NONUNIFORM HEAT GENERATION
EXPERIMENTAL PROGRAM

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THE UNITED STATES ATOMIC ENERGY COMMISSION
by
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Atomic Energy Division
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PREFACE

The Babcock & Wilcox Company and the United States Atomic Energy Commission, acting for the Joint U.S. -Euratom Research and Development Board, signed an agreement for a nonuniform heat generation experimental program.

The program includes experimental and analytical investigations to determine how nonuniformly distributed heat flux along lengths of tubular and annular channels affects the onset of burnout (departure from nucleate boiling). The experimental program is being conducted in the 1.8-MW heat transfer facility at B&W's Research Center, Alliance, Ohio. The analytical program is being conducted by the Atomic Energy Division, Lynchburg, Virginia.

SUMMARY

Since the beginning of the program, complete sets of data have been obtained on four tubular test sections. One had uniform flux to serve as a reference condition, but three had nonuniform axial heat flux to show the effect of flux distribution on critical heat flux conditions. These data were compared with the data of other investigators where comparable data were available. Empirical correlations were developed to express mathematically the effects of the various operating variables on critical heat flux. The data were compared with published burnout correlations. The comparison shows the need for improved correlations. This work on the tubular test sections is being described in a topical report.

The work during this report period includes data from two annular test sections. In the first case the inside surface was heated, but in the second case the outside surface was heated. The data tabulated in this report have been reviewed, and a preliminary analysis is presented. For the same conditions of pressure, mass velocity, and inlet temperature the annular test sections produce higher critical heat fluxes than the fluxes in the tubular test sections.

SCOPE

A serious design problem still facing the reactor designer is the phenomenon called burnout (critical heat flux). Although considerable attention has been given to this problem in recent years, the predictability of the occurrence of burnout conditions is still quite uncertain. In fact, there is still much disagreement as to how the channel geometry and operating conditions affect burnout.

In an effort to clarify some of the areas of disagreement, Babcock & Wilcox, as part of the Joint U. S. -Euratom Research and Development Program, is conducting an experimental and analytical program to determine how nonuniform heat generation rates in tubular and annular flow channels affect the operating conditions causing burnout, under experimental conditions representative of water reactor systems. The objective of the program is to seek improved design correlations suitable for direct use by reactor designers; the technical approach to the work emphasizes the development of an improved understanding of the physical phenomena involved and their relation to design variables.

The scope of the experimental program includes data taken on tubular test sections with these conditions:

<u>Axial flux shape</u>	<u>Pressure, psia</u>	<u>Mass velocity, lb/hr-ft² × 10⁻⁶</u>	<u>Inlet subcooling, F</u>
Uniform	2000	0.5	20
Peak near inlet	1500	1.5	50
Peak near midpoint	1000	2.5	100
Peak near outlet	--	--	150

In addition, corresponding data will be taken on five annular test sections involving uniform and cosine axial flux shapes.

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1. INTRODUCTION

Nuclear reactors and modern boilers require more and more knowledge about the limitations on the transfer rates of heat from channel walls to flowing liquids. Burnout (departure from nucleate boiling, or critical heat flux) is a serious design problem still facing the reactor designer. As a result of this phenomenon, the heat transfer conductance is reduced considerably, causing the metal and fuel temperatures to rise and initiate failure of the fuel element. Although considerable attention has been given to this problem in recent years, the predictability of the occurrence of burnout conditions is quite uncertain. In fact, there is still much disagreement as to how the channel geometry and operating conditions affect burnout.

In an effort to clarify some of the areas of disagreement, Babcock & Wilcox (B&W), as part of the Joint U.S.-Euratom Research and Development Program, is conducting an experimental and analytical program to determine the effects of nonuniform heat generation rates in tubular and annular flow channels on the operating conditions causing burnout under experimental conditions representative of water reactor systems. The objective of the program is to seek improved design correlations suitable for direct use by reactor designers. The technical approach to the work emphasizes the development of an improved understanding of the physical phenomena involved and their relation to design variables.

The experimental program, which was discussed in the first quarterly report¹, is being conducted on a heat transfer facility at B&W's Research Center in Alliance, Ohio. The controlled variables for the tests are pressure, inlet subcooling, and mass velocity. The tests are being performed in 6-foot-long tubular and annular test sections having both uniform and nonuniform axial heat flux distributions. The analytical program is being conducted by the Atomic Energy Division in Lynchburg, Virginia.

Fabrication progress on both tubular and annular test sections along with experimental work and data analysis on the tubular test sections have been reported previously.²⁻⁷ Here the first annular data, a review of these data, and a discussion of the annular experimental work are presented.

2. EXPERIMENTAL EQUIPMENT

2.1. Annular Test Sections

The general arrangement of the annular test sections is shown in Figure 1. Additional detail of the outside tube can be found in Figure 2. The geometry of the annulus is described as follows:

OD (inside tube)	0.607 inches
ID (outside tube)	1.053 inches
Heated length	72 inches

Figure 3 shows the detail of the annular test section pins. The spacer pin design as shown is the third attempt in designing a satisfactory pin, as discussed in reference 7. Spacer pin damage resulted from steam erosion—considerable damage occurred after 60 hours of test operation. Because any damaged pin is known to affect our results, we are changing the aluminum oxide cylinder material. Recent autoclave tests by our chemistry section have proved that "Lucalox" is superior to the material being used—"Al-Si-Mag".

2.1.1. Test Section No. 5 Instrumentation

Figure 4 shows the instrumentation for test section No. 5 (inner tube heated). A description of the instrumentation (voltage taps and thermocouple) is contained in reference 6. The voltage taps, as shown in Figure 4, failed during test operation. The taps were originally fabricated from stainless steel, and the spring constant of this material was too low. New taps were fabricated from Inconel (higher spring constant) to press the taps more firmly against the tube surface. The response time of the thermocouple shown in Figure 4 was too slow (5 seconds). To improve response time, we have installed a smaller (0.093-inch diameter) stainless steel sheath thermocouple with an insulated junction. The new thermocouple has a response time of about 0.1 second, and the sheath is not coated with aluminum oxide.

2.1.2. Test Section No. 6 Instrumentation

Figure 5 shows the instrumentation for test section No. 6 (outer tube heated). The voltage taps are heliarc welded to the outside tube and make up twelve station numbers. Thirty-six thermocouples are attached to the outside tube and are spaced on 1-inch centers. Thermocouple No. 1 has been supplemented with two additional thermocouples (1A and 1B). Thermocouple 1C is the same as the remaining 35 thermocouples. Thermocouple 1A is a "Microdot" weldable sheath couple. Thermocouple 1B is a BLH (Baldwin-Lima-Hamilton) "Micro Miniature" sheath couple. The "Microdot" weldable sheath thermocouple is the "new" thermocouple that was installed in test section No. 5 and is discussed in section 2.1.1. Both the BLH and the "Microdot" couples have about equal response times (0.1 second).

