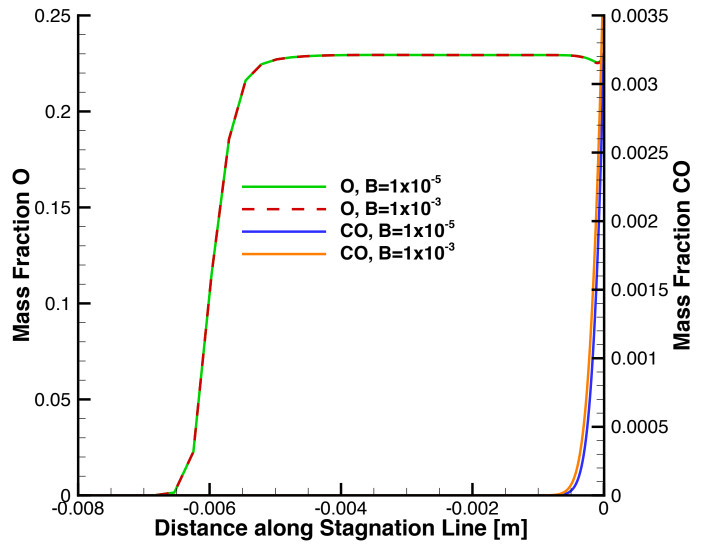

Figure 3: Mass fractions of O and CO along stagnation line

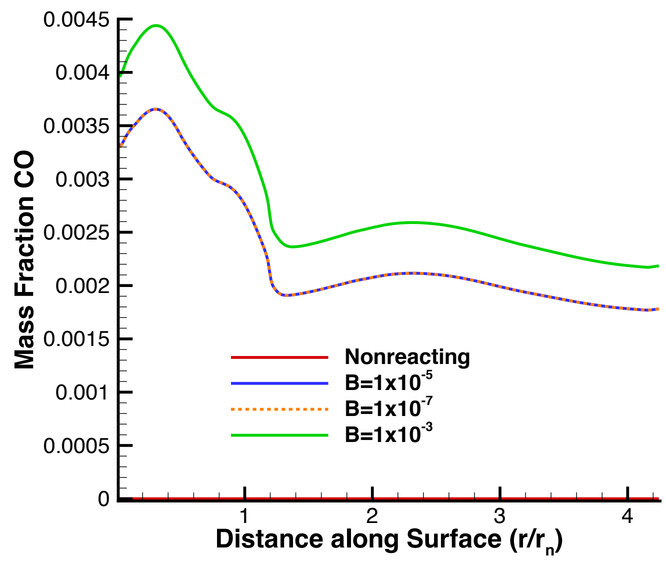

Figure 4: Comparison of CO mass fractions along surface between different site densities

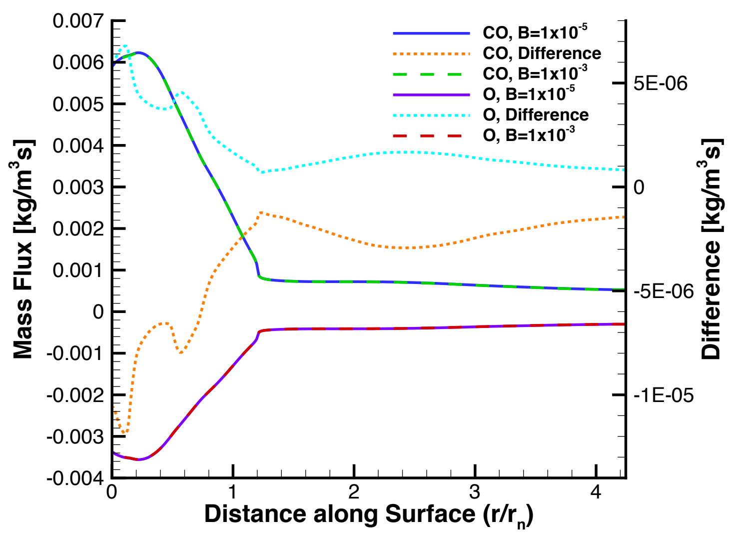

Figure 5: Comparison of O and CO mass flux across surface between different site densities

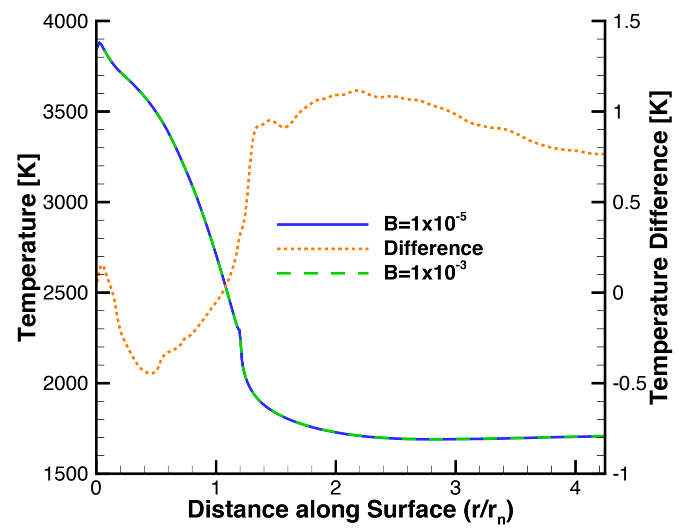

Figure 6: Comparison of Temperature along surface between different site densities

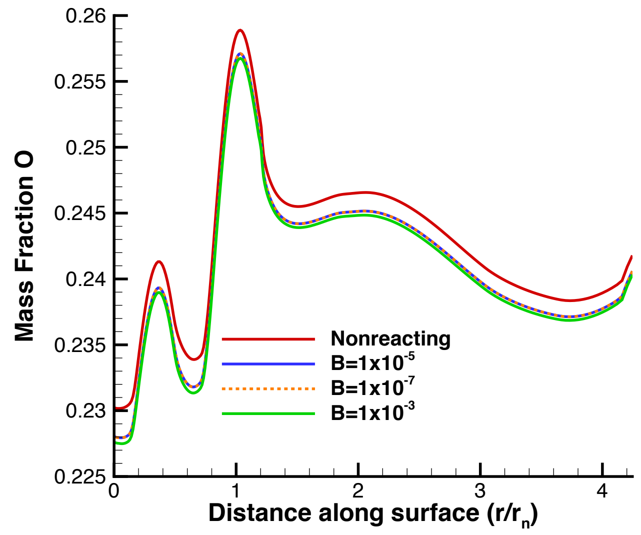

Figure 7: Comparison of O mass fractions along surface between different site densities

Future Work

Using a novel approach to handle the fluxes through the surface faces [5], the methodology will be extended by using the oxidation rates to calculate surface recession, thereby evaluating the non-uniform effects of B on the heat flux.

References

[1] Poovathingal et al., AIAAJ, 2017
[2] Candler, G. V., ARFM, 2019
[3] Davuluri et al., JTHT, 2016
[4] Candler, G. V., AIAA Paper 2012-0742, 2012
[5] Fu et al., AIAA Paper 2020-0482, 2020.

Acknowledgements

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