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COMPARISON OF MEASURED AND CALCULATED AVERAGE VOID FRACTION IN
VOLUME-BOILING POOLS WITH INCLINED BOUNDARIES*

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COMPARISON OF MEASURED AND CALCULATED AVERAGE VOID FRACTION IN
VOLUME-BOILING POOLS WITH INCLINED BOUNDARIES

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Accident analysis of an HCDA in an LMFBR often involves consideration and calculation of thermal hydraulic events related to boiling pools of fuel and steel mixtures in the disrupted core, as well as the subsequent motion of these two-phase mixtures out of the core. In many cases, the thermal-hydraulic state of the boiling fuel-steel or fuel pool may determine the initial or boundary conditions for subsequent calculations. Calculations of boundary heat losses are directly dependent on knowledge of the local and pool-average void fraction,⁽¹⁾ and assessment of models to predict the average void fraction depends on the availability of these experimental data.

Experiments have been performed to determine the distribution of boundary heat losses from volume-heated boiling pools and the pool-averaged void fraction. The simulant fluid was a 15 percent weight solution of zinc sulfate in water, and the volumetric vaporization source was supplied by joule heating. The average void fraction is defined as

$$\bar{\alpha} = \frac{H_B - H_0}{H_B} \quad (1)$$

where $\bar{\alpha}$ is the average void fraction, H_B is the boiling depth, and H_0 is the static pool depth at the saturation temperature. In these experiments, H_B and H_0 are determined by a traversable voltage transducer which provides an

objective and accurate determination of the fluctuating pool surface.

The net vaporization power corresponding to evaporative and boiling losses is calculated from the net water flow rate necessary to replenish these vapor losses from the pool. This flow rate is determined through a constant level weir to which the gross flow is measured, and the timed overflow is subtracted, yielding the net make-up flow rate. This flow rate corresponds to a gross vaporization power including evaporative and boiling losses and is presented as the dimensionless superficial vapor velocity,

$$j_{g\infty}/U_{\infty} = \frac{\overset{\cdot\cdot\cdot\cdot}{Q}_{BOIL} H_o}{\rho_v h_{fg} U_{\infty}} \quad (2)$$

where $\overset{\cdot\cdot\cdot\cdot}{Q}_{BOIL}$ is the vaporization power (cal/cm³ sec), ρ_v is the vapor density (gm/cm³), h_{fg} is the latent heat of vaporization (cal/gm), and U_{∞} is the terminal rise velocity of a bubble.

The data for the average void fraction as determined from Eq. 1 is shown as a function of $j_{g\infty}/U_{\infty}$ in Figure 1. These data are compared to the results of calculations based upon an existing two-phase flow model previously reported. (1,2) Consider a boiling pool where the vapor source is proportional to the local liquid volume; the vapor mass conservation equation may be written as

$$\frac{dj_g}{dx} = \frac{\overset{\cdot\cdot\cdot\cdot}{Q}_{BOIL}}{\rho_v h_{fg}} (1 - \alpha) = \frac{\Gamma_v}{\rho_v} \quad (3)$$

where Γ_v is the vapor source (gm/cm³ sec) per unit liquid volume. The Zuber-Findlay relationship for the superficial vapor velocity may be written as

$$\frac{\langle j_g \rangle}{\langle \alpha \rangle} = C_o \langle j \rangle + v_{gj} \quad (4)$$

If we assume $\langle j \rangle \sim \langle j_g \rangle$ and $C_o \sim 1.2$, this reduces to

$$j_g = \frac{\alpha v_{gj}}{1 - C_o \alpha} \quad (5)$$

Furthermore, assuming the drift velocity function can be represented as

$v_{gj} = U_\infty (1 - \alpha)^n$, the vapor mass conservation equation becomes

$$\frac{d}{d\xi} \left[\frac{\alpha(1 - \alpha)^n}{1 - C_o \alpha} \right] = K(1 - \alpha) \quad (6)$$

where $n = 2$ for bubbly flow regime and subject to the initial condition $\alpha = 0$

at $\xi = 0$ where $\xi = x/H_o$ and $K = \frac{Q'''_{BOIL} H_o}{\rho_v h_{fg} U_\infty}$. The boundary condition for the integration is based on the experimental observation that initial vapor is formed by surface evaporation without the generation of bulk boiling. For these experiments, the limit of this condition appears to be near $j_{g\infty}/U_\infty)_o$ of 0.2 (Fig. 1). This value appears to be system dependent and a function of free surface area to volume ratio.