2.2. Test Section Metal Temperature Recorder

Nine different test section metal temperatures can be continuously recorded. Six temperatures can be recorded on three Honeywell Elektronik 17 two-pen strip chart recorders, and three temperatures can be recorded on three Esterline-Angus Panel-Graph strip chart recorders. The characteristics of each recorder are shown below:

	<u>Honeywell Elektronik 17</u>	<u>Esterline-Angus Panel-Graph</u>
Minimum range, mv	1	1
Maximum range, mv	100	100
Step span re- sponse time, sec	1	1/8
Accuracy	For spans less than 4 mv: $\pm 10\mu\text{v}$ or 0.5% of span For spans greater than 4 mv: $\pm 0.25\%$ of span width	

A feature of the Esterline-Angus recorders is the "Speed Servo", which represents a departure from the standard servo recorders, which use servomotors, gear trains, and a cable pen drive. The "Speed Servo" provides a response time four to eight times faster than the response of most potentiometric recorders.

2.3. Test Section Inlet Pressure System

Test section inlet pressure is continuously monitored by a system that uses a Dynisco pressure transducer and a Leeds & Northrup Azar strip chart recorder.

The Dynisco pressure transducer, model PT25, is a water-cooled strain gauge transducer. The transducer is coupled through a Sanborn d-c amplifier to the null-balance Leeds & Northrup strip chart recorder. This system permits recording any midscale pressure between 50 and 2950 psi and has a full-scale recorder range of 100 psi. When the system is properly calibrated, its accuracy is ± 3 psi. The step span response time of the L&N recorder is 1.0 second.

2.4. Primary Loop Flow System

The system that records transients in primary loop flow uses a turbine flow meter coupled through a frequency-to-millivolt converter to a Bristol strip chart recorder. The turbine flow meter, which was manufactured by Potter Aeronautical Corporation, has a 5/8-inch throat diameter and an effective range of 1 to 30 gpm. When properly calibrated, the turbine meter has an accuracy of $\pm 1.0\%$ of the actual flow. In order to obtain more-sensitive measurements of the flow rate at low flows, the range of the chart recorder can be changed to 1 to 10 gpm. The Bristol null-balance strip chart recorder used with the turbine meter has a step span response time of 0.2 second.

2.5. Automatic Data System

Since we plan to use the automatic data acquisition equipment in the next (ninth) quarter, it is appropriate that we describe the equipment at this time. Our automatic data acquisition equipment basically consists of (1) a digital data system, (2) a d-c standard, and (3) a digital recorder. Four analog recorders will also be used to measure pressure, power, flow, and temperature.

Our digital data system consists of 200 channels and is specifically designed to measure low-level d-c signals from thermocouples, pressure transducers, strain gauges, etc., in the presence of severe common mode and superimposed noise. The system uses six digits and includes a low-level input range to 10 millivolts and a high-level

input range to 1000 volts. The high-voltage range is primarily used for measuring test section voltages. Intermediate-voltage ranges of 100 mv, 1 volt, 10 volts, and 100 volts are available with automatic ranging between voltage levels. The system is completely guarded and has an integrating digital voltmeter with integration periods of 1, 0.1, and 0.01 second. The accuracy of the system is about ± 5 microvolts for a 0 to 30 millivolt signal. In order to maintain overall system accuracy, an external d-c voltage standard is used to supply calibration voltages from 1 to 1000 volts, full scale. In addition, the d-c standard measures voltages from 1 millivolt to 1000 volts. The accuracy of the d-c standard is within 0.01% of the setting. Digital recording is provided by an incremental magnetic tape unit and a digital printer. The maximum recording speed is 150 characters per second. The magnetic tape is used as a direct input to our RCA 301S digital computer for processing raw data.

Figure 1. Annular Test Section Arrangement

Figure 2. Annular Test Section Detail

Figure 3. Detail of Annular Test Section Spacer Pins

Figure 4. Annular Test Section Instrumentation

DETAIL OF THERMOCOUPE INSTALLATION

DETAIL OF VOLTAGE TAP INSTALLATION

Figure 5. Instrumentation for Annular Test Section No. 6

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3. EXPERIMENTAL OPERATION

3.1. Test Section Checkout

The preliminary checks before DNB tests include: (1) the determination of pressure drop without heat addition, (2) fluid thermocouple calibration, (3) heat losses without power addition, and (4) heat balance with power addition.

3.1.1. Results of the pressure drop tests are presented in Figure 6. The pressure drop across the test section was measured at various mass flows with both cold and hot pressurized water flowing through the test section. Shown in Figure 6 is the curve for annular test sections 5 and 6. Also shown in the same figure is the curve from the tubular test sections. Both curves are for a nominal hydraulic diameter of 0.446 inch. The curve for the annular test section falls above the other curve. This is probably due to the additional pressure drop across the spacer pins in the flow channel. Pressure drop data are also taken each day before testing in order to detect any possible change in the system or flow channel.

3.1.2. The fluid thermocouples at the test section inlet and outlet were checked for calibration by saturating the fluid around the thermocouples and checking the thermocouple reading against the saturation temperature. Calibration curves can be generated with this data. Saturation pressure is determined by a Heise 0 to 3000 psig gauge calibrated with a dead-weight tester to ± 1 psig.

3.1.3. The heat losses without power are concentrated around the electrical lugs at the test section inlet and outlet. This is true because the rest of the test section is thermally insulated. The heat losses are determined by passing subcooled pressurized water through the test section and calculating the enthalpy drop between the inlet and outlet. The product of the weight flow and enthalpy drop is equal to the heat loss. Heat loss corrections may be applied to the DNB data.

3.1.4. The heat balance with power is calculated by comparing the electrical heat input with the heat pickup of the fluid. The difference between these two measured values consists of a heat loss correction as determined in section 3.1.3 and a correction for the ripple on the d-c power supply.

3.2. Continuous Records During Operation

Analog recordings (charts) of test section inlet pressure, primary loop flow, and test section metal temperature are shown in Figures 7 through 9. Run No. 432 has been selected because it is representative of the results obtained. Figure 7 (pressure), Figure 8 (flow), and Figure 9 (temperature) provide a graphical aid in determining burnout.

A run number can be identified in two ways: (1) data point (safe point) and (2) DNB point (burnout point); the DNB column as shown in Tables 1 through 10 designates the type of data reported. Data points are unlettered in this column. DNB points are lettered "O" for the outside tube and "I" for the inside tube. Run No. 432 starts when the flow, pressure, and temperature have reached steady state conditions. For example, the data point (safe point) as shown in Figures 7 through 9 is representative of steady state conditions before burnout. The following procedures are used in obtaining the burnout (DNB) heat flux after the data point:

1. Start Power Increase - The test section power is increased, as shown in all the figures, until some indication of burnout is recorded—the onset of burnout is observed in Figure 9 as a fluctuating test section metal temperature (thermocouple 1C). The location of thermocouple 1C is at the outlet, as shown in Figure 5. Thermocouple 9 is 9-1/2 inches from the outlet and is used as a reference temperature in Figure 9.

