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"Investigation of Pressure Drops and
Heat Transfer Coefficients for
Loss of Coolant Evaluation"

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MASTER

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

Quarterly Report for Period
Oct. 1, 1973 to Dec. 30, 1973

The objective of this contract is the study of pressure drop and heat transfer phenomena of importance during a loss of coolant accident. The study is 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.

I. Transient Pressure Drop Investigation

The transient pressure drop apparatus operates by discharging heated Freon 113 from a large storage accumulator to the test lines. The Freon flashes across a needle valve and proceeds to a 3-way valve. There a portion of the two-phase mixture is directed to a storage accumulator and the remainder is directed through the test section. By appropriately varying the position of the 3-way valve, a sinusoidally varying flow is obtained.

In the previous quarter, test data in the range of 0-30% void was reported for two abrupt area change test sections. These had area ratios of .09 and .35 respectively. These data were compared with predictions from one-dimensional momentum theory coupled with the assumption of homogeneous flow. The comparison indicated that the data across the contraction was reasonably well explained but that the data across the expansion-contraction combination was not well explained.

During this quarter, additional data were obtained across test section #2 (area ratio = .35). The range of the data was extended to void

fractions in excess of 60% for operation at $\omega 1.25$ cps. These data, and that previously obtained, are shown in Figs. 1 and 2. The same general trends as observed previously still appear. However, the disagreement between the observed and predicted phase shift (shift between pressure and flow curves) is considerably reduced at the higher void fractions.

In all runs made to date, the void fraction was estimated by using the average volumetric flow indicated by the turbine flowmeter and assuming homogeneous flow. The latter assumption is questionable and another void fraction indication is desirable. A capacitance type voidmeter, of the design used in the steady-state Freon loop, is therefore being constructed. It will be installed in the transient apparatus during the next quarter.

II. Two Phase Pressure Drop and Flow Pattern Study

Experimental: These experiments, which are being conducted in a recirculating loop using Freon 113, have measured two-phase pressure drop across abrupt area changes. In this study, void fraction measurements have been made using a capacitance type voidmeter. It has been assumed that the capacitance varied linearly with void fraction. This assumption was indicated to be correct by tests in which the voidmeter was immersed to various levels in a Freon pool. To determine whether this linear behavior held under more typical conditions, a second test was conducted following a procedure by GE. Here the voidmeter was placed in a stream of Freon-Freon vapor which was flowing very slowly. The void fraction was determined by computing density from the pressure drop reading across a section of vertical line. Since the frictional Δp is negligible, the measured Δp allows ready computation of the mixture density. The density so computed and that obtained from the voidmeter appear to be the same within

the error limits of the measurements.

The voidmeter used in the above tests is being installed in the boiling Freon loop. This second voidmeter will allow void fraction measurements to be taken both before and after the test section.

Analysis of Expansion Data

The literature data on 2 phase pressure drops across abrupt expansions have been carefully reviewed. The approach followed has been essentially the same as that taken in the previously reported analysis of the contraction data⁽¹⁾. From a force momentum balance⁽²⁾, one obtains

$$\Delta p = \frac{G_1^2}{\rho_f g_c} \left[\frac{\rho_f}{\rho_g} x^2 \left(\frac{1}{\alpha_1 \sigma} - \frac{1}{\alpha_2} \right) + (1 - x)^2 \left(\frac{1}{\sigma(1 - \alpha_1)} - \frac{1}{\alpha_2} \right) \right]$$

where G_1 = mass velocity in small diameter line, lb m/ft²hr

ρ_f = liquid density, lb m/ft³

ρ_g = vapor density, lb m/ft³

α_1 = void fraction in small diameter line

α_2 = void fraction in large diameter line

σ = area ratio

x = mixture quality

To evaluate α_1 and α_2 three models were considered.

Model E - No slip at any point (homogeneous flow)

Model F - Slip at section 1 and 2 correspond to that for straight pipe flow

Model G - No slip after expansion (due to possible mixing after area change) but slip corresponding to that in straight pipe flow prior to expansion.

Figs. 3, 4 and 5 compare the data of Ferrell and McGee⁽³⁾, Janssen and Kervinen⁽²⁾ and Mendler⁽⁴⁾ to these models. It is clear that model F is the best of the three and it is therefore recommended.

Reconsideration of Abrupt Contraction Data

In the previous quarterly, it was found that the homogeneous model provided the best data fit of all the contraction models which were examined. However, the homogeneous model makes little sense from a phenomenological viewpoint. Examination of high speed photographs clearly show that the flow is generally not homogeneous at reasonable distances upstream and downstream. Observation of the vena contracta region indicate mixing in this region. A model based on slip flow away from the expansion and mixing at the vena contracta would seem most plausible.

