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University of Cincinnati

Department of Chemical and Nuclear Engineering

Quarterly Progress Report

Period Ending

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Investigation of Pressure Drops
and Heat Transfer Coefficients
for Loss of Coolant Evaluations

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Report C00-2152-17

MASTER

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Contract AT(11-1) 2152 "Investigation
of Two-Phase Pressure Drop for Loss
of Coolant Evaluation"

Quarterly Report for Period
January 1, 1975 to March 31, 1975

The objectives of this contract have been the study of pressure drop and heat transfer coefficients of importance during the loss of coolant accident. The study was divided into three experiments.

- a) Transient Pressure Drop Investigation
- b) Two-Phase Pressure Drop and Flow Pattern Study
- c) Transition Boiling and Reflooding Heat Transfer Tests

During the previous quarter, the Reactor Safety Research Division of NRC requested that the work of this contract be redirected towards the study of transient two-phase pressure drop across area changes and fittings under simulated blowdown conditions. Accordingly, the work on transition boiling under this contract has been terminated. This will be the last quarter in which progress under this topic will be reported.

I Transient Pressure Drop Investigation

Previous transient two-phase pressure drop studies were conducted in an oscillatory mode. Heated Freon was discharged from a large accumulator to the test lines. The Freon flashed across a needle valve and then proceeded to a three way valve. There a portion of mixture was directed through a storage accumulator and the remainder directed to the test section. By varying the position of the 3-way valve, a sinusoidally varying flow was obtained.

The oscillatory mode testing has now been terminated. The results of these tests have been compiled and a final technical report is being prepared.

The transient flow apparatus is now being modified to permit simulated blowdown runs. These runs will be conducted with available instrumentation

and equipment. The prime objective of these tests is to determine what changes will be required for the more carefully instrumented runs to follow.

The present piping is being modified to allow simulated blowdown tests. A turbine meter has been installed in the line from the upstream accumulator (before needle valve) to allow direct measurement of the liquid flow rate. The diversion path from the 3-way valve has been removed and all flow will be directed through the test section. The downstream accumulator will act as the blowdown tank for the preliminary runs.

A large (50 ft³) blowdown tank has been designed as a replacement for the downstream accumulator. The tank will allow blowdown runs with less of a variation in downstream pressure than is possible with the small size accumulator now available. Bids have been requested on the tank fabrication.

Design of the carefully instrumented blowdown tests which are to follow the preliminary runs has begun. The first task is the calculation of the expected system behavior.

II Two Phase Pressure Drop and Flow Pattern Study

Topical Reports - A topical report, C00 2152-15, entitled "Two Phase Pressure Drop Across Abrupt Area Changes" has been issued. The report summarizes the pressure drop studies across well separated area changes. The reader's attention is called to two typographical errors in this report.

- 1) Equation (9) on page 32

Equation holds for $\alpha_4 \geq 0.5$

- 2) Equation (9) is repeated in the conclusions given on p. 42. In this version the symbol "A" has been omitted. Equation should read

$$\alpha_3 = \alpha_{\text{slip}} + A (\alpha_{\text{homogeneous}} - \alpha_{\text{slip}}) \text{ for } \alpha_4 \geq 0.5$$

A second topical report C00 2152-16, entitled "Applicability of the Homogeneous Model to Two-Phase Flow" has been completed and will be issued in the next quarter. The report summarizes the results of the previous studies of flow patterns and the relationship of flow patterns to pressure drop.

Steady State Pressure Drop Studies

These experiments, which are conducted in a circulating loop using Freon 113, have measured pressure drop across several area changes. The initial studies were with well separated area changes. In view of data in the literature⁽¹⁾ indicating that behavior of a contraction and expansion in close proximity may not be the same as that for well separated area changes, a series of experiments to determine the effect of the distance between the area changes has been undertaken.

Tests were previously conducted (see C00-2152-13) with a test section having a two inch length between area changes. Revised data for this test section are shown in Fig. 1. It may be seen that these results are well predicted by the previous model for well separated area changes. That is

$$\Delta p = \Delta p_c - \Delta p_e \quad (4)$$

where Δp_c and Δp_e are given by the one dimensional-momentum balance equations (Eq. 1 and 2) shown in Fig. 2, and

a) α_1, α_5 = measured (slip flow) α values

b) α_4 = value of α assuming slip flow but correcting for difference in velocity between small and large flow area

c) $\alpha_3 = \alpha_{\text{homogeneous}}$ for $\alpha \leq 0.5$ (5)

$\alpha_3 = \alpha_{\text{slip}} + A (\alpha_{\text{homogeneous}} - \alpha_{\text{slip}})$ for $\alpha \geq 0.5$ (6)

The quantity A is representative of the degree of mixing at the vena contracta.

Previous tests also included (see C00-2152-14) an examination of a restriction which was only 1/2 in. thick. A revised set of these data are shown in Fig. 3. These data are clearly below the previous curve but are above the curve which is obtained assuming no mixing ($A = 0$) at the vena contracta.

During this quarter, a restriction 0.215 in. thick was tested. The restriction had a diameter of .777 inches and was placed in a pipe having a .991 inch diameter. To analyze the data for this test section it is necessary to recognize that the vena contracta falls beyond the contraction. (See Fluid Meters - Their Theory and Application, p 2, ASME.) The momentum balance given by Equation (3) of Fig. 2 must therefore be used.