The nonlinear ordinary differential equation has been numerically integrated by an Euler predictor-corrector method and a fourth order Runge-Kutta method with good agreement. The average void fraction was calculated for values of $j_{g\infty}^*/U_\infty$ corresponding to the experimental data,

$$\frac{j_{g\infty}^*}{U_\infty} = \left(\frac{j_{g\infty}}{U_\infty} - \frac{j_{g\infty}}{U_\infty} \right)_o \quad (7)$$

The comparison of the measured void fraction at wall angles of 90° , 75° and 60° to the calculations based on a bubbly flow regime and $j_{g\infty}^*/U_\infty$ is

presented in Figure 2.

The following conclusions can be made based on both the experimental observations and model calculations:

- (1) For $j_{g\infty}/U_{\infty} < 1$, the bubbly flow regime persists, in which boiling is not observed to penetrate to the pool bottom, and the pool surface exhibits a periodic swelling nature.
- (2) In the bubbly flow regime, $\bar{\alpha}$ is a sensitive function of the boiling power; small fluctuations in $j_{g\infty}/U_{\infty}$ will cause large changes in $\bar{\alpha}$ as observed. These experiments clearly demonstrate that evaporative losses, $(j_{g\infty}/U_{\infty})_0$, may be important in the bubbly flow regime for pools of surface area to volume ratio characteristic of these experiments, and represent an improvement over previous works which did not take it into account.
- (3) A one-dimensional drift flux model based on bubbly flow and the threshold boiling power predicts the data well for $j_{g\infty}^*/U_{\infty} < 1$. For a boiling UO_2 pool in a CRBR-size core, this corresponds to less than .1 percent full power, indicating that PAHR pools will most likely exceed the bubbly-churn turbulent transition criterion ($j_{g\infty}^*/U_{\infty} < 1$) by a large margin, and churn-turbulent flow may be the dominant flow regime.

References

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2. Ginsberg, T., Jones, O. C., Jr., Schwarz, C. E., and Chen, J. C., "Observations of Flow Characteristics of Volume-Heated Boiling Pools," BNL-NUREG-24270 (December 1977).

