T H E U N I V E R S I T Y O F M I C H I G A N

COLLEGE OF ENGINEERING
Department of Mechanical Engineering
Heat Transfer and Thermodynamics Laboratory

Fourth and Fifth Quarterly Progress Reports
For the Period April 1, 1962, to October 1, 1962

LOW HEAT-FLUX BOILING

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ORA Project 04653

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ABSTRACT

This report describes progress made in the construction of an experimental system to study boiling of water from the outer surface of tubes at low values of heat flux (from 5,000 to 100,000 Btu/hr ft^2) and pressures up to 2,000 psia for both natural and forced convection. All major system components have been installed. As of October 1, 1962, the system was ready for cleaning and preliminary tests.

I. INTRODUCTION

This report combines the fourth and fifth quarterly progress reports of research completed under Contract No. AT(38-1)-260 at the U. S. Atomic Energy Commission, Savannah River Operations Office. It covers the period April 1, 1962, to October 1, 1962.

The first three quarterly reports[1,2,3] are cited in the list of references. These earlier report included design details of experimental apparatus, a statement of the initial fabrication progress, and a comprehensive literature survey pertaining to nucleate boiling heat transfer and heat transfer in two-phase flow. The literature survey will be extended in a later report to cover recent references.

This report is concerned with the progress made in the construction of the experimental apparatus, the design of which was reported previously. All major components were received and installed on the laboratory floor. Interconnecting piping was completed. The entire system was completed to the point of cleaning and testing.

II. EXPERIMENTAL APPARATUS

A. GENERAL

The schematic arrangement and general description of the experimental equipment have been described previously.[3] The equipment consists of a test vessel into which may be inserted either a vertical or horizontal test section, consisting of a heated tube 3/4-in. O.D. by 0.049-in. wall. The tube is heated electrically by direct current resistance heating caused by a current which passes axially through the tube. The tube material will be carbon steel, Monel, and Inconel with commercial finish.

The system is designed to permit pool boiling or forced-convection boiling in the range 500 psia to 2000 psia. The primary area of interest centers on low heat-flux boiling in the range of 5,000 to 100,000 Btu/hr ft^2.

In order to maintain specified conditions of pressure, water purity and flow velocity, auxiliary apparatus such as a condenser and pressure control valve, ion exchange bed and circulating pumps are required. The construction of these various components will be described in detail in the following sections.

B. TEST VESSEL

The fabrication, hydrostatic test, delivery, and erection of the test vessel were completed during the period covered by this report. The vessel was completely designed by the staff members of the Heat Transfer and Thermodynamics Laboratory. It was fabricated on a fixed-price basis by the Taylor Engineering Corporation, Detroit, Michigan. The entire vessel is made of Type 347 stainless steel, of wall thicknesses as specified by the ASME Pressure Vessel Code, Section VIII. The design conditions were 2000 psig and 650°F.

Upon completion of fabrication the vessel was subjected to a hydrostatic test pressure of 4000 psig to meet the ASME requirements and determine tightness of all joints. The sight glass openings were sealed with steel plugs during this test. The test was satisfactory as attested by the Form U-1, Manufacturers' Data Report for Unfired Pressure Vessels, (Fig. 1). Representatives of the Laboratory as well as the certifying insurance inspector witnessed the test.

The test vessel was cleaned by sand blasting and washing after the proof test at the factory. It was delivered to the Laboratory on July 30, 1962. It was placed on the supporting framework which positions it over a 4-ft-

TAYLOR *Engineering Corporation*

PIPE FABRICATORS

6500 EPWORTH BLVD. • TYler 8-6232 • DETROIT 10, MICHIGAN

FORM U-1 MANUFACTURERS' DATA REPORT FOR UNFIRED PRESSURE VESSELS

1. Manufactured by TAYLOR ENGINEERING CORPORATION (Name and address of Manufacturer)

2. Manufactured for UNIVERSITY OF MICHIGAN (Name and address of Purchaser)

3. Type Vert. (Horiz. or Vert.) Kind Tank (Tank, Jacketed, Heat Exch.) Vessel No. (AGL 3940) (2577) (Mfrs' Serial) (~~State & State No.~~) Nat'l Bd. No. ...... Year Built 1962

Items 4-9 incl. to be completed for single wall vessels (such as air tanks), jackets of jacketed vessels, or shells of heat exchangers.