2. DNB Point ($\phi = 945,000$ Btu/hr-sq ft) - The DNB point (burnout heat flux) is approached in two steps. The first step is to reduce the test section power about 1% ($\phi < 945,000$ Btu/hr-sq ft) at the first indication of burnout and then take data. The second step is to increase power to its initial value ($\phi = 945,000$ Btu/hr-sq ft), take only power data, and check the flow nozzle pressure differential and test section inlet temperature. The DNB heat flux ($\phi = 945,000$ Btu/hr-sq ft) is

the highest actual flux observed and is that reported in Table 6 for DNB points. The techniques used in defining the burnout heat flux (DNB point) make it possible to repeat the flux to within ± 5000 Btu/hr-sq. ft.

3. Decrease Power - Decreased power is shown in all the figures and is representative of postburnout conditions brought about by manually reducing the test section power. Figure 7 shows an abrupt decrease in pressure; Figure 8 shows a rise in flow; Figure 9 shows a decrease in metal temperature. The changes in pressure and flow are the result of a reduction in the specific volume of the fluid within the test section.

Definition of Symbols Used in Tables

- DNB 0 or 1 indicates the station number at which DNB occurred. 0 on left side of column indicates DNB on tubular test section or outside tube of annular test section. 1 on right side of column indicates DNB on inside tube of annular test section.
- P Test section outlet pressure, psia.
- ΔP Total test section pressure drop, psid.
- G Test section mass velocity, lb/hr-sq ft.
- KW Net electrical power input to the test section, kilowatts.
- Sta. No. Location on test section for which local operating conditions are calculated.
- ΔT_s Fluid subcooling at center of station number indicated, degrees F.
- h Fluid enthalpy at center of station number indicated, Btu/lb.
- x Steam quality, by weight, at center of station number indicated, %.
- V_m Fluid mixture velocity at center of station number indicated (assuming zero slip), ft/sec.
- $\phi_{1,o}$ Local heat input rate at station number indicated, for tubular test sections and outside tube in annular test sections, Btu/hr-sq ft.
- ϕ_o Integrated average heat input rate from test section inlet to center of station number indicated, for tubular test sections and outside tube in annular test sections, Btu/hr-sq ft.
- $\phi_{1,i}$ Local heat input rate at station number indicated, for inside tube in annular test section, Btu/hr-sq ft.
- ϕ_i Integrated average heat input rate from test section inlet to center of station number indicated for inside tube in annular test section, Btu/hr-sq ft.

Table 1. Data Summary Sheet, Test Section No. 5

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA. NO.	ΔT_s	h	x	V_m	$\frac{\phi_o}{10^6}$	$\frac{\phi_e}{10^6}$	$\frac{\phi_{11}}{10^6}$	$\frac{\phi_i}{10^6}$
346		03-12-65	11:12	1000		.514	95.5	INLET	7.5	533.7	-1.46	3.1				
								1	2.3	540.3	-1.44	3.1			.347	.347
								2	.0	553.6	1.60	4.1			.344	.347
								3	.0	566.5	3.60	5.3			.345	.344
								4	.0	579.5	5.61	6.5			.345	.343
								5	.0	592.6	7.63	7.7			.342	.343
								6	.0	605.7	9.64	8.9			.341	.342
								7	.0	619.1	11.71	10.1			.340	.344
								8	.0	632.1	13.71	11.3			.341	.343
								9	.0	645.8	15.84	12.6			.340	.345
								10	.0	659.2	17.90	13.9			.341	.346
								11	.0	671.5	19.79	15.0			.342	.343
								12	.0	684.3	21.76	16.2			.336	.343
347		3-12-65	12:29	1010		.523	111.9	EXIT	.0	690.7	22.75	16.8				.342
								INLET	3.1	540.0	-1.60	3.1				
								12	.0	713.5	26.20	19.1			.393	.401
348		3-12-65	13:01	990		.499	111.2	EXIT	.0	720.9	27.34	19.8				.401
								INLET	1.7	538.8	-1.31	3.0				
								12	.0	719.4	27.41	19.3			.394	.399
349		3-12-65	14:10	1026		.504	114.1	EXIT	.0	727.2	28.60	20.0				.399
								INLET	35.9	501.9	-6.90	2.9				
								12	.0	685.3	21.57	15.5			.401	.409
350		3-12-65	15:05	1010		.513	131.2	EXIT	.0	693.2	22.78	16.2				.409
								INLET	30.4	506.2	-5.82	3.0				
								12	.0	713.7	26.23	18.7			.460	.470
351		3-15-65	11:33	995		.514	145.3	EXIT	.0	722.6	27.59	19.5				.470
								INLET	77.7	448.8	-14.27	2.8				
								12	.0	676.1	20.98	15.9			.508	.521
352		3-15-65	13:26	998		.522	158.4	EXIT	.0	687.8	22.48	16.8				.520
								INLET	125.4	396.3	-22.44	2.7				
								12	.0	642.6	15.47	12.7			.547	.568
353		3-15-65	14:21	1000		.534	164.6	EXIT	.0	652.9	17.06	13.6				.567
								INLET	125.8	396.1	-22.53	2.8				
								12	.0	646.1	15.98	13.2			.569	.590
354		3-15-65	14:36	1000		.535	170.9	EXIT	.0	656.6	17.59	14.3				.589
								INLET	125.9	396.0	-22.54	2.8				
								12	.0	654.9	17.33	14.1			.591	.613
355		3-15-65	14:51	1000		.529	179.7	EXIT	.0	665.6	19.00	15.2				.612
								INLET	125.5	396.5	-22.47	2.8				
								12	.0	672.5	20.03	15.6			.622	.645
								EXIT	.0	684.1	21.82	16.7				.644

