

COMPUTATIONAL AND EXPERIMENTAL STUDY OF ENERGETIC MATERIALS IN A COUNTERFLOW MICROGRAVITY ENVIRONMENT

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Abstract

We investigate the modeling of counterflow diffusion flames in which the products of AP combustion are counterflowed against methane and ethylene fuel streams. The two-dimensional problem can be reduced to a one-dimensional boundary value problem along the stagnation point streamline through the introduction of a similarity transformation. By utilizing recent developments in hydrocarbon, chlorine, NO_x and AP kinetics, we can formulate a detailed transport, finite rate chemistry system for the temperature, velocity and species mass fractions of the combined flame system. We compare the results of this model with a series of experimental measurements in which the temperature is measured with radiation-corrected thermocouples and OH rotational population distribution, and several important species are measured with planar laser induced fluorescence and emission spectroscopy.

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. Previous ground based experiments were severely limited in the range of strain rates that could be studied by the effects of buoyancy [4]. Low strain rates are selected by using large separation distances between the fuel and oxidizer flows (there is no independent control over the flow speeds; the AP regresses according to heat feedback from the flame and the fuel velocity must be chosen to place the stagnation plane in the proper location). In the AP/methane experiments 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). With the experimental strain rate limited on the high end by heat loss to the burner and on the low end by the effect of buoyancy, the ground based experiments were limited to essentially a single strain rate. Investigation of flame structure and extinction under varying strain rates is a vital technique to exercise and validate the kinetic database upon which the model is based.

We investigate the modeling of counterflow diffusion flames in which ammonium perchlorate oxidizer (AP) is counterflowed against a hydrocarbon fuel. We consider both methane and ethylene. 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 solid oxidizer-fuel counterflow diffusion flames is illustrated in Figure 1. It consists of an oxidizer pellet (AP in this case) and binder are held at a controllable separation via a quick change pellet holder cartridge. The surface positions are 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.

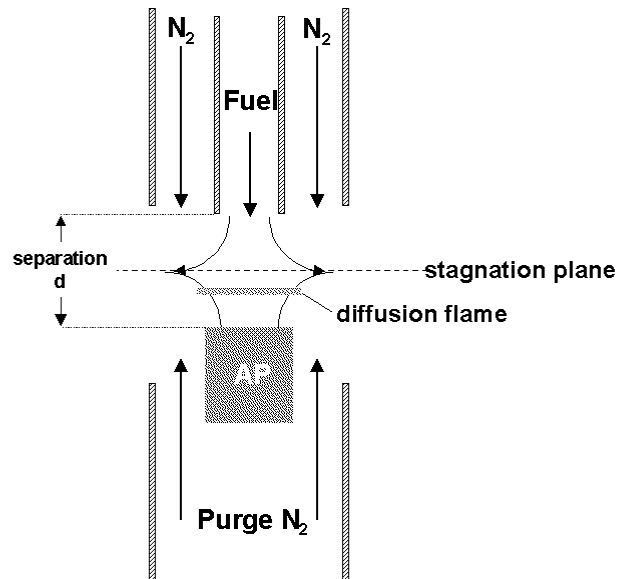


Figure 1 – Schematic of experimental configuration for hydrocarbon fuel vs. AP counterflow flame system.

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 is 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).

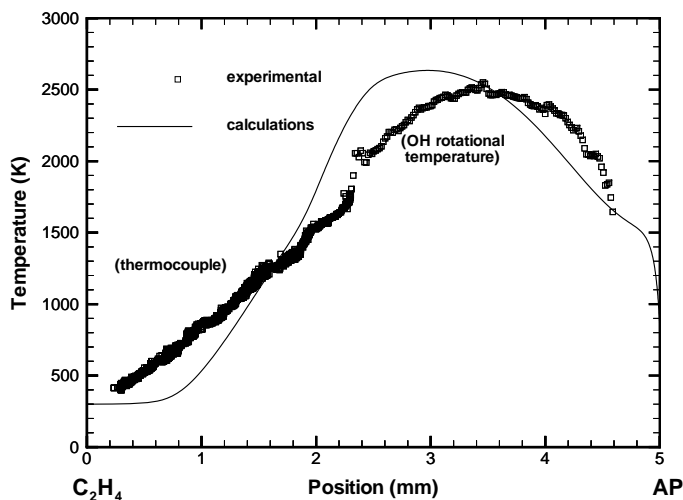


Figure 2 – Comparison between experimentally measured and calculated temperature profiles for the hydrocarbon fuel vs. AP counterflow flame.

ACKNOWLEDGEMENT

This work was supported by the Office of Naval Research. Drs. R. Miller and J. Goldwasser were the technical monitors.

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