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University of Cincinnati
Department of Chemical and Nuclear Engineering

Quarterly Progress Report
Period Ending March 31, 1972
"Investigation of Pressure Drops and
Heat Transfer Coefficients for Loss of
Coolant Evaluations

Report No. C 00-2152-3

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Contract AT(11-1)-2152
Investigation of Pressure Drops
and Heat Transfer Coefficients for
Loss of Coolant Evaluations

Quarterly Report for Period
Jan. 1, 1972 - March 30, 1972

The basic purpose of this contract is the investigation of the pressure drop and heat transfer phenomena of importance during a loss of coolant accident. The study is divided into three major experiments: a) Transient Pressure Drop Investigation; b) Two-Phase Pressure Drop and Flow Pattern Study; c) Transition Boiling and Reflooding Heat Transfer Tests

I Transient Pressure-Drop Investigation

The basic design of this system (described in detail in report(C00-2152-1) allows transient flow conditions to be observed at area changes by rapidly discharging a fluid from a storage accumulator to a receiving accumulator. An order for the apparatus was placed during the last quarter. Actual fabrication was delayed because of late receipt of the accumulators and flow control valve. These items have now been received by the vendor and fabrication is underway. Delivery of the basic apparatus is expected in the next quarter.

Detailed design of the gas supply system and the flow-valve positioner were completed. The flow-valve positioner design will allow operation of the system in three modes: (a) single step transient - flow increased from minimum to maximum value (b) cyclic operation - continuous changes in flow rate at selected frequencies (c) pulse operation - multi-step transients. The valve positioning is accomplished by means of a Scotch-yoke type mechanism attached to a variable-speed motor drive. The positioner is designed to provide single step transient times of 0.05 to 0.5 seconds. Selection of these times were based on the requirement that the transient Δp be significantly different from the steady state Δp at the same flow value.

Calculations have been conducted to establish the conditions at which it is feasible to operate the system. It is expected that the system will be operated using Freon-113 at test section exit pressures varying from 50 to 150 psia. A glass pipe length will be present during low pressure tests to allow visual observations.

II. Two-Phase Pressure Drop and Flow Pattern Study

Experimental Work - These tests are to be conducted in a recirculating test loop using two phase mixtures of Freon 113. During the checkout runs at the end of the last quarter a failure of the pump seal occurred. After some delay, a new seal was obtained, installed and checkout operation with Freon 113 continued. Difficulties were then encountered with the loop power control circuit. These were resolved and two-phase flow operation was begun.

It was observed that void production started at temperatures significantly below the saturation temperatures. It appears that very appreciable quantities of subcooled boiling voids are created. This non-equilibrium state persists even after cooling. Some, voids appear to be present at the cooler exit even though the fluid temperature is substantially below saturation. This non-equilibrium condition makes it difficult to determine the total flow rate since bubbles of vapor accumulate in the lines to the flowmeter causing an erratic reading.

Pressure drop measurements have also been hampered by the presence of vapor in the lines to the D/P cell although diaphragm seals were used to keep vapor out of all vertical lines. It therefore appears that cooling will have to be supplied on the lines to the D/P cell and flowmeter.

Consideration is also being given to a revised void fraction measurement techniques. Both capacitance measurement systems and gamma attenuation techniques are under consideration.

Flow Pattern Analysis

During the previous quarter, the frothy separated flow transition line proposed by Baker⁽¹⁾ was compared with the transition data of Hoogendorn^(2,3). An appreciable disagreement was noted (see fig. 1 of Report No.(C00-2152-2)). Various alternative methods of correlation of this data have therefore been investigated. In fig. 1, a modified Baker approach is used. Instead of plotting G/λ as $L\lambda\psi/G$, we have plotted G/λ vs $(L\lambda)/G$. It may be seen that an appreciably improved correlation is obtained.

Although the modified Baker plot provides a fair representation of the data, there is no theoretical foundation for the procedure used. A procedure having a firmer theoretical base is therefore being sought. One possible approach can be derived from the treatment of solid suspensions. By assuming that suspension occurs when the turbulent velocity fluctuators are great enough to overcome particle settling, Weisman and Efferding⁽⁴⁾ obtained that, in very dilute suspensions, the minimum power for suspension as

$$P_p = \frac{g V_p (\Delta\rho) U_o}{4 g_c} \quad (1)$$

where;

P_p is vertical component of power input to a single particle when suspending and settling forces are equal; ft-lbf/sec.