4. SHELL: Material A312 T347 (Kind and Spec. No.) T.S. 89,000 (Flg. or F.B. & lowest T.S.) Nominal Thickness 1 in. Corrosion Allowance – in. Diam. 1 ft. 3/4 in. Length 3 ft. 2 in.

5. SEAMS: Long 3'-2" Butt (Welded, Dbl., Single, Lap, Butt) S.R. No (Yes or No) X.R. Comp (Spot or Compl.) Sectioned No (Yes or No) Efficiency 100 %

 Girth 12 3/4 OD S.R. NO X.R. NO Sectioned NO No. of Courses ~~1~~

 [If riveted describe seams fully on reverse side of form]

6. HEADS: (a) Material T347 Forgings T.S. ---------- (b) Material T347 Forging T.S. ----------

Location (Top, bottom, ends)	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a) TOP	4"	Flat	–	–	–	–	–	--
(b) BOTTOM	4"	Flat	–	–	–	–	–	--

If removable, bolts used NO (Material, Spec. No., T.S., Size, Number) Other fastening NO (Describe or Attach Sketch)

7. STAYBOLTS: ...... (Material) If hollow ...... (Size of Hole) Attachment ...... (Threaded, Welded) Pitch ...... (Horiz.) × ...... (Vert.) Diam. ...... (Nominal)

8. JACKET CLOSURE: ...... (Describe as ogee & weld, bar, etc. If bar give dimensions, if bolted, describe or sketch.)

9. Constructed for {Int. / ~~Ext.~~} pressure of 2,000 psi. Max. Temp. 650 °F. Subzero ...... °F. Hydrostatic Test 4,000 psi.

Items 10 and 11 to be completed for tube sections.

10. TUBE SHEETS: Stationary. Material ...... (Kind & Spec. No.) Diam. ...... in. (Subject to pressure) Thickness ... in. Attachment ...... (Welded, Bolted)

 Floating. Material ...... Diam. ...... in. Thickness ... in. Attachment ......

11. TUBES: Material ...... (Kind & Spec. No.) O.D. ...... in. Thickness ...... inches or gage. Number ...... Type ...... (Straight or U)

Items 12-15 incl. to be completed for inner chambers of jacketed vessels, or channels of heat exchangers.

12. SHELL: Material ...... (Kind and Spec. No.) T.S. ...... (Flg. or F.B. & Lowest T.S.) Nominal Thickness ... in. Corrosion Allowance ... in. Diam. ... ft. ... in. Length ... ft. ... in.

13. SEAMS: Long ...... (Welded, Dbl., Single, Lap, Butt) S.R. ...... (Yes or No) X.R. ...... (Spot or Compl.) Sectioned ...... (Yes or No) Efficiency ...... %

 Girth ...... S.R. ...... X.R. ...... Sectioned ...... No. of courses ......

 [If riveted describe seams fully on reverse side of form]

14. Heads (a) Material ...... T.S. ...... (b) Material ...... T.S. ...... (c) Material ...... T.S. ......

Location	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a) Top, bottom, ends								
(b) Channel								
(c) Floating								

If removable, bolts used (a) ...... (Material, Spec. No., T.S., Size, Number) (b) ......

(c) ...... Other fastening ...... (Describe or attach sketch)

15. Constructed for {Int. / Ext.} pressure of ...... psi. Max. Temp. ...... °F. Subzero ...... °F. Hydrostatic Test ...... psi.

Fig. 1. Form U-1, Manufacturers' Data Report for Unfired Pressure Vessels.

Items below to be completed for all vessels where applicable.

16. SAFETY VALVE OUTLETS: Number........ Size........ Location........

17. NOZZLES:

Purpose (Inlet, Outlet, Drain)	Number	Diam or Size	Type	Material	Thickness	Reinforcement Material	How Attached
Inlet	1	3"	Beveled End	A312T347	.300	--	Welded
Outlet	1	4"	Beveled End	A312T347	.337	--	Welded

18. INSPECTION OPENINGS: Manholes, No. NO Size........ Location........
Handholes, No. 2 Size 6" Location Side of vessel
Threaded, No. 10 Size 3/4" & 1/2" Location Sode of vessel

19. SUPPORTS: Skirt NO (Yes or No) Lugs 2 (Number) Legs NO (Number) Other NO (Describe) Attached........ (Where & How)

20. REMARKS: High pressure water test vessel reactor
(Brief description of purpose of the vessel, as Air Tank, After Cooler, Jacketed Cooler, etc. State contents of each part.)

