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GEAP-4863
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MAY 1965

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**TWO-PHASE FLOW AND
HEAT TRANSFER
IN MULTIROD GEOMETRIES**

**SECOND QUARTERLY PROGRESS REPORT
JANUARY 26, 1965
- APRIL 25, 1965**

APPROVED FOR PUBLIC RELEASE

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-189
PROJECT AGREEMENT 44

ATOMIC POWER EQUIPMENT DEPARTMENT

GENERAL ELECTRIC

SAN JOSE, CALIFORNIA

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IN MULTIROD GEOMETRIES

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JANUARY 26, 1965 - APRIL 25, 1965

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U. S. ATOMIC ENERGY COMMISSION
Contract AT (04-3) - 189
Project Agreement 44

*Printed in U.S.A. Available from the
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National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia
Price: \$2.00 per copy*

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2381-TIO-2
85-AG-5/65

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ACKNOWLEDGMENTS

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SUMMARY

An annular test section apparatus for air-water flow structure measurements is in operation. Single-phase and two-phase pressure drop data, operating both as a simple round tube and as a concentric annulus, agree with well-known correlations. The inlet mixing device appears to provide fully developed two-phase flow in the test section. Thus, this apparatus is suitable for meaningful detailed flow structure measurements.

Instrumentation development continues. Difficulty in obtaining true isokinetic flow sampling has been encountered. Five probe designs have been tested. A direct wall shear measurement instrument model has been designed and tested.

SECTION I

INTRODUCTION

This is the second quarterly report on the work done under Contract AT (04-3)-189, Project Agreement No. 44, and covers the period from January 26, 1965, to April 25, 1965.

The objectives for the program are as follows.

Task A

1. Obtain detailed measurements of flow structure (pressure drop, liquid film thickness, wall shear stress, local mass flux, local impact pressure) for air-water and steam-water mixtures. Three series of tests are to be performed:
  - a. Air-water mixtures in a vertical annulus,
  - b. Air-water mixtures in a vertical nine-rod assembly, and
  - c. Steam-water mixtures at high pressure (600 to 1400 psia) in a vertical nine-rod assembly.
2. Carry on an analytical effort in parallel with the air-water tests. It is hoped that a two-phase flow model will be developed as a result of this effort, which will prove useful in predicting two-phase flow behavior in other systems.

Task B

1. Measure the critical heat flux for a vertical nine-rod geometry, under forced convection conditions, with water at high pressure (600 to 1400 psia) and flow upward. Tests will be performed with
  - a. "Clean" multirod geometry (as little disturbance as possible to the flow by the provisions for maintaining the rods in correct relative alignment), and
  - b. Spacers typical of current reactor practice added to the multirod geometry.
2. Apply model developed in Task A to the prediction of critical heat flux.

Shakedown tests of the annular air-water apparatus were conducted, a data-reduction computer code was written, and instrument development continued (Task A).

No work was scheduled on Task B for this quarter.

A report on the progress during the second quarter follows.

SECTION II

EQUIPMENT

Task A

The test apparatus for the annular air-water flow investigations is operational (see Figures 1 and 2). The annular test section consists of a vertical, 12-foot-long, 1-inch-i.d. round tube, with a 1/2-inch-diameter concentric center rod. The test section may also be used as a straight round tube by removing the center rod. The flow is once-through, with the water supplied by a feedwater pump (which is isolated from city water pressure by an isolation tank) and the air supplied from a portable air compressor. System pressure can be varied from 1 to 6 atmospheres. A special inlet device places inlet water on the walls of the tube and rod, and the air in the center gap.

Quality is determined by separate measurement of the inlet water flow rate (by a calibrated orifice), and the inlet air flow rate (by a rotometer). Average void fraction in the central 10 feet of test section may be determined by isolation of flow samples with quick closing valves. Accurate pressure drop data may be obtained with seven water-purged pressure taps (connected to U-tube manometers) along the test section.

Five different isokinetic probes have been designed and built (Figure 3). A traversing mechanism has been built for accurate probe placement at any radial position within the test section (Figure 4).

Other equipment necessary for Task A has not yet been procured.

Figure 1. Annular Test Section Apparatus

Figure 2. Air-Water Annular Test Tower Line Diagram

PROBE NO. 2 $d = 0.020$ in.

PROBE NO. 3 $d = 0.031$ in.

PROBE NO. 4 $d = 0.031$ in.

PROBE NO. 5 - INSTALLED IN
TRAVERSING DEVICE - $d = 0.0595$ in.

Figure 3. Various Isokinetic Probe Designs, with Diameters of Sample Tube Noted

Figure 4. Probe Traversing Mechanism on Annular Test Section

SECTION III

RESULTS AND DISCUSSION

Pressure drop data for water flowing alone in the round tube geometry are shown in Figure 5 as friction factor versus Reynolds number based on hydraulic diameter. The data show excellent (± 4 percent scatter) agreement with the Blasius correlation for smooth tubes. These shakedown data show that the apparatus provides well-behaved flow, and that the pressure drop instrumentation is working.

Air-alone and water-alone data taken in the annular geometry are also shown in Figure 5. The water data are about 6 percent higher than the round-tube data correlation. This 6 percent difference does not appear to be caused by roughness effect since the data show the same slope on $\log f$, $\log Re$ coordinates as the tube data. The difference is probably due to basic uncertainty, or due to the inadequacy of the hydraulic diameter concept to account for the geometry difference.

The air-alone annulus geometry friction factor data do not show good agreement with the correlation; additional data will be taken.

Preliminary two-phase pressure drop data for the round-tube geometry show good agreement with the Lockhart-Martinelli* correlation (Figure 6), considering the scatter in the original data upon which that correlation is based.

A true isokinetic sampling probe does not change the pre-existing conditions at the inlet of the probe. The static pressure at the probe inlet should, therefore, be the same as it was with no probe in place, or the same as the static pressure far from the probe (at the same cross section). For the probe sizes required by the present study (see Figure 3), measurement of the static pressure at the sample probe inlet is difficult. Actual measurements must be made inside the sample tube, and the setting of true isokinetic conditions is complicated by the unknown pressure drop between the probe inlet and the pressure tap. Figure 7 illustrates typical sample probe behavior for single-phase flow. The data reveal that when the static pressure inside the sample tube (P_s) is equal to the freestream static pressure (P_∞), isokinetic conditions are not attained. For the typical example shown, the mass velocity by sampling when $P_s = P_\infty$ is 20 percent lower than that determined by impact pressure or from known total flow rate. The best probe design (No. 4) reduces this discrepancy to -10 percent. It appears that this effect is an inherent characteristic of these probes, and that an inlet pressure drop correction factor will

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*R. W. Lockhart and R. C. Martinelli, "Proposed Correlation of Data for Isothermal Two-Phase, Two-Component Flow in Pipes", Chem. Eng. Progr., Vol. 45, No. 1.

Figure 5. Friction Factor Versus Reynolds Number - Single Phase

Figure 6. Comparison of APED Round Tube Data with Lockhart-Martinelli Correlation

have to be applied in order to attain true isokinetic sampling. In this regard, the probe characteristic predicted by the laminar flow solution in the inlet of a tube is also shown in Figure 7. This solution appears to overcompensate for the inlet pressure drop. Work is continuing on this instrumentation problem.

Figure 7. Typical Isokinetic Probe Behavior

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