

COMPUTATIONAL AND EXPERIMENTAL STUDY OF AMMONIUM PERCHLORATE COUNTERFLOW DIFFUSION FLAMES

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INTRODUCTION

Many solid rocket propellants are based on a composite mixture of ammonium perchlorate (AP) oxidizer and polymeric binder fuels. In these propellants, complex three-dimensional diffusion flame structures between the AP and binder decomposition products, dependent upon the length scales of the heterogeneous mixture, drive the combustion via heat transfer back to the surface. Changing the AP crystal size changes the burn rate of such propellants. Large AP crystals are governed by the cooler AP self-deflagration flame and burn slowly, while small AP crystals are influenced more by the hot diffusion flame with the binder and burn faster. This allows control of composite propellant ballistic properties via particle size variation. While the ultimate goal in composite propellant modeling is the ability to carry out a full three-dimensional computation that includes the random distribution of oxidizer crystals in the fuel matrix binder, such a study is beyond our current computational and modeling capabilities. Although previous measurements of AP/binder diffusion flames undertaken in planar two-dimensional sandwich configurations have yielded insight into the controlling flame structure [1,2], there are several drawbacks that make comparison with modeling difficult. The flames are two-dimensional in structure making modeling much more complex computationally than with one-dimensional propellant systems, such as RDX self- and laser-supported deflagration [3]. The melting of the binder can interfere with the composite propellant diffusion flame. This can complicate the interpretation and the implementation of experiments designed to help elucidate complex issues. Also, the length scales in the two-dimensional composite experimental configuration are extremely small – the majority of the heat release occurs in a region only 100 to 200 microns off the surface. It is much too difficult from a diagnostic viewpoint to resolve the combustion processes occurring within this region. The counterflow configuration greatly spreads the heat release region allowing spatial resolution of the chemical kinetic process in the AP/binder diffusion flame. This provides an excellent geometric configuration within which AP/binder diffusion flames can be studied both experimentally and computationally. Low strain rates can be selected by using large separation distances between the fuel and oxidizer flows, however, in the AP/methane and AP/ethylene ex-

periments the AP regression rate decreased with low strain rates leading to very low gas velocities. This, coupled with the larger length scale, leads to buoyancy affecting the flame structure. The negative buoyancy of the cold fuel compared to hot AP decomposition products causes the AP gases to expand radially and the stagnation plane to be pushed lower. This seriously distorts the flame structure for large separation distances required for low strain rates ($Gr/Re^2 = 2.5$ for $d = 10$ mm). As a result, we considered systems with smaller separation distances and higher strain rates. Investigation of flame structure and extinction under varying strain rates, however, is a vital technique to exercise and validate the kinetic database upon which the model is based.

In this paper we investigate the modeling of counterflow diffusion flames in which ammonium perchlorate oxidizer (AP) is counterflowed against methane and ethylene. Both gas phase and condensed phase chemistry are included. The results of the computational model are compared with a series of experimental measurements in which advanced laser diagnostics are used to measure species and temperature profiles. These include planar laser induced fluorescence, emission spectroscopy, and Raman scattering.

The proposed apparatus for studying these flames is illustrated in Figure 1. The separation distance between the surface of the AP pellet and the fuel jet is held constant during regressive deflagration by a spring load from below and tension wire across the surface. This simple technique has been successfully used on RDX and HMX combustion (which burn much faster) and can keep the surface at a constant position to within less than 100 micrometers.

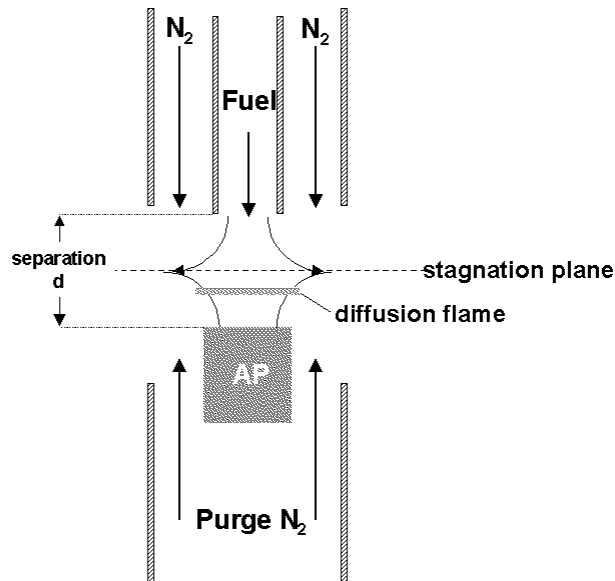


Figure 1 – Schematic of experimental configuration for fuel vs. AP counterflow flame system.

A color video camera with a macro lens is used to monitor the flame and provide images of its structure. This camera is gateable for the particle tracking velocimetry (PTV). A

UV-Visible gated intensified camera with UV macro lens is used to acquire 2D images of selected chemiluminescent species (such as CN, NH, CH, C₂, OH, etc.). This camera can also be used for PTV. Quantitative species concentration data are obtained using line resolved UV-Visible absorption spectroscopy. A xenon lamp is used as a light source with the beam being formed into a sheet which passes through the flame perpendicular to the surfaces of the binder and oxidizer. Spectral fitting of certain absorption bands, such as OH, may afford limited temperature profiling as well.

The temperature is measured on the fuel side using radiation corrected thermocouples and on the oxidizer side with OH rotational population distributions measured using PLIF (see Figure 2).

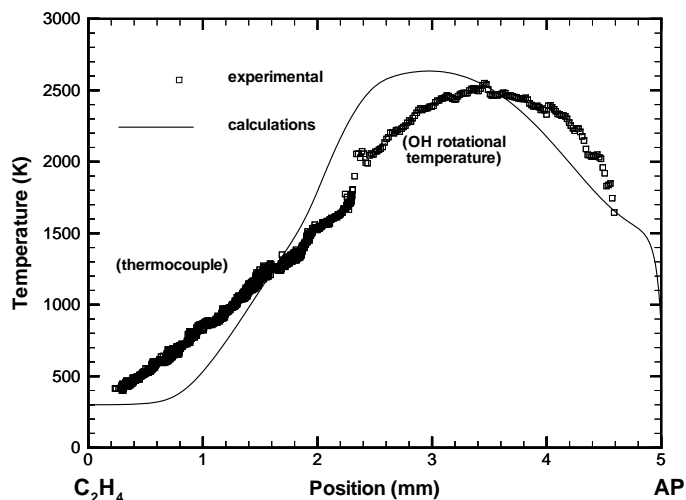


Figure 2 – Comparison between experimentally measured and calculated temperature profiles for the fuel vs. AP counterflow flame.

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REFERENCES

1. Parr, T. P. and Hanson-Parr, D. M., “AP Diffusion Flame Structure”, *Proceedings of the 33rd JANNAF Combustion Meeting*, Monterey, CA, November 1996.
2. Parr, T. P. and Hanson-Parr, D. M., *Twenty-Sixth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, 1997, p. 1981.
3. Prasad, K., Yetter, R. and Smooke, M. D., “An Eigenvalue Method for the Determination of Burning Rates for RDX Monopropellants,” *Comb. Sci. and Tech.*, **124**, p. 35, (1997).