V_p is volume of individual particle; ft³

$\Delta\rho$ is difference in density of solid and liquid, $\frac{\text{lbm}}{\text{ft}^3}$

U_o is particle settling velocity, ft/sec

After application of semi-empirical correction for concentration and diameter effects, Weisman⁽⁵⁾ was able to correlate the suspension of particles in horizontal pipe lines by

$$\frac{g_c P}{g V (\Delta\rho) U_o} = 0.4 \left(\frac{1-\epsilon}{\epsilon} \right)^{\frac{1}{2}} (D/D_p)^{\frac{1}{2}} \quad (2)$$

Here

P is total input power; ft-lbf/sec.

V is system volume; cu-ft.

$\Delta\rho$ is difference in solid and liquid densities; $\frac{\text{lbm}}{\text{cu.ft.}}$

U_o is settling velocity of particle in infinitely dilute suspension; ft/sec.

ϵ is liquid fraction

D is pipe dia; ft.

D_p is average particle dia, ft.

It was postulated that analogous to slurry transport a minimum power will be required to maintain froth flow and below this minimum power the flow will change to separated flow. Equation (2) was changed to the following form in order to express it in terminology more applicable to gas-liquid flow

$$G_g = \phi x$$

where

$$\phi = \left[\frac{.8 \rho_1^2 D}{Rf} g (\Delta\rho) U_o \left(\frac{\alpha}{1-\alpha} \right)^{1/2} \left(\frac{D}{D_p} \right)^{1/2} \right]^{1/3}$$

Here;

G = mass velocity of gas phase; lbm/sec ft²

ρ_1 = liquid density; $\frac{\text{lbm}}{\text{ft}^3}$

D = diameter of pipe; ft

g = acceleration due to gravity; $\frac{\text{ft}}{\text{sec}^2}$

$\Delta\rho$ = difference in liquid and gas density, $\frac{\text{lbm}}{\text{ft}^3}$

x = quality, dimensionless

U_o = rise velocity of bubbles; ft/sec

α = void fraction

D_p = average diameter of bubbles

R = two phase fraction multiplier factor

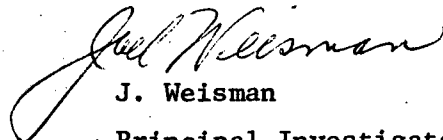
f = friction factor

Bubble rise velocities were computed following the equation suggested by Harmathy⁽⁶⁾ and bubble sizes were predicted using the equation given by Hinze⁽⁷⁾. G and ϕ of equation (3) were then calculated for Hoogendoorn's transition data taking \bar{R} directly from Hoogendoorn's pressure drop data. The results of this calculation are shown in fig. 2. The experimental data appear to cluster around the line derived for solid particle data. The agreement is believed to be quite good considering the nature of the assumption on bubble size and rise velocity. Examination of this approach in greater detail is intended.

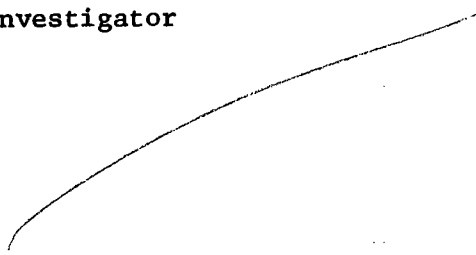
III Transition Boiling and Reflooding Heat Transfer Tests

There tests are to be conducted using a loop in which hot mercury is circulated as a heat source. Boiling occurs in an annulus around a vertical steel pipe containing the mercury.

The major activity this quarter was concerned with completing the construction of the loop. During this quarter the construction of both the water and mercury sides was completed. All electrical work and control wiring has also been completed. Pressure testing of the loop is expected to occur early in the next quarter.


