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Reports and Papers Published Under
MIT Fuel-Coolant Interaction Project

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Introduction

The objective of the continued work on this project at M.I.T. is to study experimentally and developed mathematical models to analyze the dominant mechanisms in fuel coolant thermal interactions which could lead to vapor explosions.

Our exploration of mechanisms is focused in two areas

- a) Mechanisms responsible for fragmentation in molten metal droplet experiments (here we include assessment of the validity of the proposed Spontaneous Nucleation Mechanism),
- b) Thermal Stress Initiated Fracture as a fragmentation mechanism (this mechanism is not considered responsible for the fragmentation of molten metal drops - see Knapp's work).

Work is being performed in both these areas simultaneously and will be briefly described below.

I. Mechanisms Responsible for Fragmentation
in Molten Metal Droplet Experiments
(Gautam Shiralkar)

A. Experimental Work

Experiments were conducted using solid spheres of steel heated and dropped into water, in order to compare the pressure traces with those using molten tin drops, i.e. to see if there is any difference between the solid-liquid and liquid-liquid systems. There does not seem to be any "big bang" for solid drops. There is a peaking of pressure but it is much more gradual and no low frequency period is observed. This pressure peak value followed the same pattern as the tin and bismuth drops i.e. increased with drop temperature initially and then fell off again after reaching a maximum at about 500°C. In this respect, the solid-liquid system behaves like the liquid-liquid one; however, the absence of the "big bang" appears significant. Frequency analysis of the pressure tapes indicates an additional departure - the frequency spectrum is very uniform, and does not have the 2 dominant frequencies of the liquid-liquid system.

The experiments were repeated using a number of smaller solid drops to compare the pressure traces in the region of maximum pressure. Again, no "big bang" was observed. Also, a number of gradual pressure peakings are noticed. The frequency spectrum is very uniform.

More recently, experiments were conducted to check that the pressure measured by the transducer does indeed vary linearly with distance in the water. Owing to the scatter in the experiments generally observed, two transducers and two recorders were observed simultaneously. The results indicate that there is a margin of error and a scatter is observed about the linear behavior. It is possible that this is due to reflections of pressure pulses from the stand holding the transducers in the water, or the sides of the tank. This is being investigated.

B. Gas Solubility Mechanism

More recently, work is going on with respect to the hypothesis that dissolved gas may be responsible for drop fragmentation - Michael Epstein's theory. Such a theory could well explain the outward bursting of the drop. We also suspect that the "triggering temperature" for the process is the melting point of the metal. (Generally, the solubility of the gas decreases with decreasing temperature, and drops sharply at the freezing point).

In attempting an analysis of this theory, various difficulties present themselves, in addition to the one problem of scant information on the actual solubilities of gas in molten metals. There does not seem to be any well formulated theories upon which to establish rate equations for the process of gas coming out of solution.

However, experiments have been designed to run tests of molten tin, varying the heating time in atmospheres of oxygen (which dissolves relatively easily) and in nitrogen (which is practically insoluble). The process of dissolving of oxygen into the metal takes place due to gas dissociation

and subsequent diffusion into the interior of the metal. The time for the total process is governed by the diffusion process. Based on this diffusion time, the heating times in oxygen will be established.

II. Thermal Stress Initiated Fracture

(W. Fred Lenz)

The anticipated scope of the immediate work has been broken down into four major areas. The first is that of numerical development. It has been determined that due to the complexity of the actual heat transfer boundary conditions, finite element analysis will be the most useful tool for the evaluation of both the temperature distributions and the resultant thermal stress field. Work therefore has been directed toward developing the skills necessary to apply such methods and develop appropriate finite elements for the particular problem.

The second major area of research is in the field of fracture mechanics. To establish the surface area generated due to fragmentation during a fuel coolant interaction, it is necessary to develop a thorough understanding of fracture mechanics so that developed overall approaches to the problem are recognizably possible. As of this moment, one approach has been outlined as to how, given the necessary material information and the thermal stress calculations, the problem of calculating the surface area generation rate can be attacked. Briefly described, this approach utilizes stress intensity factors to assess 1) whether a crack proceeds and 2) if so, how far will it travel before branching. It is expected that several such outlines will be made before a choice will be made among them as to which one will be chosen.

The third area of work involves the experimental design. This area includes both the selection of the necessary laboratory equipment and the selection of suitable test materials. The selection of simulants for UO_2 and Na will attempt to provide a balance between good simulant materials and materials that will not require overly elaborate laboratory equipment. Current work includes an analysis of selected ceramics and their properties to determine a suitable simulant for the properties and the particular behavioral characteristics (i.e., thermal shock behavior) of UO_2 . Al_2O_3 was first considered to be a good simulant however it is now thought that the difference in crystal structure between alumina and UO_2

lead to significant differences in the internal stress buildup due to the anisotropic characteristics of Al_2O_3 . A similar analysis to determine a simulant for Na will be performed. At this moment, NaK appears to be the best coolant simulant.

The fourth area of work is concerned with the acquisition of microstructure information for UO_2 and the chosen simulant. It will be necessary to acquire such information as grain, size, pore size, flaw sizes, etc. for both materials as fabricated and as crystallized from a melt assuming specific crystallization rates. Such information will be requested from National Laboratories which have worked extensively on experiments involving solidified UO_2 .