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MASTER

TRANSITION BOILING HEAT TRANSFER PROGRAM

NINTH QUARTERLY PROGRESS REPORT JANUARY - MARCH 1965

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ATOMIC POWER EQUIPMENT DEPARTMENT

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JANUARY - MARCH 1965

E. P. Quinn

Prepared For The
U. S. ATOMIC ENERGY COMMISSION

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Project Agreement 34

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PREFACE

The United States and the European Atomic Energy Community (Euratom), on May 29, and June 18, 1958, signed an agreement which provides a basis for cooperation in programs for the advancement of the peaceful applications of atomic energy. This agreement, in part, provides for the establishment of a Joint U. S. -Euratom research and development program which is aimed at reactors to be constructed in Europe under the Joint Program.

The work described in this report represents the Joint U. S. -Euratom effort which is in keeping with the spirit of cooperation in contributing to the common good by the sharing of scientific and technical information and minimizing the duplication of effort by the limited pool of technical talent available in western Europe and the United States.

SUMMARY

Satisfactory operation of the stroboscopic lighting system has been obtained in photographic trial tests.

Observational tests were started, using the new loop configuration. Measurements indicate a low two-phase flow disturbance level similar to that obtained with non-visual tests. High-speed motion pictures, now under examination, were obtained with steady lighting.

Planning and organization of equipment for forthcoming heat transfer tests with induced flow oscillations have been completed. An adjustable solenoid valve will be used to vary the subcooled inlet flow, and a turbine-meter will be used to measure the flow variations.

OBJECTIVES

The objectives of the program are to obtain measurements, motion photographs, and analyses of:

1. The critical heat flux,
2. The transient surface temperature characteristics associated with the transition boiling regime,
3. The convection heat transfer coefficient in stable film boiling, and
4. The effect of geometrical devices on minimizing transition boiling temperature fluctuations and increasing film boiling heat transfer coefficients.

The following range of conditions pertinent to reactor design will be explored: 600, 1000, and 1400 psia pressures, 0.5×10^6 to 1.5×10^6 lb/h-ft² mass velocities, and 0.20 to 0.60 steam qualities.

PROGRAM TASK BREAKDOWN

Task A - Simulated Fuel Geometry Tests

1. Optimize configurational devices to minimize temperature fluctuations, and improve film boiling heat transfer in tests using a one-rod assembly.
2. Conduct tests of optimum devices on a multirod assembly, and obtain additional smooth-wall multirod data to determine the influence of variations in geometry and of more than two rods on transition boiling. A long-term performance test will be run.
3. Obtain film boiling coefficients for long, upstream, dry-wall lengths.

Task B - Effect of Loop Characteristics on Transition Boiling

1. Conduct tests, and use available technology to eliminate flow disturbances in the test loop by appropriate modifications.
2. Obtain test data using the modified loop over the range of existing data for comparison and evaluation of the effect of flow disturbance parameters on temperature fluctuations.
3. Introduce flow disturbances of known magnitude and frequency, and measure the effect on transition temperature behavior.

Task C - Observational Study of Transition Boiling

1. Obtain additional and improved high-speed motion pictures of transition boiling fluid behavior over a wider range of conditions and geometries. Included will be the behavior between two heated surfaces, the fluid flow over configurational devices, and the use of microscopic as well as macroscopic fields of view.
2. Develop analyses of the heat transfer mechanism, based on interpretation of the motion pictures.

Task D - Reactor Transient Thermal Properties Simulation

Perform tests with rods of different heat capacity. Determine the effect of heat capacity on the magnitude of temperature oscillations. Interpret this result in terms of the distribution of heat generation and clad temperature variation of typical fuel rods.

Task E - Program Coordination

Plan, organize, review, and integrate work carried out under each task, to assure satisfaction of Program objectives.

TECHNICAL PROGRESS

Task A-2 - Multirod Tests (E. P. Quinn)

Fabrication of a new three-rod assembly described in the last quarterly Report (GEAP-4769) has started. Initial test data will be obtained in the next quarter.

Task A-3 - Fully-Developed Film Boiling (T. Sorlie)

Film boiling coefficients measured to date have shown a decrease in magnitude as the upstream dry wall length increased. The measured value of the coefficient tends toward a value independent of length, that was only approached in the previous tests. Knowledge of the asymptotic coefficient values is required for interpretation of space-dependent results and for maximum wall temperature design applications. Initial planning has been started to measure fully-developed coefficients with a special test configuration.

Task B - Effect of Loop Characteristics on Transition Boiling (G. Gaudiosi*)

Induced Flow Oscillation Tests

The objective of this phase of Task B is to investigate the effect of the forced flow disturbances of known amplitude and frequency on transition boiling temperature fluctuations. It is expected that the flow disturbances will increase the size of the transition boiling region and the magnitude of wall temperature oscillations in a manner similar to that noted for natural two-phase hydraulic disturbances. The additional flow control and measurements available in these tests will be helpful in understanding this behavior.

A new set of tests has been planned to measure the relative magnitude and phase relation between the heat transfer behavior in the transition boiling region, and the induced flow oscillations.

