Conf-810606--108

Downward Heat Transfer in a Miscible Melting System*

by

CONF-810606--108

DE83 008883

R. Farhadieh
Reactor Analysis and Safety Division
ARGONNE NATIONAL LABORATORY
9700 S. Cass Avenue
Argonne, IL 60439

The integrity of an ex-vessel core-retention system in the event of core meltdown is of concern in PAHR safety assessment. Several ex-vessel core retention concepts incorporate sacrificial beds. The integrity of the ex-vessel core-retention system is dependent on the directional growth of the molten pool into soluble boundaries of the sacrificial bed. Mutual dissolution of the molten pool of core-debris and the sacrificial material is expected to change the thermal characteristics of the pool and thus affect the heat transfer to the boundaries. The two-dimensional simulation study[1] of the penetration of a dense, hot liquid pool into the boundaries of a meltable, soluble solid revealed the dependency of the directional pool growth on the density ratio, ρ^*, of the liquid pool to the meltable solid. In the one-dimensional study of the downward penetration of the hot pool into a soluble boundary[2] four different hydrodynamic flow regimes were identified that occurred at different ranges of ρ^*. The downward heat transfer enhanced beyond $\rho^* \approx 1.1$. The present study investigates the effect of test cell geometry and material properties on the downward heat transfer in a horizontal melting system.

The downward penetration of the solid by an overlying hot liquid pool was carried out in an evacuated, de-silvered Dewar, having an internal diameter of 76 mm, using several material pairs. A thermostatically controlled flat

*Work performed under the auspices of the U.S. Department of Energy.

heater, suspended in the liquid 35 mm above the solid-liquid interface, was used to maintain a constant pool temperature. A movable thermocouple was used to measure the vertical temperature profile of the liquid phase. To determine the melting rate the advancement of the liquid-solid interface was recorded at regular time intervals. The density ratio of the liquid to the melt used in this study varied in the range of $0.96 < \rho^* < 2.28$. The liquid and melt Prandtl numbers were in the range of $2.8 < Pr_\ell < 400$ and $13.5 < Pr_m < 2000$, respectively.

The experimental results for circular and rectangular test cells were in excellent agreement for the same pair of test materials. This established the independency of the downward heat transfer from the test cell geometry. As can be seen from Fig. 1 the turbulent and upper turbulent flow regimes observed previously[2] were also encountered in experiments conducted with different pairs of materials. The ordinate of this Figure is the viscosity of the upper fluid times the melting rate. The more viscous upper fluid resulted in a greater downward melting. This could be attributed to the strength of large vorticies within the more viscous upper fluid which could exert a large drag force on the melt layer and peel off the less viscous lower melt.

Figure 2 shows the correlated data in terms of a modified Nusselt number times Pr_ℓ/Pr_m and the melt Rayleigh number, which are defined as,

$$Nu = \frac{\Lambda \left(\frac{\rho_m \lambda_c}{\Delta T}\right)}{k_m} , \text{ and } Ra = \frac{g\ (\rho_\ell - \rho_m)\ \Lambda^3}{\nu_m\ \alpha_m} .$$

The characteristic length Λ is defined as $(\mu_\ell^{2/3})/(\rho_\ell - \rho_m)^{2/3} g^{1/3}$, where μ_ℓ is the liquid viscosity, ρ_ℓ and ρ_m are densities of the liquid and the melt, respectively, g is the gravitational constant, λ_c the latent heat of solid, and ΔT is the temperature difference between the liquid pool and the melt. Λ

has a form similar to the Rayleigh-Taylor wave length for two superimposing, viscous fluids. The correlation is given by the expression

$$Nu \frac{Pr_{\ell}}{Pr_m} = (1.75 \times 10^{-5}) \, Ra^{1.189} \quad .$$

This correlation is sensitive to parameter $\lambda_c \rho_m / \Delta T$ which causes a parallel shift in the curve. It is worth noting that this correlation does not involve any physical dimensions of the test cell.

References

1. R. Farhadieh and L. Baker, Jr., "Experimental Study of the Growth of an Internally Heated Liquid Pool in a Solid Bed," J. of Nuclear Science Engineering, 65, (2), 394 (1978).

