EFFECT OF OVERLAYING STEEL LAYERS ON THE
GROWTH OF MOLTEN CORE DEBRIS POOLS IN CONCRETE*

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Following a hypothetical core disruptive accident (HCDA) in a fast reactor, the core debris may be in the form of a molten pool which is volumetrically heated by the radioactive decay of the dissolved fission products. The debris pool may be retained in the concrete support structure below the reactor vessel. It grows continually by melting the concrete which readily dissolves in the pool. Large amounts of gas, predominantly CO_2 , H_2O , CO , and H_2 , are released by the concrete. Initially, an immiscible layer of molten steel may exist on top of the debris pool. As the pool is continually diluted by the dissolved concrete its density decreases so that inversion of the top steel layer may eventually take place.

The purpose of this research is to simulate the heat and mass transfer processes taking place in the molten steel/core debris/concrete system. The effects of the initially-lighter steel layer atop the pool and the subsequent inversion process on the transient radial and downward growth rates of the pool are investigated.

The test cell used in this investigation is an upright rectangular box with inside dimensions of 7.5 x 35.0 x 40.0 cm. The solid bed simulating the concrete is cast from a homogeneous mixture of Carbowax 1540 and ammonium bicarbonate (NH_4HCO_3) which decomposes near the melting temperature of the wax releasing NH_3 , CO_2 , and H_2O . Different amounts of ammonium bicarbonate are mixed with the wax to obtain different gas release rates.

A rectangular cavity 7.5 cm wide and 2.5 cm deep is formed in the solid bed to contain the volumetrically heated pool and overlaying immiscible layer. An aqueous solution of potassium iodide and zinc bromide is used to simulate the core debris pool. Pools of different initial density

and viscosity can be obtained by varying the concentrations of these compounds in the solution. The overlaying steel layer is simulated using a 0.5 cm thick layer of 1-iodoheptane ($\text{CH}_3(\text{CH}_2)_5\text{CH}_2\text{I}$) liquid ($\rho = 1.38 \text{ g/cc}$) or 1-bromoheptane ($\text{CH}_3(\text{CH}_2)_6\text{Br}$) ($\rho = 1.15 \text{ g/cc}$) depending on the pool density. The top surface of the two-layer pool is bounded by a nearly-isothermal, water-cooled copper plate.

Power is applied to the pool and is maintained constant throughout the experiment. The pool temperature quickly rises to and beyond the melting temperature of the wax. The pool grows by melting the wax while gas is released by the decomposing ammonium bicarbonate. The molten wax and ammonia readily dissolve in the pool while the carbon dioxide bubbles through the pool and is removed through holes in the upper plate. For low gas release rates, the overlaying immiscible layer remains atop the pool until its density exceeds that of the diluted pool. At that time it gradually slides down the sides of the pool and stabilizes at the bottom surface. For high gas release rates, the overlaying layer breaks up into droplets to allow passage of the gas bubbles through the pool. The droplets remain afloat until their density exceeds that of the pool and gradually sink to the bottom surface.

A 35 mm camera is used to photograph the pool at regular intervals along the transient. The pool dimensions are measured from the photographs by means of an optical comparator. Experiments have been conducted at different values of power input, initial pool density, top layer density, and gas release rates. Typical results are shown in Fig. 1 where the pool aspect ratio is plotted as a function of time for pools with and without an overlaying layer with and without gas release from the solid bed.

The results show that two-layer pools have a significantly different growth pattern than single-layer pools. In all cases, the pool height initially increases at a faster rate than its width so that the pool aspect ratio decreases with time (Fig. 1). However, the rate of change of L with time gradually decreases until the trend is reversed. The critical time $\mathcal{T}^*$ at which the pool reaches its minimum aspect ratio is a function of power density, gas release rate, and pool/bed density ratio. For single-layer pools, the gas release rate has a significant effect on the pool growth pattern; shallower pools are obtained as the gas velocity is increased. Also, the critical time $\mathcal{T}^*$ decreases as the gas velocity is increased. On the other hand, for two-layer pools, the gas release rate has a minor effect on the pool growth pattern (Fig. 1). For low gas release rates, the point at which inversion of the upper immiscible layer takes place can be clearly identified. At that point the layer stabilizes at the bottom surface of the pool and the rate of change of aspect ratio decreases. For high gas release rates, the inversion point is not clearly identified (Fig. 1) since individual droplets, rather than a continuous layer, gradually sink to the bottom with little impact on the pool hydrodynamics. Generalized correlations predicting the effect of power density, gas velocity, and pool/bed density ratio on pool growth rates have been developed.

Fig. 1. Variation of Pool Aspect Ratio With Time for Pools With and Without an Overlying Immiscible Layer at Different Gas Release Rates. (Arrow indicates upper layer inversion point.)