We certify that the statements made in this report are correct and that all details of material, construction, and workmanship of this unfired pressure vessel conform to the ASME Code for Unfired Pressure Vessels.

Date July 14 19 62 Signed TAYLOR ENGINEERING CORP. (Manufacturer) By [signature] Chas. F. Kalvelage

Certificate of Authorization Expires 12/31/64

CERTIFICATE OF SHOP INSPECTION

Inspection Agency's Serial No. AGL 3940

VESSEL MADE BY Taylor Eng. Corp. at Detroit Mich.

I, the undersigned, holding a Certificate of Competency as an Inspector of Boilers and Unfired Pressure Vessels in THE STATE OF...... and employed by Zurich Amer. Ins. Co. of Detroit, inspected internally and externally, the vessel described in this report on 7/14/ 19 62, and certify that the statements made in this report are correct corresponding with mill test reports of materials furnished by the builders, and measurements made of the vessel and that this vessel is constructed in accordance with the ASME Code for Unfired Pressure Vessels.

Date 10/8/ 19 62

[signature] Inspector's Signature Commissions Mich 213 State or Nat'l Bd. & Number

CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a Certificate of Competency as an Inspector of Boilers and Unfired Pressure Vessels in THE STATE OF...... and employed by........ of........, have compared the statements in this manufacturer's data report with the completed vessel, and certify that parts referred to as data items........ were completed in the field in accordance with the requirements of the ASME Code for Unfired Pressure Vessels. The completed vessel was inspected and subjected to a hydrostatic test of........ psi.

Date........ 19......

.... Inspector's Signature Commissions........ State or Nat'l Bd. & Number

Fig. 1. (Concluded).

square hole in the floor. This hole permits the long vertical test section to be removed by withdrawing it downward into the laboratory below.

C. TEST SECTION

As described in a previous report,[3] the test section consists of a 6-in. length of 3/4-in. O.D. tubing, with an 18 gage 0.049-in. wall thickness. The tube materials will be Monel, Inconel, and carbon steel. Because one of the purposes of this research is to obtain data which may be applied readily to heat exchanger design for large scale nuclear reactors, the tube size and tube materials are those which may be considered for large scale heat exchangers.

In accordance with the above concept, the tubes for test sections were ordered to heat exchanger specifications. Four lots of tubing were ordered and received during the period discussed. The pertinent data for these tubes are presented in Table I. In addition to obtaining finished tubing, lengths of the billets or thick shells from which the tubes had been drawn were also obtained. These samples of bulk material will be used to make thermal conductivity tests of the metals during the next quarter. Precise knowledge of the thermal conductivity is required before the outside surface temperature of the tube can be accurately predicted from measurement of the inside surface temperature.

The thermometric calibration of the test section will be performed as described in Section III of this report. The test section will be pressure tested before installation in the test vessel. The pressure test apparatus was designed and fabricated during the period covered.

D. PRIMARY FLOW LOOP

The primary flow loop consists of a 4-in., schedule 80 stainless steel pipe leading from the side of the test vessel to a Melrath canned rotor pump, and 3-in. piping, orifice plate, control valve and line heater assembly which returns the flow to the test vessel. The pump is rated at 140-gpm flow against a 40-ft head.

The Melrath pump was received during this period and mounted on a flexible dual-pump baseplate assembly with the AEC furnished Chempump. The dual-pump assembly was incorporated into the primary loop piping at the shops of Taylor Engineering Corporation. The entire assembly was prefabricated and hydrostatically tested in the shop at 4000 psig on July 14, 1962. The piping was then cleaned and shipped to the Laboratory.

In the Laboratory, the piping and dual-pump assembly of the primary flow loop were assembled on spring supports and joined to the test vessel by field welds in the 4-in. suction line and in the 3-in. discharge line. Each of