2. R. Farhadieh and L. Baker, Jr., "Heat Transfer Phenomenology of a Hydrodynamically Unstable Melting System," J. of Heat Transfer, 100, (2), 305 (1978).

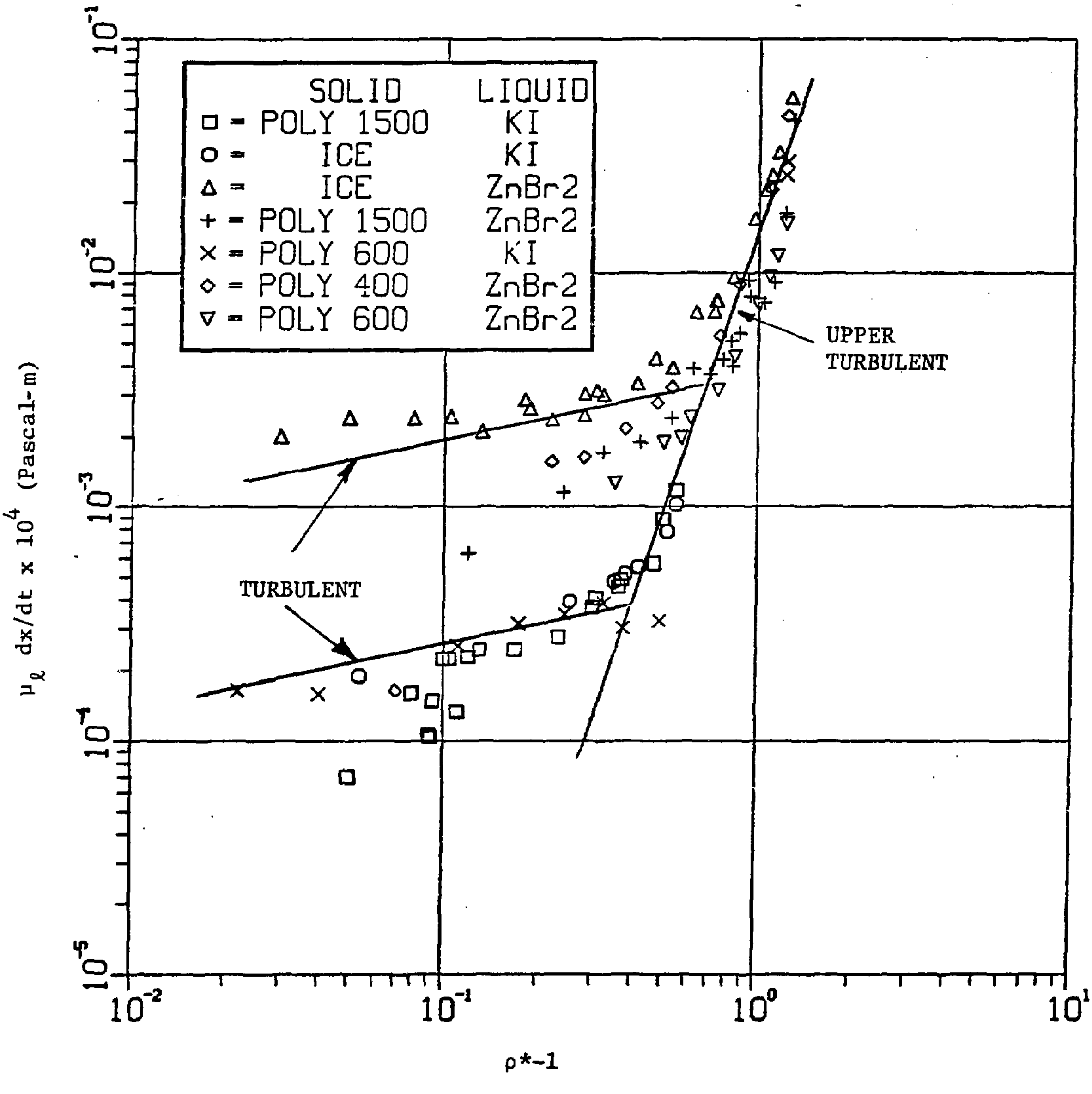

Fig. 1. Product of the Downward Melting Rate and the Upper Fluid Viscosity Versus ρ*-1.