J. Weisman

Principal Investigator



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- (2) Hoogendoorn, C.J. "Gas Liquid Flow in Horizontal Pipes", Chemical Eng. Sci., 9, 205-217 (1959).
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- (5) Weisman, Joel, "Minimum Power Requirements for Slurry Transport", A.I.Ch.E. Journal, 9, 134 (1963).
- (6) Harmathy, T.Z., "Velocity of Large Drops and Bubbles in Media of Infinite or Restricted Extent", A.I.Ch.E. Journal 6, 281 (1960).
- (7) Hinze, J.O., "Fundamentals of the Hydrodynamic Mechanism of Splitting in Dispersion Processes", A.I.Ch.E., Journal 1, 289 (1955).

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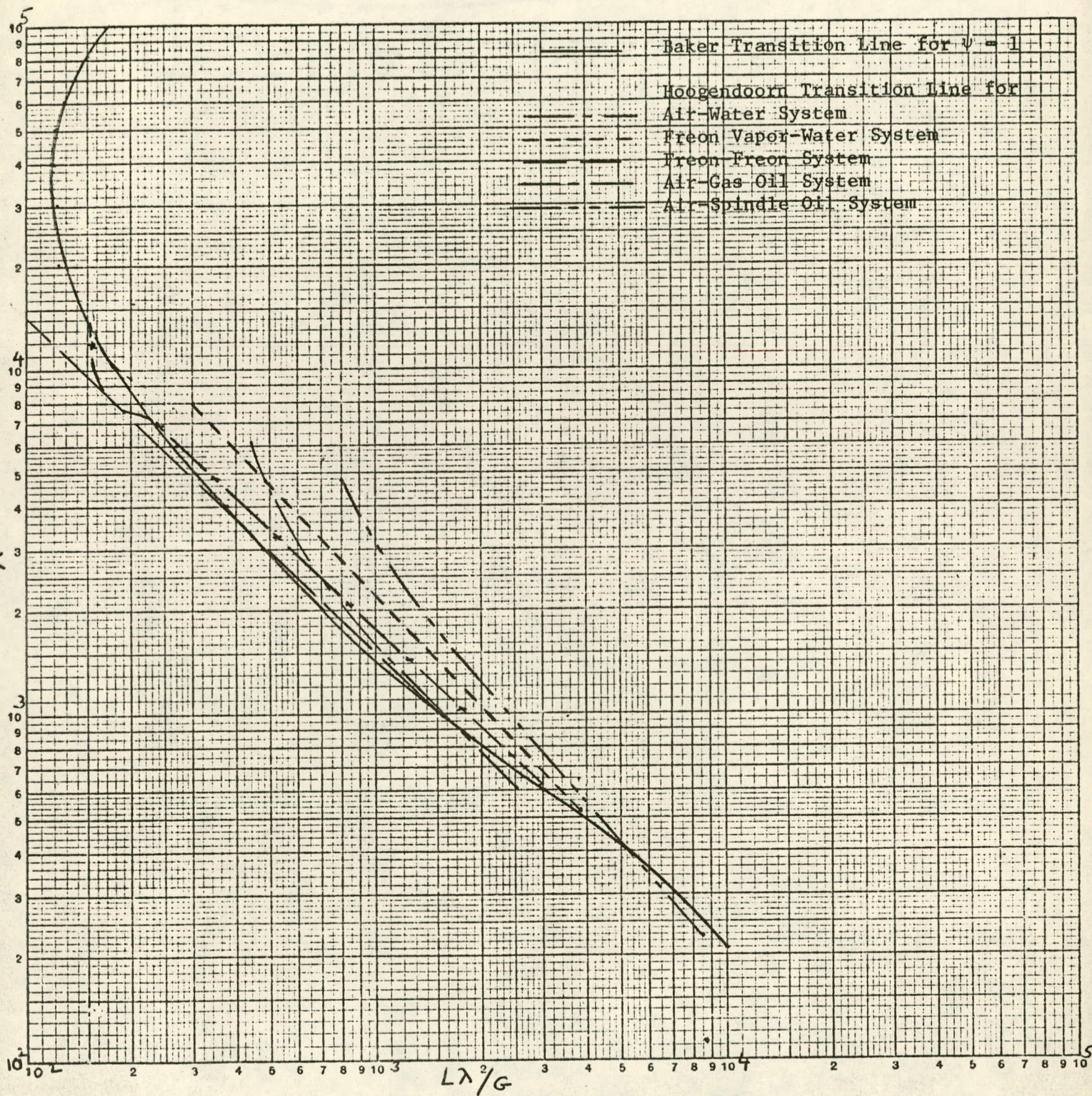