TABLE I

TEST SECTION TUBE MATERIALS

Sample Designation	A	B	C	D
Material	Monel	Inconel	Monel	Carbon Steel
ASTM Specifications	B-163	B-167-58T	B-165-58T	A-106, Gr. B
Supplier	Wolverine	Inco	Inco	Mich. Seamless
Temper	Bright Ann.	Ann.	Ann.	Ann.
Finish	Cold drawn	Ground	Pickled	Cold drawn
Analysis*				
Carbon %	--	.04	.14	.24
Manganese %	1.12	.21	.82	.50
Iron %	1.44	6.83	.88	Balance
Sulfur %	--	.007	.005	.028
Silicon %	.07	.25	.13	.21
Copper %	33.0	.38	32.60	--
Nickel %	64.2	76.53	65.40	--
Chromium %	--	15.73	--	--
Phosphorus %	--	--	--	.001
Ultimate Strength, psi	81,000	--	--	70,400
Yield Strength, psi	47,400	--	--	46,700
Elongation %, 2"	48.0	--	--	43.7

*As specified by supplier.

these welds was made in four passes, by means of the inert-gas shielded-arc welding technique. The root pass and the final pass were examined with a dye penetrant and found to be free of cracks. The entire piping and vessel assembly will be hydrostatically tested after all piping has been completed.

E. WATER PURIFICATION LOOP

In order to obtain and maintain a high degree of purity of the distilled water, as indicated by the electrical conductivity measurements, it will be necessary to remove unwanted ions from the water as they are formed. This will be done by circulating a fraction of the total flow of water through a purification or deionizing loop. The circulation rate will be approximately 1 gpm and will be on a continuous or intermittent basis as required. The flow through this loop is determined by the head developed by the main or auxiliary circulating pumps.

The nearly saturated water (500-600°F) from the pump discharge to be purified is conducted by 1/2-in. O.D. stainless steel tubing to the countercurrent heat exchanger, which cools the stream to about 150°F. This heat exchanger consists of 60 feet of 1/2-in. O.D. stainless steel tubing inside an equal length of 1/2-in., schedule 10 stainless steel pipe. It was designed, fabricated, hydrostatically tested at 4000 psig and installed during the period covered.

The water to be purified must be cooled to a temperature lower than 100°F before passing through the ion exchanger. This additional cooling will be accomplished by passing the 1-gpm flow through a heat exchanger cooled by water from the Laboratory cooling water system. The heat exchanger will consist of 20 feet of 1/2-in. O.D. stainless steel tubing inside an equal length of 3/4-in. O.D. copper tubing. This exchanger was designed, fabricated, tested, and installed during the period covered.

The purification of the water will consist of a filtration and ion exchange process and will be performed in a Laboratory owned ion exchanger, employing Rohm and Haas XE-170 resin. The specification of the resin has been changed from MB-1 in order to maintain a pH well above the neutral pH of 7 which the MB-1 tends to provide. The higher pH, about 9, will minimize corrosion and is consistent with current practice for nuclear reactor loops. The ion exchanger and its associated piping were installed during the period discussed.

The purified stream of water which leaves the ion exchanger is reheated to within 50°F of the operating temperature in the countercurrent heat exchanger previously described. This interconnecting piping and sample taps for water analysis were installed during the period discussed. The sample taps will permit pH and electrical conductivity measurements of the water entering and leaving the ion exchanger. The Industrial Instruments electrolytic conductivity cell and the Leeds and Northrup Model 7401 pH Indicator were received during this period.

The entire system for providing cooled, filtered water to the Chempump, heat exchanger, condenser, and variable resistance in the direct current circuit was installed and tested during the erection of the equipment described above.

F. PRESSURE CONTROL LOOP

The pressure in the system is determined by the saturation pressure of the boiling water. The vapor generated by the test section and by the auxiliary electrical immersion heaters is condensed by an air cooled condenser. This condenser was fabricated and installed during the fifth quarter. The cooling air piping and also the instrument air supply for all instruments and valves were completed and tested during the period discussed.

Most of the steam from the test vessel is condensed and returned to the vessel by gravity. A small excess amount of steam is generated and the precise pressure is maintained by bleeding this excess steam from the system through a valve actuated by a pressure controller. This pressure control equipment was installed during the period covered. In addition, the safety relief valve, the pressure switch, and the pressure gauge were mounted on the instrument panel and connected to the appropriate signal lines.

The steam bled from the system to control the pressure is condensed in a water cooled condenser consisting of 20 ft of 1/2-in. O.D. stainless steel tubing jacketed by a copper water tube. This condenser was designed, fabricated and installed during the period discussed. The condensate is fed to the 55-gal stainless steel make-up drum which will contain the supply of distilled water for the system. The water may be returned to the system by a manually controlled injection pump. This pump, a Wallace and Tiernan Series 200 Simplex, was purchased and mounted in the loop.

