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Gas Bubbling-Enhanced Film Boiling of Freon-11 on Liquid Metal Pools*

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In the analysis of severe core damage accidents in LWRs, a major driving force which must be considered in evaluating containment loading and fission product transport is the ex-vessel interaction between molten core debris and structural concrete. Two computer codes have been developed for this purpose, the CORCON-MOD2[1] model of ex-vessel, core-concrete interactions and the VANESA[2] model for aerosol generation and fission product release as a result of molten core-concrete interactions. Under a wide spectrum of reactor designs and accident sequences, it is possible for water to come into contact with the molten core debris and form a coolant pool overlying the core debris which is attacking the concrete. As the concrete decomposes, noncondensable gases are released, which bubble through the melt and across the boiling interface, affecting the liquid-liquid boiling process. Currently, the CORCON code includes the classical Berenson[3] model for film boiling over a horizontal flat plate for this phenomenon. The objectives of this activity are to investigate the influence of transverse noncondensable gas flux on the magnitude of the stable liquid-liquid film boiling heat flux and develop a gas flux-enhanced, liquid-liquid film boiling model for incorporation into the CORCON-MOD2 computer code to replace or modify the Berenson model.

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DISCLAIMER

The development of the experimental apparatus and allied instrumentation and the experimental procedure have been described in detail elsewhere[4,5] and will not be repeated here.

The R11/liquid metal liquid-liquid film boiling tests with gas injection were performed over a range of superficial gas velocity from 0.6 cm/s to 5.0 cm/s. An example of the transient thermal behavior of the liquid metal pool during film boiling with gas injection is shown in Figure 1a-b for Run 219 (J_G = 5.0 cm/s). Seven thermocouples were submerged in the liquid metal pool; TC5 was closest to the free surface while TC11 was closest to the base. The depths of the thermocouples below the free surface are indicated in parentheses on the figure.

The data indicate that the liquid metal pool is well mixed over its entire 8 centimeter depth, both due to the film boiling above as well as the gas injection from below. The pool appears to cool isothermally (0-210 s) until it reaches its fusion temperature (Pb fusion temperature = 600 K). The pool remains isothermal throughout its depth at the fusion temperature as a bubbling slurry (210-280 s) until almost all the latent heat is removed by the boiling layer above. As the slurry concentration increases, its viscosity increases until convection can no longer be sustained to keep the pool well mixed. At this point, the pool is essentially completely frozen (280 s) and a temperature gradient develops across the new solidified pool, indicating a transition from convection to conduction as the mechanism of heat transfer within the metal layer.

In addition to the observation that slurry freezing appears to be the dominant mode of solidification of a bubbling liquid metal pool (no conclusions are being made concerning oxidic pools), it was found that the solidified mass was porous even after freezing was complete. The gas injection flow rate remained constant and the pressure drop across the metal pool remained constant during the entire time of the test.

A third observation was that at even the highest gas injection superficial velocity ($J_G \approx 5.0$ cm/s), there were observed no R11/liquid metal vapor explosions such as occurred with water. This indicated that R11 is highly stable in liquid-liquid film boiling, as compared to water, which was found to be unstable; an understanding of why may shed some light on the mechanisms of vapor explosions in the future.

A sample of the experimental results for four of the experiments that were analyzed is shown in Figure 2. Shown is the averaged boiling heat flux normalized by the prediction of the Berenson film boiling model as a function of the gas superficial velocity.

Although the results are preliminary, there appears to be a linear relationship between the average boiling heat flux and the superficial gas velocity as shown in the figure. A preliminary liquid-liquid film boiling model with transverse gas flux that can be derived from the data is given below,

$$q^* = 1.26 + 4.98\ J_G^* \quad ,$$

where q^* is the dimensionless film boiling heat flux ($q''/q''_{Berenson}$) and J_G^* is the dimensionless gas superficial velocity (J_G/U_∞). The data exceed the Berenson model by approximately 20% at zero gas flux and increase almost linearly with gas flux to the limits of the present experiments. Further tests are planned and under way to examine the zero gas flux result and to extend the range of J_g to higher gas flux to determine if an asymptotic limit exists.

