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FLAME PROPAGATION AND EXTINCTION IN
PARTICLE CLOUDS*

By

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INTRODUCTION AND BACKGROUND

Microgravity combustion studies of particle clouds can eliminate intractable experimental and theoretical problems, thereby permitting successful resolution of essential issues associated with particle cloud flame propagation and extinction (1-7). It is important to note the scientific issues at stake and UCSD approaches to their resolution through Orbiter Middeck and related microgravity combustion studies of premixed, quiescent particle clouds. These previously presented observations are noted below:

The central problem in nonadiabatic theory of flames is concerned with flame propagation and extinction. For gas phase, premixed fuel and air, experimental and theoretical studies (8-15) have provided important insights into controlling mechanisms for flame propagation and extinction. The classic studies generally conclude the following: In the absence of natural convective processes, flame extinction (flammability limits, pressure limits, and wall quenching) is due to heat losses from flame to boundaries (10-13). Recent studies have been aimed at a more comprehensive understanding of flame structure and extinction through use of more complete chemical kinetic representations and general (time-dependent) constitutive equations of fluid dynamics. Modern computational systems permit numerical integration of these more comprehensive representations. Although definitive correspondence of premixed gaseous combustion theory and experiment is incomplete, a substantial level of fundamental understanding has been achieved.

For the case of flame propagation/^{and}extinction in premixed clouds of fuel particles, progress in development of both theory and experiment have been slow. (2,3,6) The reasons are several, and complex. Essential limitation on our understanding of premixed particle cloud combustion derives principally from the inability of experiments

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conducted at normal gravitational conditions:

- (a) to permit the establishment of uniform, quiescent clouds of uniformly distributed (non-settling) combustible particulates;
- (b) to yield data that are independent of natural convective effects.

Experiments at reduced gravitational conditions are expected to permit the resolution of both of these experimental problems. Combustion experimentation in Space Shuttle facilities can provide a unique body of data, thereby stimulating and complementing the corresponding development of two-phase flame propagation and extinction theory.

The current investigation has been concerned with

(a) ~~the further development of~~ two-phase flame propagation and extinction theory required to support the corresponding experiments planned for space shuttle, ~~is~~ ^{IS BEING DEVELOPED.}

^{ALSO BEING DEVELOPED ARE} (b) specialized collaborative, experimental and theoretical NASA-UCSD studies needed to support the ongoing definition of needed experimental hardware, experimental procedures, data acquisition philosophy, and other ground-based support activities required to assure the success of Space Shuttle-based experiments concerned with Combustion of Clouds of Particulates at Reduced Gravitational Conditions;

(c) the further development of relations delineating premixed particle cloud and premixed gaseous systems as well as burner-stabilized and freely propagating flame systems. ~~is~~ ^{IS CONSIDERED}

FLAME PROPAGATION
EXTINCTION
REDUCED GRAVITY
CLOUDS
PARTICLES

SPACE SHUTTLES
COMBUSTION
CONVECTION
PREMIXING
PRESSURE OSCILLATIONS

RECENT ADVANCES

The UCSD research team has collaborated with NASA's Lewis Research Center in addressing technological issues required for the Particle Cloud Combustion Experiment. These have included the successful resolution of cloud ignition, particle cloud mixing, the suppression of wall saturation effects and the further development of particle pyrolysis data, and two-phase flame propagation and extinction theory.

Several papers prepared recently by UCSD researchers are reproduced in APPENDIX (A). Important aspects of our current theoretical and experimental approaches are given in these papers.

NASA-LeRC scientists and engineers are currently concerned with design and development of a Particle Cloud Combustion Experiment (PCCE) and associated apparatuses. UCSD researchers have supported this effort in a number of ways:

(1) Work on wall saturation effects and on optical extinction characteristics of particle clouds has furnished information required for successful design of the PCCE. Studies of particle-particle and particle-wall interactions continue.

(2) Theoretical and experimental work on particle vaporization and pyrolysis kinetics is required to support the broad theoretical objectives of two-phase flame propagation and extinction theory. These studies are currently in progress at UCSD.

(3) Bench top (and drop tower) studies at UCSD (and at LeRC) have helped to resolve a number of experimental issues regarding particle cloud mixing processes, as well as particle cloud ignition, flame propagation and extinction. These ongoing studies support NASA's current design and development efforts, provide quantitative bases for rational selection of the matrix of orbiter and of ground-based experiments planned for the PCCE program.

They contribute importantly to the development of flame propagation and extinction theory. Findings reported in reference (6) (also Appendix (A)-Part 3) illustrate the supportive importance of drop tower and other ground-based studies.

THEORETICAL MODELLING

Methods of nonadiabatic premixed two-phase flame theory have been extended to include a two temperature flame structure (gas and particulates) as well as detailed information on volumetrically distributed endothermicities (e.g., see reference 6 and part 3 of Appendix (A), and the coupled roles of omnidirectional energy transport to boundaries ⁽⁶⁾. Theoretical modelling to date, taken together with selected drop tower experimentation, has been able to demonstrate the importance of inclusion of these considerations in theoretical models. An extensive discussion of these theoretical issues is given ⁽⁶⁾ in part (3) of Appendix (A). Based on these approaches, the current theoretical work will be extended to include detailed homogeneous and heterogeneous pyrolysis and oxidative chemical kinetics for the particulates of interest. Under microgravity conditions, the radiation-conduction flame propagation and extinction model will be developed further and applied to the experimental data to be derived from the planned Space Shuttle based experiments.

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