Table 2. Data Summary Sheet, Test Section No. 5

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA NO.	ΔT_s	h	x	V_m	$\frac{\phi_o}{10^6}$	$\frac{\phi_i}{10^6}$	$\frac{\phi_o}{10^6}$	$\frac{\phi_i}{10^6}$
356		3-16-65	14:20	1005	4.67	1.477	200.5	INLET	11.3	528.9	-2.19	8.7				
	I							10	.0	620.0	11.85	29.4			.718	.720
	I							11	.0	629.3	13.28	31.8			.718	.717
	I							12	.0	639.1	14.80	34.5			.690	.719
	I							EXIT	.0	643.7	15.51	35.7				.718
357		3-16-65	15:23	1008	3.87	1.483	227.2	INLET	36.9	458.0	-7.03	8.5				
	I							12	.0	628.3	12.14	29.9			.784	.815
	I							EXIT	.0	627.5	12.94	31.3				.813
358		3-17-65	13:01	1005		.498	145.5	INLET	77.2	450.7	-14.26	2.7				
	I							12	.0	667.5	22.27	16.0			.502	.522
	I							EXIT	.0	697.4	23.79	16.9				.521
359		3-18-64	09:15	1495		.487	91.2	INLET	10.0	596.8	-2.54	3.1				
	I							12	.0	749.0	24.77	11.7			.316	.328
	I							EXIT	.0	755.3	25.91	12.1				.327
360		3-18-65	10:17	1500		.511	109.4	INLET	35.2	563.5	-8.64	3.1				
	I							12	.0	737.1	22.55	11.4			.378	.392
	I							EXIT	.0	744.3	23.86	11.9				.392
361		3-18-64	11:27	1490		.512	132.7	INLET	80.2	505.7	-18.75	2.9				
	I							12	.0	715.9	18.91	10.2			.457	.476
	I							EXIT	.0	724.6	20.48	10.8				.475
362		3-18-65	12:58	1500		.513	158.9	INLET	127.1	452.1	-28.68	2.8				
	I							12	.0	703.5	16.52	9.3			.548	.570
	I							EXIT	.0	714.0	18.41	10.0				.569
363		3-18-65	14:56	1500	2.22	1.512	142.0	INLET	18.5	585.7	-4.66	9.5				
	I							12	.0	661.9	9.04	19.5			.488	.510
	I							EXIT	.0	665.1	9.61	20.1				.509
364		3-18-65	15:12	1495		1.509	150.9	INLET	17.1	587.0	-4.30	9.5				
	I							12	.0	668.1	10.26	20.8			.520	.541
	I							EXIT	.0	671.5	10.87	21.4				.540
365		3-19-65	10:29	1500	1.88	1.497	179.6	INLET	40.7	556.2	-9.96	9.1				
	I							12	.0	653.5	7.94	17.7			.620	.644
	I							EXIT	.0	657.6	8.27	18.5				.643
366		3-19-65	13:22	1503	1.31	1.490	216.8	INLET	89.8	495.5	-20.96	8.4				
	I							12	.0	613.5	.28	10.0			.749	.778
	I							EXIT	.0	618.5	1.17	11.0				.776
367		3-19-65	15:36	1500	1.31	1.478	229.8	INLET	90.8	494.1	-21.13	8.4				
	I							12	.0	620.2	1.55	11.3			.792	.824
	I							EXIT	.0	625.5	2.50	12.2				.823
368		3-20-65	9:44	1505	1.20	1.497	257.2	INLET	132.2	446.8	-29.79	8.1				
	I							12	18.6	566.2	-4.69	9.4			.884	.923
	I							EXIT	14.4	592.0	-3.64	9.5				.921
369		3-20-65	13:35	2005	1.36	1.504	118.0	INLET	21.1	637.1	-7.60	10.1				
	I							12	.0	700.8	6.17	14.9			.407	.424
	I							EXIT	.0	703.5	6.74	15.3				.423

Table 3. Data Summary Sheet, Test Section No. 5

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA NO.	ΔT_s	h	x	V_m	$\frac{\phi_{10}}{10^6}$	$\frac{\phi_0}{10^6}$	$\frac{\phi_{11}}{10^6}$	$\frac{\phi_i}{10^6}$
370		3-22-65	13:47	2005	1.45	1.486	125.9	INLET	16.8	643.9	-6.13	10.1				
	I							12	.0	712.6	8.73	16.4			.434	.452
	I							EXIT	.0	715.5	9.35	16.8				.451
371		3-22-65	14:54	1995	1.22	1.501	151.4	INLET	40.9	606.8	-13.85	9.6				
	I							12	.0	686.6	3.77	13.3			.523	.543
	I							EXIT	.0	692.0	4.51	13.8				.542
372		3-23-65	14:56	2000	1.03	1.514	169.2	INLET	87.5	545.7	-27.19	9.0				
	I							12	14.5	647.1	-5.31	10.3			.652	.679
	I							EXIT	11.9	651.3	-4.40	10.4				.678
373		3-23-65	10:41	2000	.96	1.487	234.4	INLET	135.0	488.4	-39.56	8.3				
	I							12	34.7	616.2	-11.97	9.6			.809	.841
	I							EXIT	31.1	621.6	-10.81	9.7				.840
374		3-23-65	13:39	2005		.508	79.4	INLET	12.1	651.5	-4.49	3.9			.274	.285
	I							12	.0	778.5	22.96	8.9				.285
	I							EXIT	.0	783.8	24.11	9.1				.285
375		3-25-65	10:31	2000		.502	82.4	INLET	19.4	639.4	-6.97	3.4				
	I							12	.0	772.5	21.76	8.5			.285	.296
	I							EXIT	.0	778.1	22.97	8.8				.295
376		3-25-65	11:41	2000		.495	96.8	INLET	45.6	600.8	-15.31	3.1				
	I							12	.0	759.9	-18.94	7.8			.334	.347
	I							EXIT	.0	766.1	20.38	8.1				.347
377		3-25-65	12:49	2005		.494	117.1	INLET	97.7	533.4	-30.03	2.9				
	I							12	.0	725.6	11.53	6.1			.404	.420
	I							EXIT	.0	733.6	13.27	6.5				.419
378		3-25-65	14:56	2005		.508	141.2	INLET	149.0	472.6	-43.17	2.8				
	I							12	.0	698.3	5.62	4.9			.489	.507
	I							EXIT	.0	707.8	7.67	5.4				.506
379		3-26-65	10:16	2000	3.83	2.467	174.0	INLET	32.1	620.1	-11.14	16.1				
								1	30.5	622.5	-10.61	16.2			.621	.621
								2	27.1	627.6	-9.52	16.3			.627	.629
								3	23.8	632.5	-8.46	16.4			.631	.625
								4	20.6	637.5	-7.38	16.6			.626	.625
								5	17.3	642.6	-6.29	16.7			.625	.627
								6	14.2	647.5	-5.21	16.8			.621	.627
								7	11.2	652.5	-4.15	17.0			.623	.626
								8	8.2	657.5	-3.05	17.2			.623	.627
								9	5.3	662.5	-1.99	17.3			.625	.626
								10	2.5	667.5	-.92	17.4			.625	.626
								11	.0	672.4	.15	17.8			.629	.626
								12	.0	677.3	1.20	18.9			.608	.624
								EXIT	.0	679.7	1.72	19.5				.623
380		3-26-65	11:54	2005	4.26	2.399	153.4	INLET	18.8	640.8	-6.82	16.2				
	I							12	.0	642.6	4.43	21.9			.533	.552
	I							EXIT	.0	645.0	4.91	22.4				.551

