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Title

Effect of flame radiation on aluminum particle combustion

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Abstract

Aluminum is widely used in solid propellants for space and military applications for its performance and availability. However, aluminum combustion is complex and not fully understood so far. It is generally accepted that large aluminum particles burn in the vapor phase through a diffusion flame. Combustion of aluminum produces aluminum oxide, predominantly present as fine particles—commonly referred to as oxide smoke—in the detached flame around the burning aluminum particle. Many modeling efforts have been performed in the last decade focusing on the burning of a single aluminum particle with an eye to predicting burning times. However, the effect of the flux radiated by the flame has been almost systematically discarded. The only contribution is from Brooks and Beckstead [1] who used a simplistic model (grey body with emissivity varied between 0 and 1) to conclude that radiation was ineffective for small particles but could alter the burning time by 10~20 % for larger particles. There is therefore scarce information on how aluminum combustion could be affected by the radiative transfer from the surrounding flame.

This work proposes a model to predict the radiative flux emitted from the flame as well as its effect on aluminum combustion. It relies on a modified version of the Brewster-Parry model [2]—originally developed for aluminized solid propellants. The RTE (Radiative Transfer Equation) is solved using a two-flux approximation and only the radiation from the oxide smoke is modeled (gas radiation is neglected). As an input data, the model requires the radial profiles of temperature and smoke volume fraction around the burning droplet. Such profiles are obtained by numerical simulations of the combustion at the droplet level. Simulations at 1 bar for a 70 µm droplet burning in air yield a flux of ~0.7 MW/m^2, which is about 3 % of the total flux needed for vaporizing aluminum. A parametric study shows that the most influential parameters are the smoke size (radiation increases with smoke diameter until saturation for a size of about 1 µm) and ambient pressure. The flux increases with pressure and, at 30 bar, is typically twice its value at 1 bar. Combustion was also studied in pure CO_2, instead of air, but gives similar flux results. Actually, the quantity of smoke is decreased in CO_2 but the flame is closer to the droplet, yielding higher smoke temperatures. The radiated flux does not depend much on aluminum droplet size but its effect on the burning rate is enhanced for larger droplets due to the decrease in the evaporation mass rate with size. Overall, the effect of the radiated flux can—depending on conditions—reduce the total burning time by 5~10 %.

References

[1] Brooks, K. P., & Beckstead, M. W. (1995). *J. Prop. Power* 11(4), 769-780.
[2] Brewster, M. Q., & Parry, D. L. (1988). *J. Thermophys. Heat Transf.*, 2(2), 123-130