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Porous Plate Analog Burner Study of Composite Solid Propellant Flame Structure

L. D. Strand* and N. S. Cohen†
Jet Propulsion Laboratory,
California Institute of Technology, Pasadena, Calif.

A POROUS plate burner apparatus was applied to study the structure and interaction of diffusion flames from unlike adjacent sources (size or type) of oxidizer under conditions simulating those of composite solid propellants. The burner provides diagnostic flexibilities not available with solid propellants—expanded spatial and temporal characteristics to afford accurate resolution of the flames, and geometric and stoichiometric combinations not processible in actual solid propellants.

The details of the burner (Fig. 1) have been published previously.[1,2] Metered hydrocarbon gases are passed through the porous plate to represent binder decomposition. Oxidizer gases pass through ports of selectable diameter and arrangement inserted in the porous plate, representing decomposing oxidizer crystals. The gases mix to create a diffusion flame representative of composite propellant combustion. The porous plate and port arrangement is enclosed in a windowed pressure vessel.

New porous plates and manifolding were fabricated for this program (Fig. 2). The port sizing and arrangements were based upon considerations of data acquisition, ease of fabrication, simulation, oxidizer-to-fuel (O/F) ratios to be achieved, flow rates, gas velocities, and Reynolds numbers, making use of Ref. 1 experience. The plates were designed to simulate monomodal and bimodal oxidizer composite propellants, and the manifolding afforded independent flow control for each size mode and/or the use of two different oxidizer gases. The gases used in these tests were ethane, air, oxygen, and oxygen-air mixtures. Independent variables were flow rate, O/F ratio, and pressure. Diffusion flame structures were observed visually and photographically. Examples of photographs acquired are shown in Figs. 3a-c.

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*Member of Technical Staff. Associate Fellow AIAA.

†Contractor, Cohen Professional Services. Member AIAA.

Discussion of Results

The most interesting results were acquired with the bimodal oxidizer porous plates. At highest oxidizer flow rates, the coarse port flames tended to bend toward the fuel (i.e., away from the ports), whereas the fine port flames were columnar in nature. This indicates that the coarse ports were oxidizer rich, whereas the fine ports were near stoichiometric.[3] At lower oxidizer flow rates, the coarse port flames became columnar, whereas the fine port flames began to bend toward the oxidizer port centerlines and eventually close over them (forming a parabolic flame). This indicates that the coarse ports were near stoichiometric and the fine ports were becoming fuel rich. At still lower rates, both sets of flames closed over their respective oxidizer ports, but the fine port flames exhibited more carbon emission. Although flame heights were larger over the coarse ports, in accordance with diffusion requirements, the coarse port flames commenced closer to the surface of the porous plate. This indicates a shorter reaction distance with the coarse port, which may be attributed to a higher temperature and, in turn, to operating closer to stoichiometry.

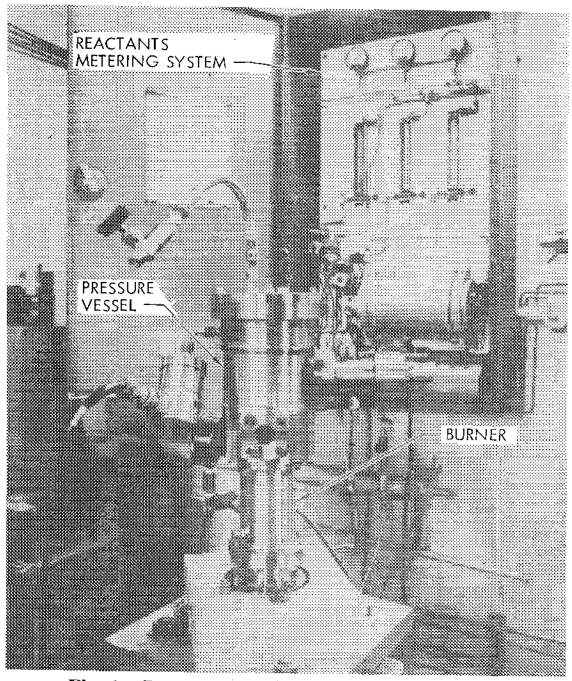

Fig. 1 Porous plate analog burner test system.

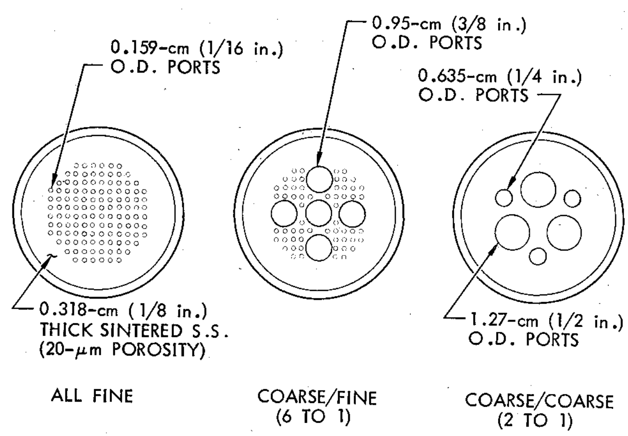

Fig. 2 Monomodal- and bimodal-oxidizer porous plate configurations.