Table 4. Data Summary Sheet, Test Section No. 5

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA NO.	ΔT_s	h	X	V_m	$\frac{\phi_{i,e}}{10^6}$	$\frac{\phi_o}{10^6}$	$\frac{\phi_{i,j}}{10^6}$	$\frac{\phi_i}{10^6}$
381		3-26-65	12:59	1995	3.69	2.464	196.3	INLET	47.0	598.4	-15.66	19.6				
	I							12	4.8	663.0	-1.76	17.3			.674	.704
	I							EXIT	3.3	605.7	-1.18	17.4				.703
382		3-26-65	14:22	2000	3.71	2.922	286.4	INLET	97.7	533.0	-29.93	14.8				
	I							12	28.7	625.1	-10.05	16.6			.980	1.027
	I							EXIT	26.1	629.0	-9.22	16.7				1.025
383		3-26-65	15:36	1995	.93	1.505	248.2	INLET	159.5	460.0	-45.48	8.2				
	I							12	50.4	593.8	-16.66	9.5			.857	.890
	I							EXIT	46.3	599.4	-15.46	9.6				.889
384		3-29-65	11:58	1003	2.26	1.489	293.4	INLET	108.1	415.9	-19.57	7.9				
	I							12	.0	575.8	5.08	17.8			1.002	1.053
	I							EXIT	.0	582.5	6.10	19.6				1.051
385		3-29-65	15:25	1005		.503	177.9	INLET	152.2	368.3	-26.97	2.6				
	I							12	.0	655.5	17.33	13.2			.609	.639
	I							EXIT	.0	667.4	19.16	14.3				.637
386		4-21-65	13:53	1015	8.30	2.450	197.7	INLET	16.8	523.5	-3.27	14.4				
								1	14.5	526.4	-2.83	14.4			.699	.699
								2	10.1	532.0	-1.97	14.5			.706	.698
								3	5.7	537.5	-1.11	14.6			.706	.697
								4	1.6	543.3	-.21	14.7			.706	.703
								5	.0	549.0	.66	16.6			.708	.704
								6	.0	554.5	1.51	19.0			.704	.700
								7	.0	560.3	2.42	21.6			.706	.705
								8	.0	565.9	3.28	24.0			.707	.703
								9	.0	571.5	4.14	26.5			.706	.702
								10	.0	577.4	5.06	29.1			.704	.706
								11	.0	583.0	5.93	31.6			.706	.706
								12	.0	589.0	6.85	34.2			.691	.709
								EXIT	.0	591.8	7.28	35.4				.708
387		4-21-65	14:09	1000	8.86	2.419	205.0	INLET	15.5	522.9	-3.00	14.2				
								12	.0	591.6	7.58	36.1			.719	.735
								EXIT	.0	594.5	8.03	37.4				.734
388		4-21-65	14:32	1000	9.35	2.441	216.9	INLET	13.9	524.9	-2.69	14.4				
	I							8	.0	571.9	4.54	27.7			.780	.776
								9	.0	578.1	5.50	30.5			.780	.777
								10	.0	584.4	6.47	33.3			.777	.777
								11	.0	590.7	7.44	36.0			.777	.778
								12	.0	597.0	8.40	38.8			.762	.777
								EXIT	.0	600.0	8.87	40.2				.777

Table 5. Data Summary Sheet, Test Section No. 6

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA NO.	ΔT_s	h	x	V_m	$\frac{\phi_{i,0}}{10^6}$	$\frac{\phi_o}{10^6}$	$\frac{\phi_{i,1}}{10^6}$	$\frac{\phi_i}{10^6}$
420		4-26-65	10:23	1000	.75	.513	224.0	INLET	24.4	512.1	-4.67	3.0				
								1	12.4	526.8	-2.40	3.0	.444	.444		
								2	.0	556.9	2.24	4.4	.450	.449		
								3	.0	567.7	6.98	7.3	.467	.455		
								4	.0	618.9	11.79	10.2	.470	.459		
								5	.0	648.5	16.34	12.9	.444	.455		
								6	.0	678.8	21.01	15.8	.472	.455		
								7	.0	710.9	25.95	18.7	.474	.460		
								8	.0	741.4	30.64	21.6	.444	.459		
								9	.0	772.7	35.47	24.5	.470	.461		
								10	.0	805.7	40.54	27.6	.472	.464		
								11	.0	835.2	45.09	30.3	.446	.462		
								12	.0	866.5	49.90	33.2	.448	.463		
								EXIT	.0	881.4	52.20	34.6		.462		
421		4-26-65	12:10	1000	.68	.504	232.6	INLET	26.9	509.0	-5.15	2.9				
0								12	.0	883.1	52.47	34.2	.467	.481		
0								EXIT	.0	898.9	54.90	35.6		.480		
422		4-26-65	13:18	1000	.59	.494	243.0	INLET	48.1	483.6	-9.05	2.8				
0								12	.0	882.1	52.31	33.4	.488	.502		
0								EXIT	.0	898.9	54.90	34.9		.501		
423		4-26-65	14:14	1000	.66	.517	278.1	INLET	102.5	421.7	-18.59	2.8				
0								12	.0	858.0	48.49	32.7	.554	.575		
0								EXIT	.0	876.3	51.41	34.4		.574		
424		4-27-65	11:00	1010	6.75	1.479	324.9	INLET	24.7	513.2	-4.75	8.6				
								1	18.6	520.6	-3.60	8.7	.644	.644		
								2	6.4	535.8	-1.26	8.8	.656	.652		
								3	.0	551.0	1.10	10.8	.680	.656		
								4	.0	567.2	3.60	15.1	.681	.669		
								5	.0	582.4	5.95	19.1	.644	.667		
								6	.0	597.8	8.32	23.2	.681	.667		
								7	.0	613.9	10.81	27.5	.689	.671		
								8	.0	628.8	13.11	31.9	.646	.668		
								9	.0	644.9	15.60	35.8	.686	.671		
								10	.0	660.0	17.93	39.8	.688	.670		
								11	.0	675.5	20.33	43.9	.652	.670		
								12	.0	691.4	22.77	48.1	.652	.671		
								EXIT	.0	698.9	23.63	50.1		.671		
425		4-27-65	11:54	1005	5.82	1.454	346.0	INLET	46.4	486.3	-8.77	8.2				
0								12	.0	679.3	21.00	44.5	.695	.715		
0								EXIT	.0	687.5	22.25	46.6		.714		
426		4-27-65	12:58	995	4.71	1.472	405.0	INLET	94.9	429.5	-17.24	7.9				
0								12	.0	652.6	17.06	38.6	.814	.837		
0								EXIT	.0	662.0	18.51	41.1		.836		

