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**TWO-PHASE FLOW
AND HEAT TRANSFER
IN MULTIROD GEOMETRIES
THIRTEENTH
QUARTERLY PROGRESS REPORT
OCTOBER 1 - DECEMBER 31, 1968**

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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TWO-PHASE FLOW AND HEAT TRANSFER
IN MULTIROD GEOMETRIES

THIRTEENTH QUARTERLY PROGRESS REPORT

October 1—December 31, 1968

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SUMMARY

Task C

The nine-rod test section which was built specially for subchannel and flow structure measurements is described. Results of measurements of the velocity profile at inlet to test length are given. On the basis of these measurements, the honeycomb flow straighteners initially installed ahead of the channel inlet were removed.

SECTION I

INTRODUCTION

This is the thirteenth quarterly report on the work done under Contract AT(04-3)-189, Project Agreement No. 44, and covers the period from October 1 to December 31, 1968.

The objectives for Phase 1 of the program were 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.
2. Carry on an analytical effort in parallel with the air-water tests.

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 are to 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).
2. Investigate the effect of certain parameters; specifically, quality, flow rate, heated length, pressure, and rod-wall spacing.
3. Use the results to evaluate one or more computer models as a basis for CHF prediction.

The work under Phase 1 has been reported in Quarterly Reports Nos. 1 through 10, plus certain topical reports and "Final Summary" reports, either issued or to be issued soon.

The objectives for Phase 2 are as follows.

Task C

1. Make measurements of both fully-developed and developing two-phase flow (steam-water at 600 to 1400 psia, adiabatic and with heat addition, flow vertical upward) from which can be determined rates of mass and energy transfer in the transverse direction, such measurements to be made in a circular tube, eccentric annulus, and nine-rod channel.
2. Determine the relationships between rate and driving potential, or potential gradient, and the effect of certain parameters (e.g., total flow, pressure, local void) on these relationships. In particular, determine the effect of grid-type spacers in the nine-rod channel.
3. Analyze the results to evaluate existing models of two-phase flow. Endeavor to develop an improved model in light of the results. Such a model should be useful in the prediction of flow structure, pressure drop, and critical heat flux in developing two-phase flow in multirod geometries, both "clean" and with grid-type spacers.

Task D.

1. Measure critical heat flux in a nine-rod channel fitted with grid-type spacers characteristic of modern water-cooled reactors.
2. Determine, if possible, whether, and to what degree, the effect of spacers on the CHF is caused by a redistribution of the flow among the various subchannels, or by a highly localized disturbance which might, for example, disrupt the liquid film.
3. Modify the prediction methods developed in Task C as appropriate, and check them against the data obtained under Item 1.

Subchannel analysis has become an important part of current knowledge of two-phase flow in complex channels.* Improvements in subchannel analysis depend upon experimental measurements of subchannel flow and enthalpy, from which can be deduced information concerning cross flow and mixing. Such measurements are consistent with the objectives for Task C. Therefore, the scope of Task C has been modified to include measurements of total subchannel flow and enthalpy in a nine-rod channel. The nine-rod test section which was built for this purpose during the current reporting period is described, and the results of measuring single-phase velocity distribution at test length inlet are given in the following sections.

*E. Janssen, "Nine-Rod Critical Heat Flux Investigation, Steam-Water at 600 to 1400 psia, Final Summary Report," GEAP-5616, April 1968.

SECTION II

DESCRIPTION OF NINE-ROD
TEST SECTION

The test section described here was built specially for subchannel and flow structure measurements. The salient geometrical features are:

Number of Rods	Nine (3 × 3 array)
Rod Diameter	0.570 inch
Radius of Channel Corner	0.400 inch
Rod-Rod Clearance	0.168 inch
Rod-Wall Clearance	0.135 inch
Hydraulic Diameter	0.474 inch
Test Length	120 inches

The rods are of a new type developed by GE. Each rod is clad with a nickel tube insulated from the electrical heater element so that the exterior of the rod may be at ground potential, thereby eliminating any shorting problems. The rods pass out the bottom end of the test section through water-cooled O-ring glands, to permit differential expansion and access to electrical power leads. The power supplied is three phase.

Tests can be run with all nine rods heated, or alternately with only six or only three of the nine rods heated. Each of the nine rods has uniform axial heat flux. Different sets of rods can be used so that the heated length may occur over the last 3 feet of the 10-foot test length, over the last 6 feet of the test length, or over the first 6 feet of the test length—the last 4 feet in this case being unheated.

A sectional view of the test section is shown in Figure 1. Subcooled water enters the channel at the bottom. A mixture of steam and water, generally at a bulk flow quality greater than zero, leaves the channel

at the top. Rod-rod and rod-wall clearances are maintained in the "clean" channel configuration* by means of 1/8-inch-diameter stainless steel pins. Each pin is cut to length corresponding to the clearance to be maintained, then lightly fusion-welded ("zapped"), and finally secured by silver soldering into place on one of the two surfaces. A set of pins is installed at each of several positions along the channel located on 12-inch centers so that the last set is located 10 inches before the top end of the test length.

As an alternate to the pins, a series of grid-type spacers may be used, which are the same as the spacers actually used in reactors except for the smaller number of rods.

Provision is made for bringing static pressure lines out through glands in a blind flange located at the same elevation as the inlet flange (Figure 2). These are for measuring static pressure drop along the channel and for setting the isokinetic condition for subchannel measurements. The lines, shown in Figure 2, are running horizontally from the blind flange to "seal pots." It is the static pressures in the seal pots which are actually measured, by means of transducers (Figure 3).