References

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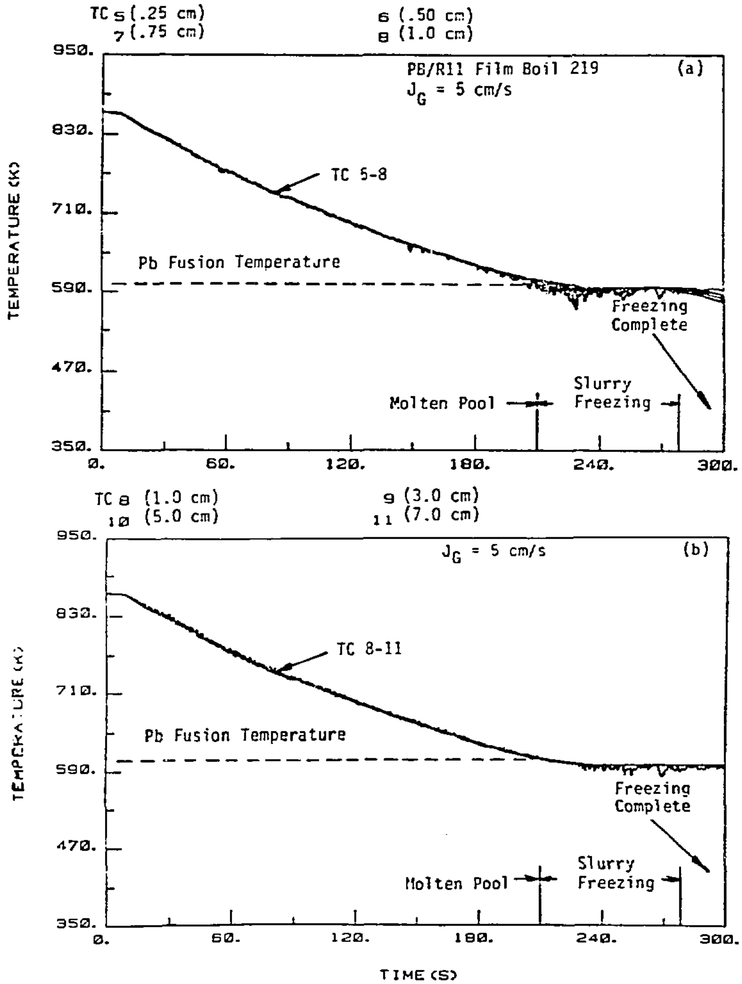

Figure 1 Transient Thermal Response of Molten Lead Pool During R11 Liquid-Liquid Film Boiling: Run No. 219

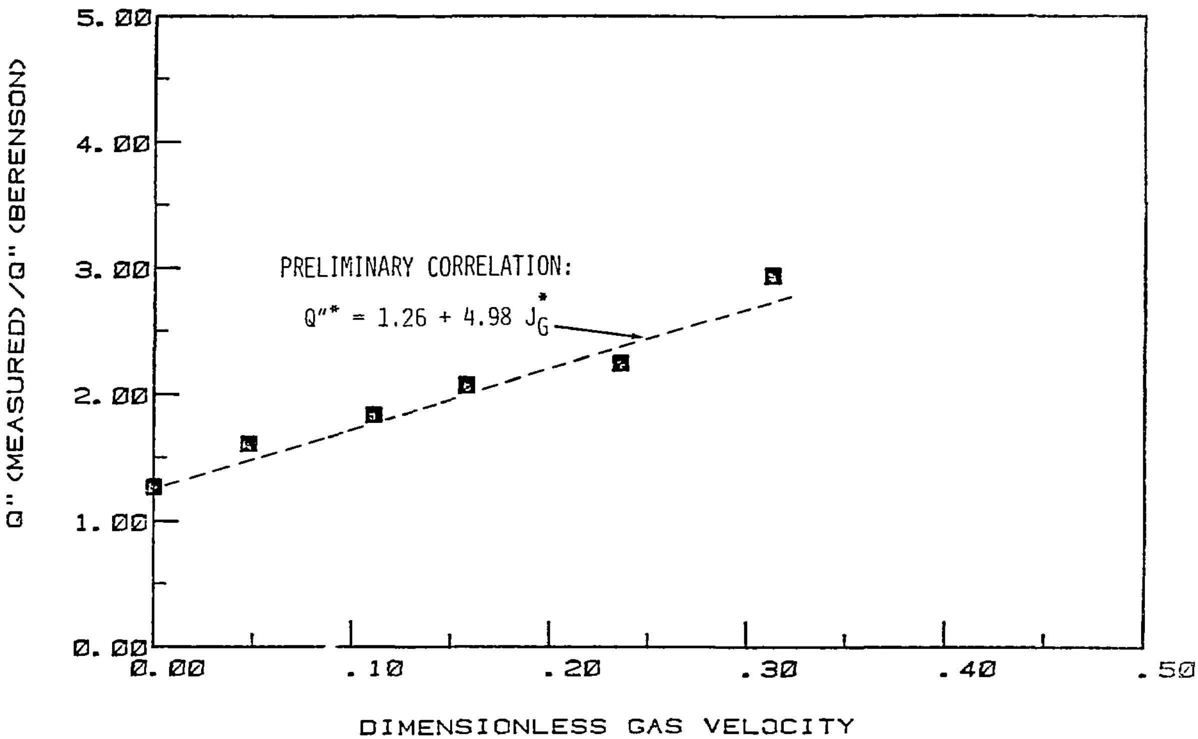

Figure 2 Dependence of R11 Liquid-Liquid Film Boiling Heat Flux Versus Superficial Gas Velocity