Table 6. Data Summary Sheet, Test Section No. 6

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA NO.	ΔT_s	h	x	V_m	$\frac{\phi_o}{10^6}$	$\frac{\phi_i}{10^6}$	$\frac{\phi_{ij}}{10^6}$	$\frac{\phi_i}{10^6}$
427		4-27-65	14109	1000	3.91	1.476	454.5	INLET	145.6	374.8	-25.21	7.6				
	0							12	.0	624.5	12.64	30.8	.916	.939		
	0							EXIT	.0	635.1	14.27	33.7		.938		
428		4-27-65	14141	995	3.67	1.480	456.5	INLET	143.1	376.8	-25.34	7.6				
	0							12	.0	626.9	13.11	31.9	.918	.943		
	0							EXIT	.0	637.4	14.73	34.7		.942		
429		4-27-65	16121	995	.27	.506	264.6	INLET	146.5	373.1	-25.91	2.6				
	0							12	.0	800.7	39.84	28.9	.937	.951		
	0							EXIT	.0	818.8	42.62	28.6		.950		
430		4-28-65	10107	1010	11.26	2.362	357.3	INLET	27.4	509.9	-5.25	13.7				
	0							12	.0	632.6	13.69	51.9	.717	.738		
	0							EXIT	.0	637.8	14.49	54.1		.737		
431		4-28-65	11100	1005	9.92	2.450	396.2	INLET	51.0	480.9	-9.61	13.8				
	0							12	.0	612.0	10.61	45.2	.798	.818		
	0							EXIT	.0	617.5	11.47	47.6		.817		
432		4-28-65	14125	1000	6.39	2.424	458.0	INLET	99.9	424.6	-18.14	13.0				
	0							12	.0	577.7	5.44	30.1	.924	.946		
	0							EXIT	.0	584.2	6.44	32.9		.945		
433		4-28-65	15125	993	4.89	2.510	515.5	INLET	145.2	374.2	-25.68	12.9				
	0							12	.9	540.8	- .09	15.0	1.039	1.065		
	0							EXIT	.0	547.8	1.00	18.0		1.064		
434		4-29-65	9147	1498		.512	157.6	INLET	23.1	979.3	-5.76	3.2				
								1	15.4	589.8	-3.87	3.2	.316	.316		
								2	.3	611.2	- .03	3.3	.319	.319		
								3	.0	632.4	3.79	4.7	.334	.319		
								4	.0	654.2	7.70	6.1	.338	.321		
								5	.0	676.9	11.77	7.6	.316	.326		
								6	.0	697.5	15.47	8.9	.333	.323		
								7	.0	720.8	19.66	10.4	.334	.327		
								8	.0	742.6	23.58	11.9	.316	.327		
								9	.0	763.9	27.40	13.2	.334	.326		
								10	.0	787.2	31.59	14.7	.337	.329		
								11	.0	808.3	35.39	16.1	.316	.327		
	0							12	.0	828.7	39.05	17.4	.319	.326		
	0							EXIT	.0	839.3	40.65	18.1		.325		
435		4-29-65	10155	1505		.504	173.9	INLET	54.2	539.6	-13.08	3.0				
	0							12	.0	619.3	37.29	16.4	.348	.359		
	0							EXIT	.0	631.1	39.41	17.2		.359		
436		4-29-65	12103	1503		.504	190.6	INLET	100.4	483.0	-23.21	2.8				
	0							12	.0	789.5	31.65	14.6	.384	.394		
	0							EXIT	.0	802.5	34.29	15.4		.393		
437		4-29-65	13114	1488		.498	193.6	INLET	149.7	425.6	-33.02	2.7				
								12	.0	741.2	23.49	11.5	.386	.400		
								EXIT	.0	754.5	25.86	12.4		.399		

Table 7. Data Summary Sheet, Test Section No. 6

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA NO.	ΔT_s	h	X	V_m	$\frac{\phi_o}{10^6}$	$\frac{\phi_i}{10^6}$	$\frac{\phi_o}{10^6}$	$\frac{\phi_i}{10^6}$
438		4-29-65	13:46	1495		1.519	207.5	INLET	148.0	428.2	-32.80	2.8				
	0							12	.0	752.2	25.35	12.7	.418	.429		
	0							EXIT	.0	766.0	27.82	13.6		.428		
439		4-29-65	16:14	1500	1.22	1.517	323.0	INLET	153.1	423.1	-33.88	8.1				
	0							12	11.2	595.8	-2.84	9.7	.649	.667		
	0							EXIT	6.0	603.1	-1.53	9.8		.667		
440		4-30-65	12:57	1510	2.60	1.486	197.2	INLET	24.9	578.2	-6.24	9.3				
								1	21.6	582.7	-5.43	9.3	.392	.392		
								2	14.8	591.9	-3.77	9.4	.399	.398		
								3	8.0	601.4	-2.06	9.6	.414	.404		
								4	1.4	610.7	-.38	9.7	.416	.404		
								5	.0	620.0	1.28	11.0	.393	.404		
								6	.0	629.5	3.00	12.8	.419	.406		
								7	.0	638.7	4.67	14.5	.420	.405		
								8	.0	648.5	6.43	16.4	.397	.408		
								9	.0	657.5	8.06	18.1	.416	.406		
								10	.0	667.0	9.77	19.8	.421	.407		
								11	.0	676.8	11.54	21.7	.397	.409		
								12	.0	685.8	13.15	23.3	.400	.407		
								EXIT	.0	690.4	13.98	24.2		.407		
441		4-30-65	13:18	1510	2.83	1.476	221.9	INLET	25.4	577.6	-6.36	9.2				
	0							12	.0	699.5	15.63	25.7	.445	.459		
	0							EXIT	.0	704.7	16.56	26.7		.458		
442		4-30-65	14:09	1505	2.20	1.472	242.2	INLET	51.2	543.3	-12.41	8.8				
	0							12	.0	676.8	11.63	21.6	.481	.501		
	0							EXIT	.0	682.4	12.64	22.6		.500		
443		4-30-65	16:16	1485	1.36	1.505	281.2	INLET	103.1	477.9	-23.57	8.4				
	0							12	.0	629.4	3.52	13.6	.568	.581		
	0							EXIT	.0	635.8	4.68	14.8		.580		
444		05-03-65	09:55	1505	6.48	2.481	252.8	INLET	23.6	579.5	-5.90	15.5				
	0							12	.0	682.1	8.98	31.8	.508	.522		
	0							EXIT	.0	685.6	9.61	32.9		.522		
445		05-03-65	11:32	1500	4.98	2.511	274.8	INLET	48.7	546.0	-11.80	15.1				
	0							12	.0	634.7	4.15	23.7	.555	.568		
	0							EXIT	.0	638.5	4.83	24.9		.567		
446		05-03-65	12:45	1497	3.42	2.498	316.4	INLET	100.1	482.8	-23.07	14.0				
								12	18.4	585.5	-4.62	15.7	.634	.654		
								EXIT	15.3	589.8	-3.84	15.8		.653		
447		05-03-65	13:13	1500	3.56	2.470	352.2	INLET	97.8	485.7	-22.64	13.9				
	0							12	7.3	601.3	-1.86	15.9	.711	.727		
	0							EXIT	3.8	606.2	-.97	16.0		.727		
448		05-03-65	14:42	1500	3.33	2.472	452.2	INLET	148.5	428.2	-32.97	13.2				
	0							12	25.3	576.5	-6.30	15.4	.904	.934		
	0							EXIT	20.7	582.8	-5.18	15.5		.933		