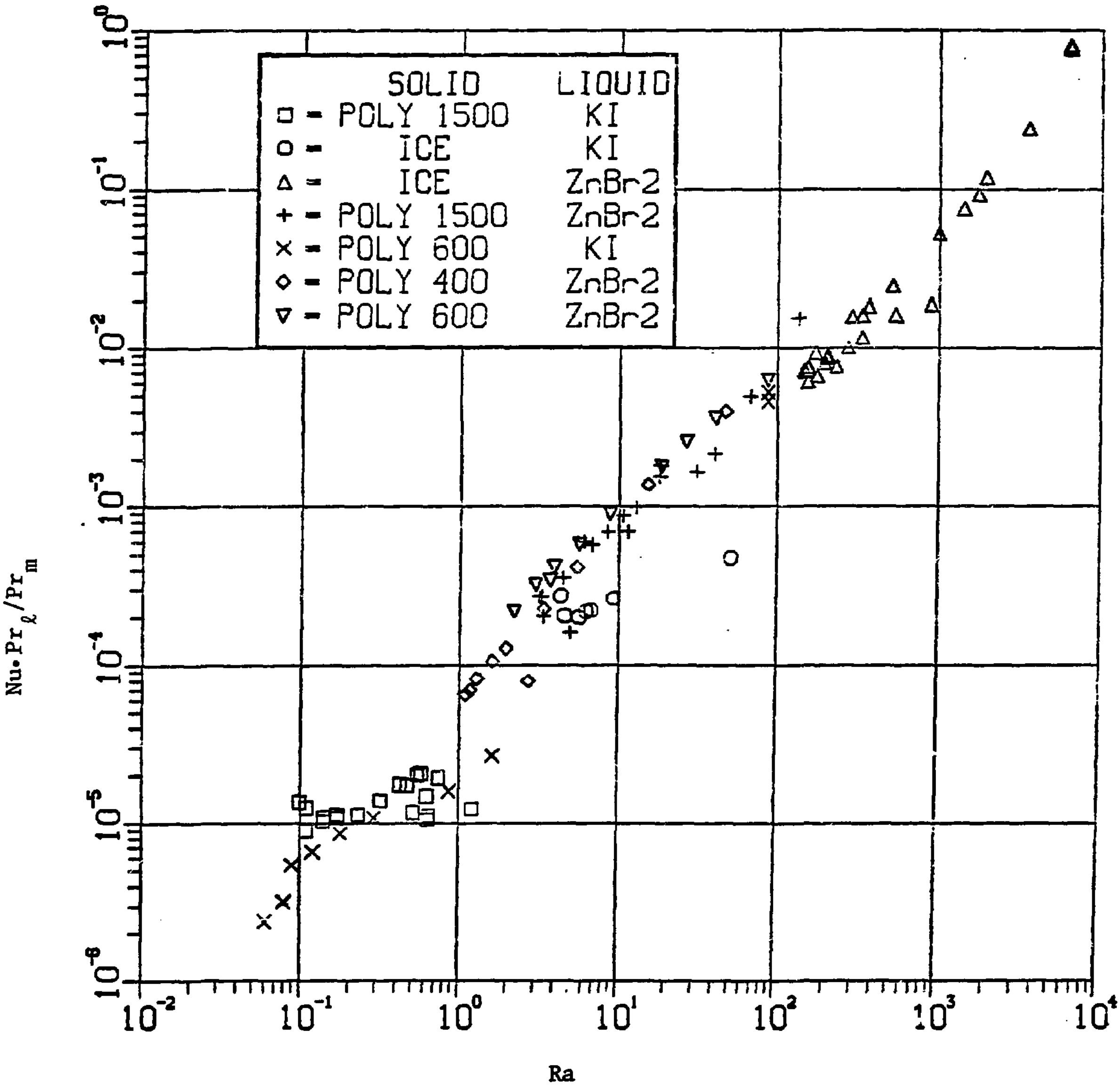

Fig. 2. Product of the Downward Heat Transfer and the Ratio of the Liquid Pool and the Melt Layer Prandtl Number Versus the Melt Rayleigh Number.