To measure the flow in any given subchannel, that subchannel must be isolated at some point from the rest of the channel. The subchannel flow (also referred to as sample flow, see Figure 3) can then be taken through

*In the "clean" channel, the means of holding the rods in their correct positions is intended to produce as little disturbance to the flow as possible.

FIGURE 1. NINE-ROD TEST SECTION FOR SUBCHANNEL AND FLOW STRUCTURE MEASUREMENTS

FIGURE 2. NINE-ROD TEST SECTION INSTALLED IN HEAT TRANSFER LOOP

FIGURE 3. SCHEMATIC OF LOOP SHOWING SAMPLING CIRCUIT

special ducting to another point outside the test section, where both the rate and energy content (enthalpy) can be measured. Figure 1 shows typical provisions for Subchannel No. 1. Thin (0.010 inch thick) pieces of metal sheet (flow splitters) are installed just past the end of the test length to separate Subchannel No. 1 from its neighbors. Similar sheets are used for Subchannels Nos. 2 and 3, but the flow for only one subchannel at a time is measured. The splitters, plus continuous segments of rod and channel wall, form a box into which the subchannel flow enters and from which it leaves at the top end via a tube (Figure 1). The tube passes out through the top closure flange, and from there to a heat

exchanger (calorimeter), as shown in Figures 3 and 4.

The subchannel flow rate is set by adjusting the sample valve, shown in Figure 3, until the difference between the static pressure just inside the box formed by the splitters and the static pressure outside the box at the same axial position is equal to the value which it has when no subchannel measurements are being made. This difference is generally zero, or very close to it. The flow rate thus set is taken to be the "isokinetic" flow rate, i. e., the flow rate that would exist in the same subchannel if the splitters were not there.

FIGURE 4. TOP END OF NINE-ROD TEST SECTION INSTALLED IN HEAT TRANSFER LOOP.

Afterheater is in the line between discharge tee outlet and steam drum (not visible in this view). It is used when exit conditions are subcooled. The discharge tee, top closure flange, and sample line are ordinarily thoroughly insulated. Insulation was removed for this photo, to show detail more plainly.

SECTION III

SINGLE-PHASE VELOCITY DISTRIBUTION
AT INLET TO TEST LENGTH

An effort was made to have relatively uniform velocity distribution, or at least symmetrical distribution, at the inlet to the test length. Thus, for example, the velocities at the centers of the four interior subchannels should be equal, or very nearly so. Honeycomb-type flow straighteners were installed just before the channel inlet (see Figure 1) to help bring this about.

Four velocity rakes were initially installed just ahead of the inlet to the test length, to get some measure of the velocity distribution. Two typical rakes are shown in Figure 5. It is recognized that the rakes themselves can affect the flow pattern by reducing the net flow area at their location. However, the rakes were intentionally designed to be symmetrical so that if the flow were disturbed, it would be disturbed in a symmetrical way. If the flow is initially symmetrical, it should continue to be symmetrical; on the other hand, if it is asymmetrical, some degree of asymmetry should remain.

The locations of the points at which the velocities were measured are shown in Figure 6. Half the points lie on a line down one row, and the other half lie on a similar line down the other row, between the rods. One check of symmetry is that the velocities in one row should be the same in magnitude as the velocities in the other row. The other check is that the velocity profile in each row should itself be symmetrical.

The velocity distribution was measured under cold, single-phase flow conditions, at channel Reynolds numbers of approximately 15,000 and 30,000. (Under test conditions,

the Reynolds number at test length inlet will vary from 40,000 to 250,000. However, this higher Reynolds number should not materially change the relative velocity distribution determined by the cold tests.) The velocity distribution was measured with the honeycomb flow straighteners in place, and with the flow straighteners removed. The results are plotted in Figures 7 and 8, respectively.

Referring to Figure 7, the two velocity profiles at the lower flow are within 15% of each other except for one point, and at the higher flow are within 20% of each other except for one point. One of the profiles (points 1 to 7) at the lower flow has a fair degree of symmetry. The other profiles are poor in this regard. But perhaps the most significant thing about the profiles of Figure 7 is that they show the highest velocities next to the channel wall, and relatively low velocities in the interior subchannels. This is the reverse of what would be the case for developed single-phase flow and indicates that the honeycomb straighteners are delaying the development of the flow ahead of the test length inlet.

Figure 8 shows the velocity profiles after the honeycombs were removed. The two profiles are within 10% of each other at both of the flows except for one point, and all four profiles show a fair degree of symmetry. Moreover, they show the highest velocities in the interior subchannels, indicating that the flow is approaching its fully developed state.

All subsequent testing will be done with both the honeycombs and the velocity rakes removed for the channel inlet.

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SHEET OF TWO SHEETS	

FCF: 731E406

② DIFFERENT PLUG
OMIT P4
OTHERWISE
SAME AS G1

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FIGURE 5. PITOT RAKE

FIGURE 6. LOCATION OF POINTS AT WHICH VELOCITIES WERE MEASURED

FIGURE 7. VELOCITY PROFILES WITH HONEYCOMB FLOW STRAIGHTENERS IN PLACE

FIGURE 8. VELOCITY PROFILES WITHOUT HONEYCOMB FLOW STRAIGHTENERS

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