Table 8. Data Summary Sheet, Test Section No. 6

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA NO.	ΔT_s	h	x	v_m	$\frac{\phi_{10}}{10^6}$	$\frac{\phi_o}{10^6}$	$\frac{\phi_{11}}{10^6}$	$\frac{\phi_i}{10^6}$
449		05-03-05	16:17	2005	3.22	2.497	430.4	INLET	148.1	473.6	-42.96	13.8				
	0							12	37.0	613.4	-12.74	16.1	.871	.889		
	0							EXIT	32.9	619.3	-11.46	16.3		.888		
490		5-04-05	9:23	2000		.506	102.7	INLET	25.1	630.5	-8.88	3.4				
								1	20.6	637.4	-7.39	3.4	.205	.205		
								2	11.9	651.4	-4.38	3.5	.209	.207		
								3	3.4	665.8	-1.28	3.6	.217	.209		
								4	.0	680.5	1.89	4.0	.216	.212		
								5	.0	694.4	4.89	4.7	.204	.210		
								6	.0	708.2	7.89	5.4	.219	.210		
								7	.0	723.3	11.13	6.2	.218	.212		
								8	.0	738.1	14.33	6.9	.204	.213		
								9	.0	752.0	17.34	7.6	.217	.212		
								10	.0	768.2	20.83	8.4	.217	.215		
								11	.0	781.8	23.75	9.0	.206	.214		
	0							12	.0	794.9	26.58	9.7	.208	.212		
	0							EXIT	.0	801.9	28.10	10.0		.212		
491		5-04-05	11:01	2005		.508	116.5	INLET	50.9	594.0	-16.94	3.2				
	0							12	.0	780.1	23.32	8.9	.235	.241		
	0							EXIT	.0	788.0	25.03	9.3		.240		
492		5-04-05	12:17	1995		.518	137.9	INLET	98.6	531.4	-30.08	3.0				
	0							12	.0	747.4	16.43	7.5	.278	.285		
	0							EXIT	.0	756.6	18.40	8.0		.284		
493		5-04-05	15:23	2000		.510	174.5	INLET	155.7	464.7	-44.67	2.8				
	0							12	.0	742.1	15.20	7.1	.355	.360		
	0							EXIT	.0	754.0	17.76	7.7		.360		
494		5-11-05	15:42	1995		.497	112.5	INLET	24.6	630.8	-8.68	3.3				
	0							12	.0	814.6	30.89	10.5	.225	.232		
	0							EXIT	.0	822.3	32.56	10.9		.232		
495		5-11-05	12:41	2005	1.83	1.511	177.4	INLET	25.9	629.8	-9.19	10.0				
								1	23.4	633.7	-8.34	10.1	.350	.350		
								2	18.0	642.0	-6.94	10.2	.357	.362		
								3	13.0	650.1	-4.80	10.4	.379	.360		
								4	7.9	658.7	-2.94	10.5	.377	.366		
								5	3.2	666.8	-1.19	10.7	.352	.364		
								6	.0	674.8	.55	11.2	.378	.363		
								7	.0	683.5	2.42	12.4	.376	.366		
								8	.0	692.6	4.40	13.8	.351	.371		
								9	.0	700.2	6.03	14.9	.376	.367		
								10	.0	708.0	7.72	16.0	.377	.365		
								11	.0	717.9	9.86	17.5	.357	.372		
								12	.0	724.9	11.38	18.5	.358	.366		
								EXIT	.0	729.0	12.26	19.1		.366		

Table 9. Data Summary Sheet, Test Section No. 6

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA NO.	ΔT_s	h	x	V_m	$\frac{\phi_{L_0}}{10^6}$	$\frac{\phi_o}{10^6}$	$\frac{\phi_{L_i}}{10^6}$	$\frac{\phi_i}{10^6}$
496		5-11-65	13:00	2005	1.95	1.500	199.1	INLET	24.7	631.5	-8.79	10.0				
	0							12	.0	739.3	14.49	20.5	.395	.411		
	0							EXIT	.0	743.8	15.47	21.1		.411		
497		5-11-65	14:14	2005	1.76	1.507	230.3	INLET	48.6	597.2	-16.24	9.5				
	0							12	.0	721.1	10.55	17.9	.463	.476		
	0							EXIT	.0	726.3	11.68	18.7		.475		
498		5-13-65	09:33	2000	1.22	1.508	287.8	INLET	98.6	531.9	-30.17	8.8				
	0							12	.0	686.7	3.24	13.0	.570	.595		
	0							EXIT	.0	693.2	4.63	13.9		.594		
499		5-13-65	10:36	2000	1.11	1.496	336.6	INLET	147.3	474.1	-42.63	8.3				
	0							12	8.8	656.5	-3.27	10.4	.683	.695		
	0							EXIT	4.3	664.3	-1.59	10.9		.695		
460		5-13-65	12:16	1997	3.51	2.474	489.1	INLET	147.6	473.6	-42.63	13.7				
	0							12	22.7	633.9	-8.08	16.5	.987	1.010		
	0							EXIT	18.3	640.7	-6.61	16.7		1.005		
461		5-13-65	14:22	2000	4.01	2.503	408.2	INLET	101.0	529.0	-30.20	14.6				
	0							11	12.7	650.0	-4.68	17.2	.820	.845		
	0							12	6.1	661.2	-2.26	17.5	.823	.843		
	0							EXIT	2.8	666.8	-1.05	17.7		.842		
462		5-13-65	16:11	2005	4.66	2.476	307.5	INLET	49.2	596.4	-16.42	15.7				
	0							11	.0	688.7	3.54	21.6	.613	.638		
								12	.0	697.1	5.37	23.7	.616	.635		
								EXIT	.0	701.4	6.29	24.7		.635		
463		05-14-65	09:35	2000	5.34	2.411	246.9	INLET	21.1	636.7	-7.55	16.2				
	0							12	.0	719.8	10.38	28.5	.494	.510		
	0							EXIT	.0	723.3	11.13	29.3		.510		
464		5-14-65	14:36	1005	9.63	2.417	391.6	INLET	48.8	483.4	-9.21	13.6				
	0							11	.0	603.8	9.35	41.0	.782	.812		
								12	.0	614.8	11.05	45.8	.787	.809		
								EXIT	.0	620.4	11.90	48.2		.808		
465		5-17-65	10:09	1010	.43	.505	269.3	INLET	99.1	426.8	-18.08	2.7				
								1	82.9	444.9	-15.29	2.7	.534	.534		
								2	51.4	481.1	-9.70	2.8	.543	.535		
								3	21.1	517.6	-4.07	2.9	.564	.537		
								4	.0	556.0	1.87	4.1	.566	.546		
								5	.0	593.7	7.68	7.6	.536	.548		
								6	.0	630.1	13.30	10.9	.570	.547		
								7	.0	669.6	19.41	14.4	.568	.552		
								8	.0	705.3	24.92	17.7	.539	.549		
								9	.0	744.9	31.04	21.3	.564	.553		
								10	.0	783.3	36.97	24.8	.567	.555		
								11	.0	822.9	43.09	28.4	.536	.558		
	0							12	.0	859.5	48.73	31.7	.537	.556		
	0							EXIT	.0	877.6	51.53	32.3		.556		

Table 10. Data Summary Sheet, Test Section No. 6

RUN NO.	DNB	DATE	TIME	P	ΔP	$G \times 10^{-6}$	KW	STA NO.	ΔT_s	h	x	V_m	$\frac{\phi_o}{10^6}$	$\frac{\phi_i}{10^6}$	$\frac{\phi_{i,j}}{10^6}$	$\frac{\phi_i}{10^6}$
466		5-17-65	11:21	1000	.59	.509	282.9	INLET	118.6	404.0	-21.31	2.7				
	0							12	.0	854.6	48.07	31.9	.972	.584		
	0							EXIT	.0	873.8	51.03	33.6		.584		
467		5-17-65	12:23	1000	.20	.486	266.6	INLET	146.6	373.7	-25.98	2.5				
	0							12	.0	818.2	42.48	27.3	.534	.551		
	0							EXIT	.0	837.0	45.36	28.9		.550		
468		5-17-65	13:44	1000	.27	.508	282.4	INLET	175.0	343.5	-30.64	2.6				
	0							12	.0	794.0	38.75	26.3	.559	.584		
	0							EXIT	.0	812.8	41.64	28.0		.583		
469		5-18-65	09:24	997	.86	.600	310.3	INLET	148.5	371.3	-26.26	3.1				
	0							12	.0	790.3	38.21	30.7	.625	.641		
	0							EXIT	.0	808.0	40.94	32.7		.640		
470		5-18-65	11:14	993	1.81	.795	363.9	INLET	145.7	373.7	-25.76	4.1				
	0							12	.0	745.0	31.29	34.3	.727	.752		
	0							EXIT	.0	760.6	33.69	36.6		.751		
471		5-18-65	11:59	990	2.70	.998	403.8	INLET	146.5	372.4	-25.85	5.1				
	0							12	.0	701.5	24.67	35.3	.752	.837		
	0							EXIT	.0	714.4	26.64	37.7		.833		

