REACTIVE MULTIPLE PHASE HYDRODYNAMICS

ALDIS, DAVID FRY

DEGREE DATE: 1987

K7

Order Number 8811672

Reactive multiple phase hydrodynamics

Aldis, David Fry, Ph.D.

Illinois Institute of Technology, 1987

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

REACTIVE MULTIPLE PHASE HYDRODYNAMICS

BY

DAVID FRY ALDIS

Submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy in Chemical Engineering
in the School of Advanced Studies of
Illinois Institute of Technology

Approved Dimitri Gidaspow
Adviser

ORIGINAL ARCHIVAL COPY

Chicago, Illinois
December, 1987

ACKNOWLEDGMENT

Numerous people gave me the will to finish my Ph.D. The most important person in my life, and the most important person in giving me the support and direct help to complete my Ph.D. is my wife, Roxane.

The assistance from Department H at the IIT Research Institute has also been invaluable. Mrs. Hyla Napadensky, Dr. Allen Tulis, Mr. Ron Pape, Mr. Arnie Wiederman, and everyone in the department has been supportive, helpful, and kind. It is difficult to complete a Ph.D. if one is working on it full time, it is more difficult if one is simultaneously working on at a job. Without the financial backing, the administrative assistance and the support, my Ph.D. would still be a task unaccomplished.

Finally, without the help, guidance, and direction of Dr. Gidaspow this thesis would not now be complete. His moral support helped me more times than he will ever know.

D.F.A.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Industrial Dust Explosion Hazards

Every year people are killed and equipment is destroyed by dust explosions. The present death rate from grain dust explosions alone averages between 5 and 15 people per year. During 1977 and 1978, the destruction caused by grain dust explosions amounted to over 100 million dollars. Last year, 1986, several people died in a coal dust explosion in Japan. The potential explosion hazard extends to almost every industry that handles combustible bulk powders. Some of the powders that have been tested for explosibility by the U.S. Bureau of Mines are grain dusts, plastic dusts, metal dusts, and a large group of mixed dusts (Aldis and Lai, 1979). In Germany, the Berufsgenossenschaftliches Institut fur Arbeitssicherheit has reported test results for 809 powders (Field, 1982).

The phenomenon referred to in the popular press as a dust explosion is either a deflagration or a detonation. A deflagration is an exothermic process in which the gas pressure is relatively uniform with respect to space. A detonation is a process in which the pressure difference between the reactants and the combustions products is so large that a shock wave forms at the interface. The shock moves into the reactants at the speed of sound of the combustion products. The reactants are heated by the shock, which then causes the reactants to deflagrate very quickly. This deflagration releases heat and moles of gas, causing a high pressure which, in turn, supports the shock. This concept of a detonation is called the ZND detonation theory, after the three researchers, Zeldovich, von Neumann, and Doring, who independently developed the analytical representation of the detonation process (Williams, 1985).

A detonation in an industrial setting is a devastating occurrence. It is possible to reduce the effects of a deflagration by venting the gas pressure formed by the combustion process. Since a deflagration is approximately a constant pressure process, the vent keeps the gas pressure from increasing above the design limits of the building or the container holding the combusting reactants. However, if a detonation occurs, and if the vent is behind the detonation front, then the detonation will proceed ahead, and its progress will continue uninterrupted. Since the detonation is traveling at the speed of sound of the combustion products, the rarefaction front caused by the vent can never catch up with the detonation.

In this thesis, theoretical studies of particulate combustion are described. Two widely differing combustion regimes are considered, packed bed combustion, as might occur in a fractured solid rocket motor, and dispersed combustion, as might occur in a propellant processing facility. Detonations will be emphasized due to their disastrous potential. This thesis begins with a literature review giving a brief description of the efforts of former researchers. Both experimental and theoretical studies are examined.

Literature Review

Dust explosions have been reported for over 200 years and have been studied for nearly as long. The history of dust explosions has been reviewed by several researchers (for example, Palmer (1972), Aldis and Lai (1979), and Field (1983)). This review is, therefore, restricted to only those works that are directly applicable to the present study.

A few papers on dust explosions and other related areas will be described. The first papers present experimental lab scale dust explosion data and include some theoretical analysis. The next work, by Butler, *et al.* (1982), is concerned with the transition of a shock in a reactive propellant bed to a detonation. A paper by Gidaspow, *et al.* (1986) presents data on the semi-free field initiation of a suspended pyrotechnic material. The paper by Tamanini (1985) describes a research program on the deflagration of grain dust in a large combustion chamber. The paper by Gidaspow, *et al.* (1984a) illustrates the numerical technique that is planned for use in this present program.

The three lab scale test programs have examined three different materials. Ogle (1986) studied aluminum dust deflagrations in a 20 liter spherical chamber. His work is the best combined experimental and theoretical research programs in the dust explosion area. Ogle's approach is based on principles of chemical kinetics and, what he terms, transport drive fluid mechanics methodologies. Using existing literature on the combustion of aluminum, he was able to develop a viable reaction rate model which could then be used to describe his experimental results.

The report from the Bureau of Mines by Hertzberg, et al. (1979) examined several experimental features of coal dust explosion testing. The report had little theoretical analysis, but it did present an excellent experimental research program. The program examined the effect of ignition energy on the minimum concentration necessary for an explosion. Subsequently, it was reported by Bartknect (1981) that it was necessary to use a chemical igniter which released at least 10 kJ to obtain results which scaled. Hertzberg goes on to examine the effect of the dust particle size on the rate of pressure rise in the combustion chamber. This rate is one of the most critical terms that are measured in a dust explosion test and is used to determine the hazard class of the material.

Hertzberg reports measurements of the temperature of both the dust particles and the gas surrounding the particles. The chamber used by Hertzberg was a 8 liter cylinder with curved ends. The chamber had a length to diameter ratio of approximately one. A serious effort was made to verify the dust concentration in the vessel prior to ignition. The investigators used a light attenuation system calibrated with a material of known particle size and dispersal characteristics.

Grain dust was studied by Garrett (1981) and Lai, et al. (1980). The explosion chamber Garrett used was the Hartmann bomb. The Hartmann bomb has been reviewed by the American Society for Testing Methods (ASTM) as a standard device for studying dust explosions. It has, however, been reported by Bartknecht (1981) that the Hartmann bomb tends to underestimate the maximum rate of pressure rise as determined by vessels of differing sizes. When vessels of differing sizes are used, it is necessary to use the cube root scaling law to relate the results. When the results obtained by the Hartmann bomb are scaled using this law, and then compared to the results obtained with, for example, spherical chambers of 20 liter and 1 m^3 size, the curves do not agree. The reason given to explain this result is increased radiative heat loss in the Hartmann bomb. It has a minimum dimension of 4 inches compared to approximately 12 inches in the 20 liter spherical chamber.