Figure 1: Modified Baker Bubble-Froth Transition Plot Compared with Hoogendoorn's Experimental Results

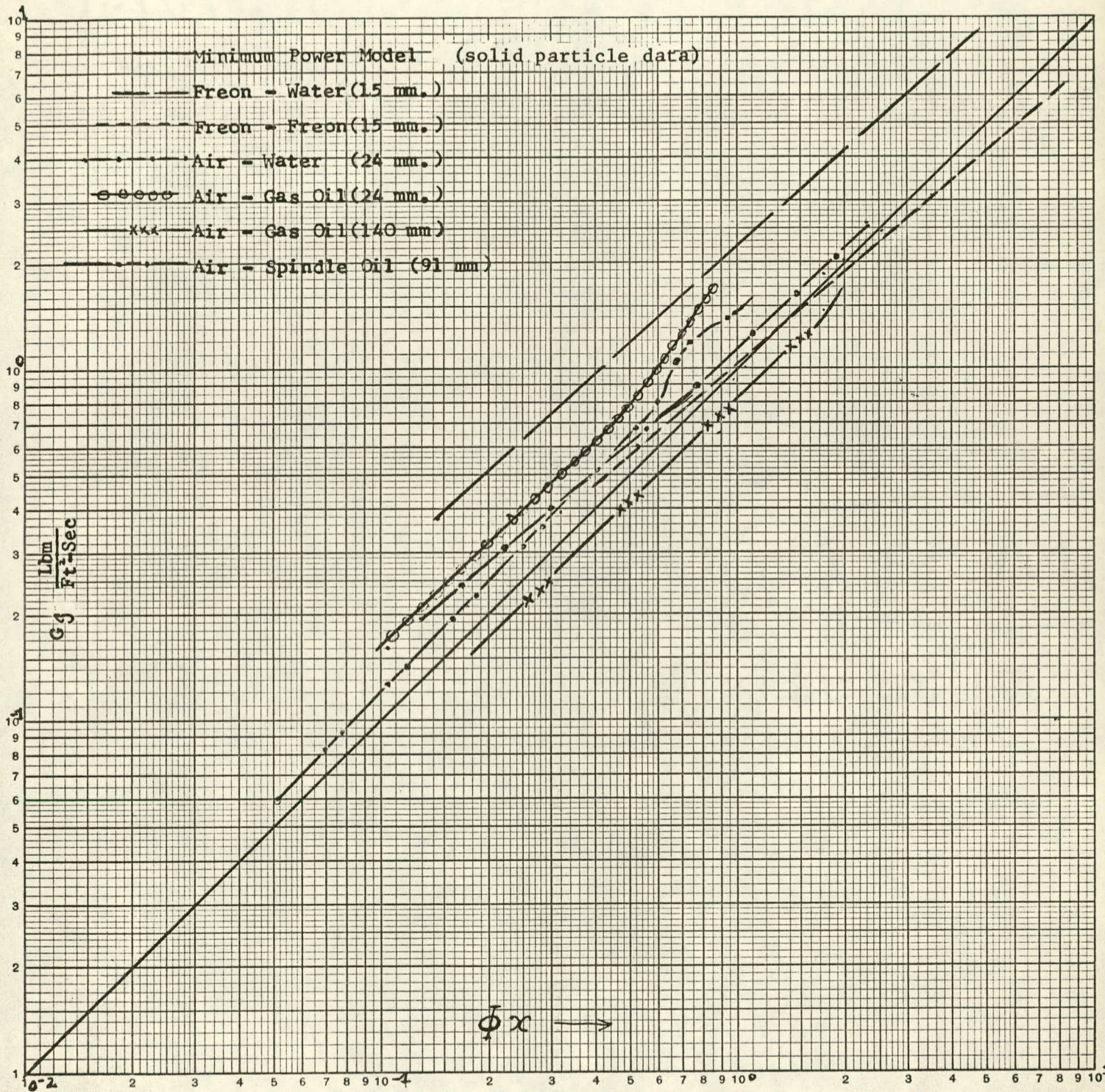


Fig.2: Minimum Power Model Transition line Compared with Hoogendoorn's Experimental Results for Froth Transition.

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