The data obtained from the .2 in. thick restriction are shown in Fig. 4. It is seen that these data fall on the line obtained assuming no mixing at the vena contracta ($A = 0$). On the basis of the data from the data obtained in these and previous tests, the variation in the mixing factor, A, with the (length/large pipe Diam.) ratio was computed. These results are shown in Fig. 5. The results obtained are consistent with Janssens' earlier data (Two Phase Δp Across Abrupt Contractions and Expansions, International Heat Transfer Conf., Chicago 1966) which also showed that for very short restrictions no mixing

should be assumed at the vena contracta. The graph also explains why the results of Cermak et al. (Trans. ASME J. Heat Transfer 86, 227 1964) gave higher pressuredrops than Janssen obtained for short restrictions. When considered in terms of the L/D ratio, the data of Cermak et al. would fall in the region where A is 1 or near 1.

To use these results, it is necessary to determine whether the vena contraction falls within or outside the restricted diameter. The appropriate momentum balance equations ((1) and (2) or (3) is then selected). Values of α at all locations other than the vena contracta are then computed via Hughmark's correlation [Chem. Eng. Prog. 58, (4) 62 (1962)]. At the vena contraction Equation (6) is used taking α_{slip} as the value obtained from Highmark's correlation for the vena contracta flow velocity and using the value of A from Fig. 5.

It should be noted that the presently available data are insufficient to determine whether the data shown on Fig. 5 should be plotted in terms of the ratio of L to the diameter of the large pipe (as shown) or to the restriction diameter.

III Transition Boiling and Reflood Heat Transfer Tests

In accordance with the directions obtained, experimental transition boiling studies under this contract have been terminated. The apparatus has been put in standby condition.

The data correlation presented in the previous quarterly report (see C00-2152-14) was compared with data from some FLECHT runs. The FLECHT data used were those points for which density measurements allowed an

estimation of the void fraction to be made. The comparison, as shown in Fig. 6, is seen to be quite reasonable. The FLECHT data tend to be above the correlation and this may be due to axial conduction effects which led to an overestimation of the FLECHT heat flux in the transition boiling region. This effect would not be significant in film boiling which is the region for which the FLECHT data analysis was designed.

Fig1 RATIO OF TWO-PHASE TO SINGLE PHASE
PRESSURE DROP ACROSS A 2 INCH
ABRUPT CONTRACTION-EXPANSION
GEOMETRY

Fig 2 Momentum Balance Models

$$(1) \quad \Delta P_E = \frac{G_F^2 v_F}{2g_c v^2} \left[\frac{v_G}{v_F} x^2 \hat{\alpha} \left\{ \frac{1}{\alpha_4^2} - \frac{v^2}{\alpha_5^2} \right\} \right. \\ \left. + (1-x)^2 (1-\hat{\alpha}) \left\{ \frac{1}{(1-\alpha_4)^2} - \frac{v^2}{(1-\alpha_5)^2} \right\} \right. \\ \left. - 2v \left\{ \frac{v_G}{v_F} x^2 \left(\frac{1}{\alpha_4} - \frac{v}{\alpha_5} \right) + (1-x)^2 \left(\frac{1}{1-\alpha_4} - \frac{v}{1-\alpha_5} \right) \right\} \right]$$

$$(2) \quad \Delta P_C = \frac{G_F^2 v_F}{2g_c v^2} \frac{1}{C^2} \left[\frac{v_G}{v_F} x^2 \hat{\alpha} \left\{ \frac{1}{\alpha_3^2} - \frac{C^2}{\alpha_4^2} \right\} \right. \\ \left. + (1-x)^2 (1-\hat{\alpha}) \left\{ \frac{1}{(1-\alpha_3)^2} - \frac{C^2}{(1-\alpha_4)^2} \right\} \right. \\ \left. - 2C \left\{ \frac{v_G}{v_F} x^2 \left(\frac{1}{\alpha_3} - \frac{C}{\alpha_4} \right) + (1-x)^2 \left(\frac{1}{1-\alpha_3} - \frac{C}{1-\alpha_4} \right) \right\} \right]$$

$$3) \quad \Delta P_L = \frac{G_F^2 v_F}{2g_c v^2} \frac{1}{C^2} \left[\frac{v_G}{v_F} x^2 \hat{\alpha} \left\{ \frac{1}{\alpha_3^2} - \frac{v^2 C^2}{\alpha_5^2} \right\} + (1-x)^2 (1-\hat{\alpha}) \left\{ \frac{1}{(1-\alpha_3)^2} - \frac{v^2 C^2}{(1-\alpha_5)^2} \right\} \right. \\ \left. - 2Cv \left\{ \frac{v_G}{v_F} x^2 \left(\frac{1}{\alpha_3} - \frac{vC}{\alpha_5} \right) + (1-x)^2 \left(\frac{1}{1-\alpha_3} - \frac{vC}{1-\alpha_5} \right) \right\} \right]$$

Fig3 RATIO OF TWO-PHASE TO SINGLE PHASE
PRESSURE DROP ACROSS A .505 INCH
ABRUPT CONTRACTION - EXPANSION
GEOMETRY

Fig 4 RATIO OF TWO-PHASE TO SINGLE PHASE
PRESSURE DROP ACROSS A .215 INCH
ABRUPT CONTRACTION-EXPANSION
GEOMETRY

	SYSTEM PRESSURE PSIG	MASS FLOW lb/HR FT ²
Δ	40	1.9×10^6
○	40	2.3×10^6
▲	60	1.9×10^6
●	60	2.3×10^6
■	60	2.8×10^6
△	25	1.9×10^6

Fig 5 MIXING FACTOR (A)
VS
LENGTH/PIPE DIAMETER

Fig 6 Comparison of FLECHT Data With Transition Boiling Heat Transfer Correlation