Figure 6. Results of Pressure Drop Tests on Annular
Test Section Nos. 5 and 6

Figure 7. Test Section Inlet Pressure, Run No. 432

Figure 8. Primary Loop Flow, Run No. 432

Figure 9. Test Section Metal Temperature, Run No. 432

4. EXPERIMENTAL DATA

4.1. Test Section Nos. 5 and 6

The results on test section Nos. 5 and 6 are tabulated in Tables 1 through 4 and Tables 5 through 10 respectively. These data have been plotted at pressures of 1000, 1500, and 2000 psia in Figures 10 through 15. The results from the uniformly heated tubular test section (test section No. 1) also have been plotted in all the figures. Figures 10, 11, and 12 (test section No. 5) and Figures 13, 14, and 15 (test section No. 6) show the effect of inlet subcooling on the average heat input rate (burn-out heat flux) at pressures of 1000, 1500, and 2000 psia. The figures are plots of three sets of data, each at mass velocities of 0.5×10^6 , 1.5×10^6 and 2.5×10^6 lb/hr-sq ft. The inlet subcooled temperature was chosen as the independent variable because it is a loop (system) parameter. The following general observations apply to all the figures:

1. In nearly all cases a linear relationship exists between the average heat input rate and inlet subcooled temperatures. For test section No. 5, (1) unexplained scatter exists in Figure 10 (1000 psia) at 0.5×10^6 lb/hr-sq ft and (2) additional data is required at 2.5×10^6 lb/hr-sq ft in Figures 10 and 11 to verify the linear relationship at 1000 and 1500 psia. This requirement is in the test schedule.

2. The slope of the straight lines representing constant mass velocity appears to increase with mass velocity. This observation is especially noticeable in Figure 12 for test section No. 5 and is true in all figures for test section No. 6.

3. The straight lines shown for the various mass velocities do not intersect. Because of this result, an inverse effect of mass velocity is not observed.

4.2. Comparison With Other Data

In Figures 16 and 17 we have compared our data with data from reference 8. The geometries of both the G. E. and B&W test sections are shown in each figure; they are similar except for the heated lengths. Note that G. E. test section lengths of 29 and 36 inches (Figures 16 and 17 respectively) are compared to the B&W test section, which is 72 inches long. Figure 16 shows one B&W mass velocity (0.5×10^6 lb/hr-sq ft) compared with two G. E. mass velocities (0.4×10^6 and 0.6×10^6 lb/hr-sq ft). Figure 17 follows and compares three B&W mass velocities (0.5×10^6 , 1.5×10^6 , and 2.5×10^6 lb/hr-sq ft) with two additional G. E. mass velocities (1.7×10^6 and 2.0×10^6 lb/hr-sq ft). We conclude from Figures 16 and 17 that our data agree fairly well with the G. E. data for sequential mass velocities.

Figure 10. DNB Points for Annular Geometry With Inner Tube Heated, Test Section No. 5, 1000 psia

Figure 11. DNB Points for Annular Geometry With Inner Tube Heated, Test Section No. 5, 1500 psia

Figure 12. DNB Points for Annular Geometry With Inner Tube Heated, Test Section No. 5, 2000 psia

Figure 13. DNB Points for Annular Geometry With Outer Tube Heated, Test Section No. 6, 1000 psia

Figure 14. DNB Points for Annular Geometry With Outer Tube Heated, Test Section No. 6, 1500 psia

Figure 15. DNB Points for Annular Geometry With Outer Tube Heated, Test Section No. 6, 2000 psia

Figure 16. Comparison of B&W Annular Test Section No. 5
With G. E. Annular Test Section at Low Flow

Figure 17. Comparison of B&W Annular Test Section No. 5
With G. E. Annular Test Section

5. ANALYSIS

5.1. Comparison of Experimental Data With Predictions

The data from the two annular test sections have been compared with the burnout correlations from references 9, 10, and 11. Each of these correlations contains a diameter term. In the case of annular channels, an equivalent diameter term must be evaluated to serve as the diameter term in computations. Two kinds of equivalent diameter have been evaluated, and comparison with the data has used each. First, there is the usual hydraulic equivalent diameter based on the wetted perimeter:

$$D_W = \frac{4 \text{ (cross section area)}}{\text{wetted perimeter}}$$

It is also possible to define an equivalent diameter based on the heated perimeter:

$$D_H = \frac{4 \text{ (cross section area)}}{\text{heated perimeter}}$$

Consideration of these two equivalent diameters increases the number of correlations from three to six. For each group and correlation, the mean ratio of experimental-to-calculated heat flux and the standard deviation have been computed by

$$\bar{R} = \frac{\sum R}{N}$$

where

$$R = \frac{\text{experimental burnout heat flux}}{\text{predicted burnout heat flux}}$$

N = number of ratios

$\bar{R}$ = mean ratio

$$S \text{ (standard deviation)}^* = \sqrt{\frac{\sum(R - \bar{R})^2}{N}}$$

The results are shown in Figure 18. The agreement of a group of data with a specific correlation can be estimate by noting the proximity of the plotted point to the coordinates (1.0, 0). Perfect agreement between the data and a correlation would show a mean ratio of 1.0 and a standard deviation of 0.0. Figure 18 shows that the choice of equivalent diameter concept makes considerable difference. In the wetted perimeter comparisons the points are widely scattered. When the heated perimeter is used, the points are concentrated in a smaller area of the graph, and in general the agreement between the equations and the data is better.

This subject of heated versus wetted perimeter is considered by Barnett¹³. His conclusion is that neither concept is adequate for extending tubular correlations to annular geometries, but a study of his plots showing the two concepts compared with data indicates that the calculations using heated perimeter are closer to the data than are the ones using the wetted perimeter. To this extent the two analyses are in agreement.

5.2. Topical Report on Tubular Data

A topical report¹⁴ has been written for the twofold purpose of collecting the tubular experimental results in one volume and presenting the analysis of the tubular results. This report is now in the draft stage and will be distributed after final editing and review.

- - - - -
 *Many authors in statistics use N-1 instead of N to compute standard deviation to remove bias. Here, the computation complies with reference 12.

Figure 18. Comparison of Burnout Equations With Annular Data

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6. FUTURE WORK

The ninth quarter is expected to include completion of the experimental work on test section No. 7 (annulus with both surfaces heated) and test section No. 8 (annulus with cosine flux on outer surface). Analyses of the resulting data will follow the experimental work in logical order.

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Casella Postale n° 1
Ispra (Varese)
Italy

Attn: M. R. Morin

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