G. ELECTRICAL SYSTEM

An electrical control and power distribution panel was designed and constructed. The panel serves to control the 480-volt, three-phase power to the twelve immersion heaters, Melrath circulating pump, Chempump auxiliary pump, and the Wallace and Tiernan injection pump. A 120-volt control circuit, providing interlocking safety devices, serves to actuate relays in the 480-volt circuits. The entire electrical system is designed on a fail-safe basis which will allow the system to be maintained at high temperature and pressure during periods of unattended operation. All circuits have indicating lights to aid in the operation.

This panel was designed and fabricated at the University shops. It was installed and the wiring to the heaters and motors was initiated.

H. CONTROL PANEL

The operation of the low heat-flux loop will be monitored and controlled from a control area consisting of a process control panel along with the electrical control and power distribution panel and the direct current generator control panel. On the process control panel are mounted the following instruments.

1.	Minneapolis-Honeywell	Differential Pressure Indicator, 0-25" water range, to indicate liquid level in test vessel
2.	Minneapolis-Honeywell	Differential Pressure Indicator, 0-25" water range, to indicate orifice differential, low flow
3.	Minneapolis-Honeywell	Differential Pressure Indicator, 0-100" water range, to indicate orifice differential, high flow
4.	Heise Pressure Gauge	2500 psi range, to indicate pressure of system
5.	Fisher Pressure Controller	0-3000 psi range, to control valve bleeding steam from system
6.	King U-Type Manometer	10" range, to indicate flow of cooling air to condenser
7.	Barksdale Pressure Switch	0-2000 psi range, to provide electrical shut-down on high pressure
8.	Leeds & Northrup	7401 pH Indicator, to indicate pH of water
9.	Industrial Instruments	Conductivity cell, to indicate electrical conductivity to water
10.	Leeds & Northrup	2285 Galvanometer, to indicate thermocouple null balance

11. Pressure Gauge — 3 gauges, 0-100 psi, to indicate cooling water pressures

12. Wilkerson Air Regulator — To regulate cooling air flow

During the period discussed the Minneapolis-Honeywell differential pressure gauges were individually calibrated against water manometers. In addition, the gauge and water flow orifice were calibrated by weigh tank measurements in the hydraulics laboratory. The orifice was designed and installed in accordance with ASME standards.

III. THERMOCOUPLE CALIBRATION

Assembly of the constant temperature block, to be used for calibration of thermocouples by comparison with a platinum resistance thermometer, has been completed. Power was applied to the heaters by means of a breadboard electrical circuit to check for satisfactory operation.

The temperature of the outer copper pipe is controlled cyclically by connecting a thermocouple embedded in the pipe to a Thermo-Electric Model 80025 Potentiometer-Type Signaling Controller. The frequency of the on-off cycle is controlled by varying the power input to the electrical pipe heaters by Variac control. This instrument will respond to a change in signal of 3 microvolts. It was found on preliminary tests that the operation of this controller was quite erratic until the control thermocouple was electrically shielded.

The inner copper block was heated to 1000°F for the preliminary test and operated satisfactorily. The entire assembly is mounted on a portable dolly to provide mobility, since the total weight is approximately 400 lb. The permanent wiring connections, complete with switches, fuses, Variacs, appropriate indicating electrical meters, and checking thermocouples are now being made. When completed, the assembly will be subjected to a series of tests to determine such operating characteristics as response time.

The thermocouple wire to be used in the main test program has been received, and calibration is expected to begin shortly. The wire consists of 30 gage Chromel-Constantan duplex with fiberglas insulation. To avoid high resistance in the thermocouple circuits with the attendant loss in sensitivity, all reference junctions (distilled water ice) will be placed as close as possible to the main test vessel with copper lead wires connecting to the potentiometers.

REFERENCES

1. J. A. Clark, H. Merte, E. R. Lady, J. Vander Veen, and W. J. Yang, Low Heat Flux Boiling, University of Michigan, ORA Report 04653-1-P, Ann Arbor, January, 1962.

2. J. A. Clark, H. Merte, E. R. Lady, J. Vander Veen, and W. J. Yang, Low Heat Flux Boiling, University of Michigan, ORA Report 04653-2-P, Ann Arbor, April, 1962.

3. J. A. Clark, H. Merte, E. R. Lady, Low Heat Flux Boiling, University of Michigan, ORA Report 04653-3-P, Ann Arbor, July, 1962.