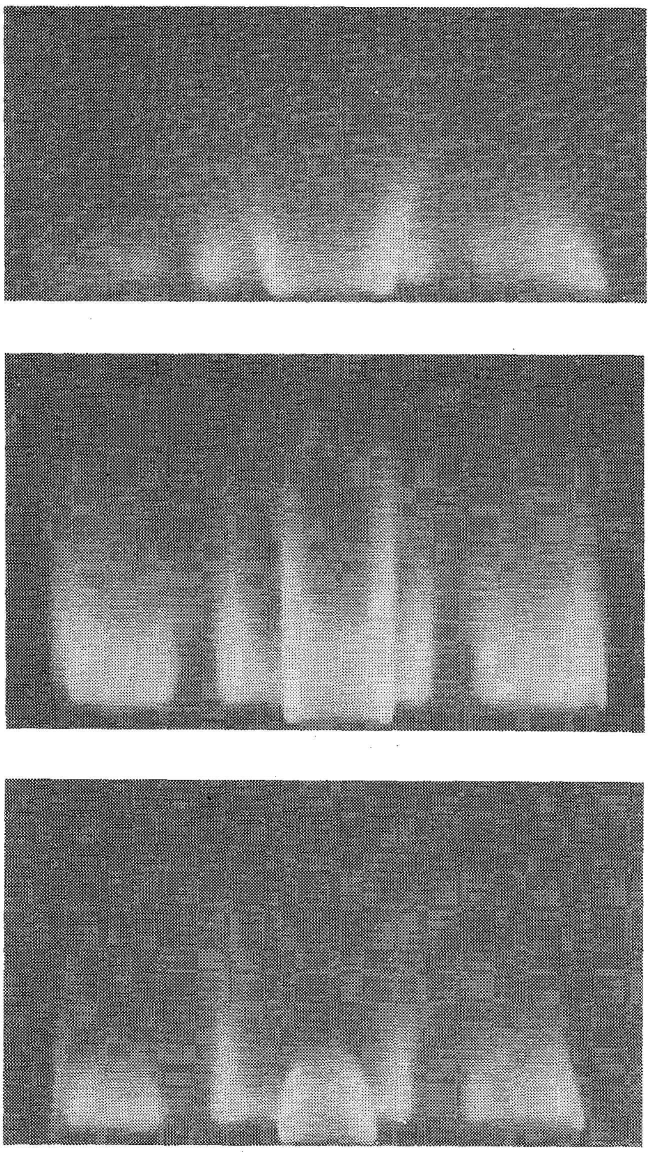

Fig. 3 Porous plate burner flames—coarse bimodal, ethane-air: a) oxidizer rich (divergent flame); b) stoichiometric (columnar flame); c) fuel rich (parabolic flame).

Flame limits encountered by independently varying fuel and oxidizer flow rates, the relative sensitivity of the fine port flames to O/F ratio, and effects of substituting oxygen for air all indicated that the fine port flames were more fuel rich. This is not surprising, since for a fixed interstitial spacing between oxidizer ports and particular values of specific flow rates, a proportionally greater amount of fuel will be associated with the fine ports. Such variable O/F ratio is a topic of current theoretical modeling of composite propellants,[4,5] but the particular allocations are not known.

Two interesting effects were noted when oxygen was substituted for air. For a given set of flow rates, the flame structure took on a less fuel-rich appearance (O/F ratio increased, as expected). Second, the porous plate became red hot in the region of the cluster of fine oxidizer ports; this confirms the higher temperature and heat feedback that would be expected with oxygen and indicates that there is more heat feedback with the fine ports. By analogy to propellants, fine particle size systems would burn faster unless the fuel allocation became such that the reduced temperature would overcome the reduced diffusion length.

Although physical overlap or intermingling between adjacent flames did not occur, two types of interaction between flames of adjacent ports were observed. First, where a fine port is adjacent to a coarse port, the fine port flame is nested under the near-surface region of the coarse port flame such that there could be heat feedback from the coarse flame to the fine flame. Second, where adjacent fine ports are sufficiently close together, the adjacent parabolic flames are joined at their bottoms by a nearly planar flame over the interstitial fuel. This feature provides a more vivid mechanism for direct heating of binder in propellants and is not predicted by current diffusion flame theory.

Conclusions

Fundamental diffusion flame data were obtained as a function of simulated oxidizer size distribution and mixture ratios utilizing a porous plate analog burner. There was much evidence in the diffusion flame structures to show that fine oxidizer ports tend to operate more fuel rich than coarse ports in a bimodal arrangement. Also, as expected, fine ports exhibited more heat feedback to the burner surface. Some interaction between flames of adjacent ports was observed, of a type that should be addressed in any future, more rigorous analytical treatment of multicomponent composite propellants.

Acknowledgments

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Performance Investigation of Superfluid Heat Pipes

M. Murakami*
University of Tsukuba, Sakura, Ibaraki, Japan

Introduction

In recent years cooling to liquid helium temperature has been required for various applications. Considerable effort has been made to apply superfluid helium to cooling systems. Several space programs, such as space infrared telescopes,

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*Lecturer, Institute of Structural Engineering. Member AIAA.