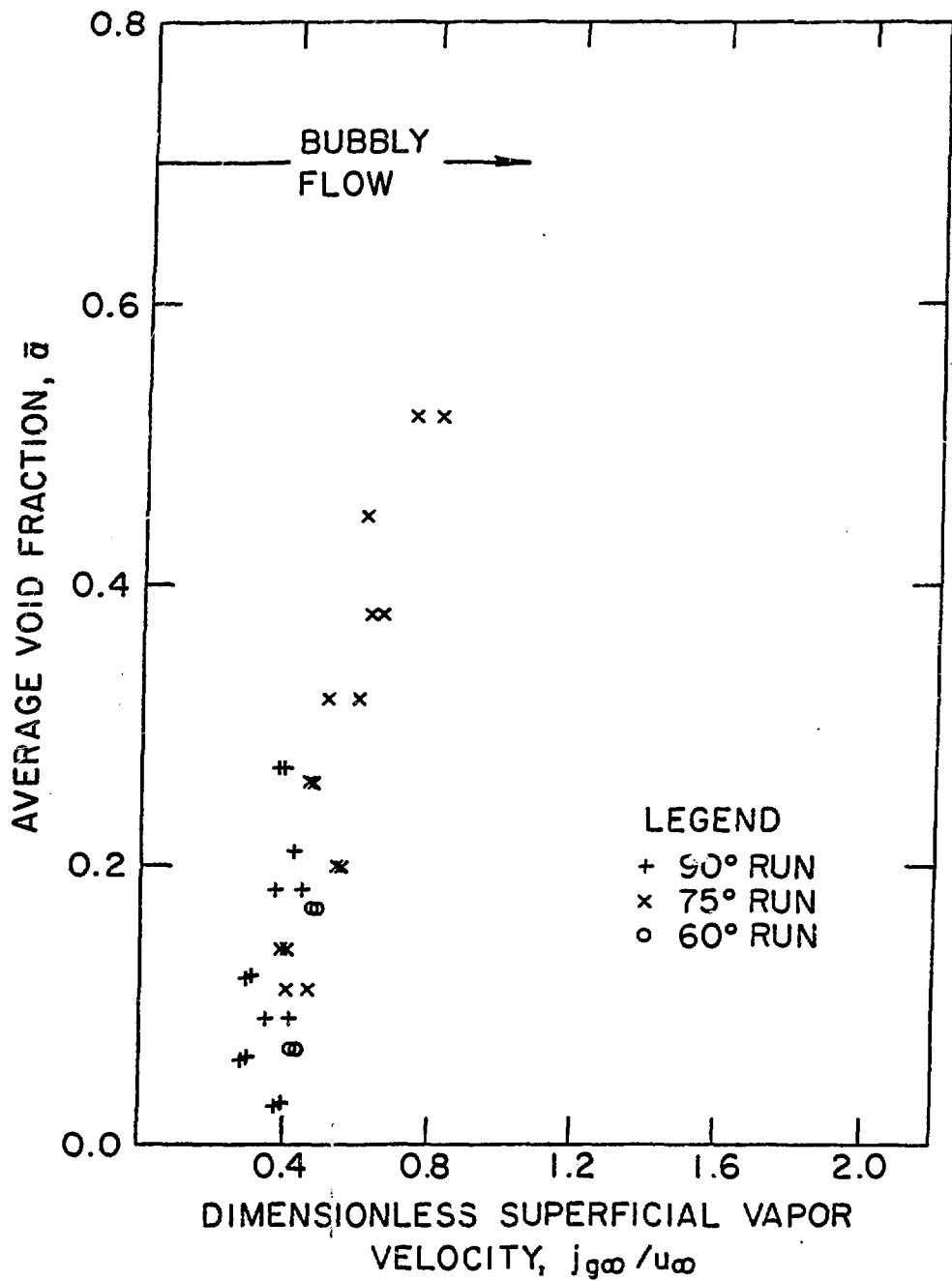


Figure 1 - Average Void Fraction vs. Dimensionless Superficial Vapor Velocity. (BNL Neg. No 1-1296-79).

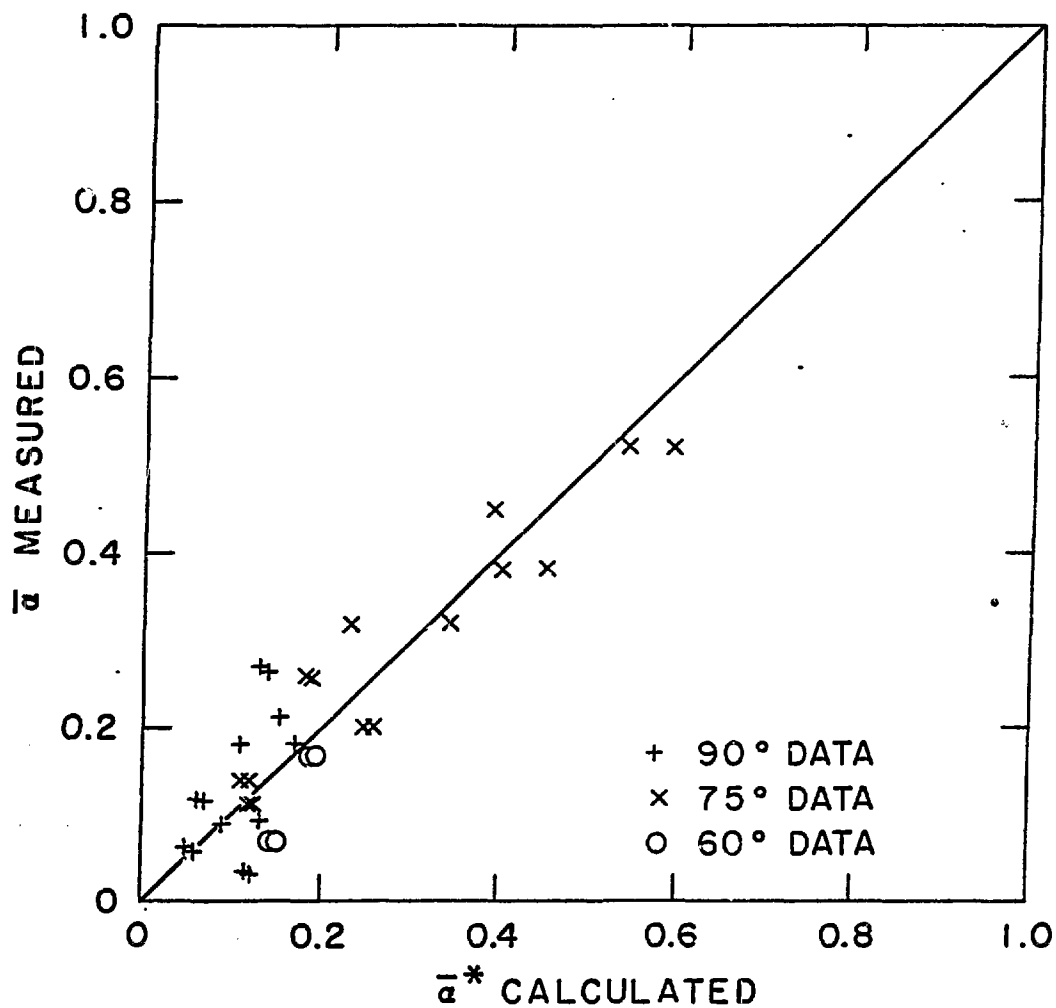


Figure 2 - Comparison of Measured Average Void Fraction to Calculated Average Void Fraction for Bubbly Flow in Volume Boiling Pools. (BNL Neg. No 2-69-79).