The flow oscillations will be induced by the periodic operation of a solenoid valve (normally closed) located on a bypass line across the main flow control valve (see Figure 1). An adjustable timer will operate the valve (fully open and closed) in the frequency range of 0.1 to 2.0 cps. The amplitude of flow oscillations will be controlled by a globe valve, connected in series to the solenoid valve on the new bypass.

A turbine flowmeter, at the test section inlet, will be used to record the flow oscillations.

Two high-pressure (one high-temperature and another low-temperature) solenoid valves have been purchased. All components for the loop modification and test section have been ordered.

*Euratom participant.

Figure 1. Flow Loop for Transition Boiling Forced-Flow Oscillation Tests

The first high subcooling test series has been scheduled for the end of April. The tests will be performed over the following loop parameter range:

Pressure	1000 psi
Mass Velocity	0.5, 1.0, 1.5×10^6 lb/ft ² -h
Inlet Subcooling	150 to 300° F
Approximate Exit Quality	20 to 50 percent
Flow Oscillation Amplitude	0, 7, 15 percent
Flow Oscillation Frequency	0, 0.1, 0.7, 2 cps

Task C-1 - Observational Transition Boiling Tests (C. L. Swan)

Test Equipment

All modifications were completed for the operation of the observational test section in the new loop configuration. The test section is attached directly to the top of a preheat section.

The test element is a single rod with a heated length of 27 feet. The end of the heated length is positioned in the observational windows, and is instrumented to record rod temperatures of the observed rod area.

Figure 2 shows the installed test section, together with the Hycam high-speed camera and strobe lamp holder.

Photographic Results

Results from photographic trials and heat transfer tests are shown in Figure 3. Both color and black-and-white photographs were taken. These reproductions have been selected from the black-and-white negatives. The color films show a more detailed fluid behavior than the black-and-white photos.

Photo 3(a) shows the test view photographed with tungsten illumination and the Fastax movie camera. The test section was installed in the old loop. The photograph shows smearing of the fluid image due to a relatively long exposure duration (80 microseconds) and low camera resolution.

Photos (d), (e), and (f) were taken in the old loop with the synchronized strobe and Hycam movie camera. Illumination from the single strobe lamp was directed on the rod surface and flow channel. The clarity of the flow pattern characteristics shows the distinct improvements obtained by the short exposure duration of the strobe lamp, and increased resolution of the camera.

Figure 2. Observational Test Section

(a)

(b)

(c)

(d)

(e)

(f)

Figure 3. Selected Frames Showing Two-Phase Flow and a Smooth Heater Rod

Photos (b) and (c) were taken from the heat transfer tests performed in the new loop. Loop conditions were 1000 psia, 1×10^6 lb/h-ft², 24 percent exit quality.

The selected frames were taken in the transition boiling region with incandescent illumination directed on one side of the rod surface. The transition boiling and flow measurements obtained during this test show characteristics of the observational test section in the new loop position to be similar to the results reported previously for Task A. These film frames show the fluid behavior near the rod surface during transition boiling. Detailed examination of both the black-and-white and color films is in progress. Temporary malfunctioning of the strobe illumination did not permit satisfactory exposures during these test runs. Photographic heat transfer tests in color and black-and-white are currently in progress on a smooth-wall test rod. Test conditions will parallel those previously reported for Task A.

Task D - Reactor Transient Thermal Properties Simulation (Unassigned)

The work on this task will begin later in the Program.

PROGRAM REPORTS ISSUED

EURAEC-640/GEAP-4228, Quarterly Report No. 1, February-March 1963.

EURAEC-751/GEAP-4307, Quarterly Report No. 2, April-June 1963.

EURAEC-840/GEAP-4390, Quarterly Report No. 3, July-September 1963.

EURAEC-940/GEAP-4487, Quarterly Report No. 4, October-December 1963.

EURAEC-1035/GEAP-4608, Quarterly Report No. 5, January-March 1964.

EURAEC-1141/GEAP-4646, Quarterly Report No. 6, April-June 1964.

EURAEC-1244/GEAP-4727, Quarterly Report No. 7, July-September 1964.

EURAEC-1300/GEAP-4769 Quarterly Report No. 8, October-December 1964.

EURAEC-1083/GEAP-4492, "Transition and Film Boiling Data at 600, 1000, and 1400 psia in Forced Circulation Heat Transfer to Water," J. E. Hench.

EURAEC-1258/GEAP-4636, "Visual Observations of Fluid Behavior in High-Pressure Transition Boiling Flows," E. P. Quinn, C. L. Swan.

EURAEC-1262/GEAP-4721, "Multirod Transition and Film Boiling in Forced Convection to Water at 1000 psia," J. E. Hench.

REPORTS TO BE ISSUED

EURAEC-____/GEAP-4785, "Experimental Results on the Dependence of Transition Boiling Heat Transfer on Loop Flow Disturbances," G. Gaudiosi.

EURAEC-____/GEAP-4786, "Single Rod, Forced Flow, Transition Boiling Heat Transfer from Smooth and Finned Surfaces," E. P. Quinn.

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