It was previously observed that the model based on complete mixing at the vena contracta performed well at low α but predicted too high a pressure drop at high α . This suggests a model in which the degree of mixing at the vena contracta depends on the void fraction. It was therefore assumed that the void fraction at the vena contracta, α_{vc} , was intermediate between that computed for homogeneous flow, α_h , and that for slip flow, α_s . That is

$$\alpha_{vc} = \alpha_s + (\alpha_h - \alpha_s) \cdot A$$

where A is a function of α_s (α_s being evaluated in small line). By appropriate choice of A, a very good correlation of the data is obtained. Fig.6 shows the correlation obtained assuming

$$A = 1.0 \quad \text{for } \alpha_s < 60\%$$

$$A = 1.0 - 1.25 (\alpha_s - .6) \quad \alpha_s > 60\%$$

The correlation coefficient for this model is slightly better than that obtained with the homogeneous model. More important, this model would appear to be more in accord with actual conditions.

Transition Boiling and Reflooding Heat Transfer Tests

Experimental - These experiments are being conducted in a heat transfer loop using hot mercury as the heat source. Boiling of water takes place in a vertical glass annulus around the mercury pipe.

It was reported last quarter that the flow indication system was not functioning properly. A new system has been adopted and the loop was successfully operated. A limited set of data has been obtained in the transition boiling regime. The data was at low ΔT (up to 45 °F) and at a flow of $G = 5.0 \times 10^4$ lbm/hr.ft². Attempts to go to a higher range of ΔT and G were foiled by the failure of an 'O' ring seal on a flange on the mercury pipe. This resulted in a substantial Hg leak and shut down of the loop. The flange has now been seal-welded.

Further delays were encountered because of breakage during installation of the thermocouples measuring mercury temperature. A new set of thermocouples has been obtained and installed.

Data Analysis

Additional transition boiling data has been collected from the literature. Fig. 7 compares the data of Bailey⁽⁵⁾ and Peterson et al⁽⁶⁾ with

the correlation reported in the last quarterly report of this series (COO-2152-9). The agreement appears to be reasonable. However, the data of Peterson et al⁽⁶⁾ show behavior which differs from the FLECHT data when examined on a plot of q'' vs. ΔT_{sat} .

In Fig. 8 some of the FLECHT data⁽⁷⁾ at low pressures are plotted in terms of q'' vs. ΔT_{sat} . It is seen that all of this data shows a peak q'' at a ΔT_{sat} of about 150 °F. The data of Ellion⁽⁸⁾ behave similarly. The data of Peterson et al⁽⁶⁾ show a peak q'' at substantially lower values of ΔT_{sat} . (See Fig.9) The value of ΔT_{sat} at which the peak q'' occurs seems to depend on flow rate here. The data obtained in the present investigation, which was obtained at a substantially lower G than that used by Peterson et al, would seem to be showing similar behavior. The reason for the difference in system behavior requires further examination.

REFERENCES

- (1) U.C. Quarterly Progress Report for Period Ending Sept. 1973, COO-2152-9.
- (2) Janssen, E. and Kervinen, J. A., GEAP-4622 (May 1964).
- (3) Ferrell, J.K. And J.W. McGee, TID-2339-Vol. 3 (1966).
- (4) Mendler, O., Ph.D. Dissertation, Univ. of Pittsburgh (1963).
- (5) Bailey, N.A., "The interactions of droplet deposition and forced convection in post-dryout heat transfer at high subcritical pressure", AEEW-R 807, UKAEA. (1973)
- (6) Peterson, W.C., M.M. Aboul Fetouh and M.G. Zaalouk, "Boiling curve measurements from a controlled forced convection process," Proceedings of British Nuclear Eng. Society Meeting.
- (7) FLECHT Group I Test Report, WCAP-7435 (1970).
- (8) Ellion, M.E., Ph.D. Thesis, Cal. Tech., (1954).

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Fig. 1. Comparison of Predicted and Observed Phase Shift for Combined Expansion-Contraction.

Fig. 2 - Comparison of Predicted and Observed Phase Shift for Contraction

Fig. 5 Comparison of ΔP_E Measured with ΔP_E Predicted by all Homogeneous Model (Model #E).

Fig 4 Comparison of ΔP_E measured with respect to ΔP_E predicted by all ship model (Model F.)

Fig. 5 Comparison of Measured Pressure rise in Expansion with Predicted Pressure rise by Model G. (slip in small pipe but Hom in big pipe)

Expected $\Delta P_c \rightarrow$ PSF

● Ferrel
○ Janssen
* Geiger
△ Present data

45°

+35%

-35%

Measured $\Delta P_c \rightarrow$
(PSF)

Fig 6 Comparison of Pressure Drops Across Abrupt Contraction With Final Model

FIG. 7 COMPARISON OF SOME NEW DATA
 WITH PREDICTION.

FIG. 8 LOW PRESSURE DATA FROM FLECHT AND ELLION AS q'' Vs. ΔT_{SAT} .

FIG. 9. COMPARISON OF PETERSON'S DATA WITH U.C. DATA AS q'' VS. T_{WALL} .