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SUBJECT: Determination of Suitable Insulation for a
1-5/16" Helium Filled Annulus in the ORR Helium
In-Pile Loop, Design No. 4
TO: Distribution
FROM: R. B. Knight and R. E. Helms

ABSTRACT

Heat loss tests were conducted with six insulation configurations for application in the riser regenerator and auxiliary regenerator sections of the loop. Insulation consisting of ten laminations of 0.003 in. stainless steel shim stock spaced 1/8 inch apart produced a temperature drop across the 1-5/16 inch annulus of 1200°F with a heat loss of 1.04 KW per foot of 2 inch schedule 40 pipe. The curve of heat loss vs. temperature difference is presented which, with results of similar tests with a 1/4 inch annulus, will permit the evaluation of a heat balance and temperature profile for the entire loop.

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I. Introduction

In order to determine the adequacy of the proposed heater for the ORR Helium In-Pile Loop Design No. 4 it is necessary to know the approximate heat losses to the pool water. The configuration of the piping of the loop consists essentially of three concentric sections of pipe. The cold coolant flows in the center pipe, the hot coolant in the inner annulus, and the outer annulus provides insulation to reduce heat losses. In sections of the loop outside of the ORR pool, sufficient external insulation may be applied to reduce losses to a negligible value. However, for those sections of the loop submerged, all insulation must be confined to the outer annulus. In addition, as the submerged sections of the piping may be filled with water during changes of fuel elements, the insulating material must be out-gassable and non hygroscopic as well as capable of withstanding temperatures up to 1400°F.

Operational data from other Helium In-Pile Loops (Battelle Memorial Institute and General Electric Vallecitos Atomic Laboratory, see references 1 and 2) indicated that an outer annulus of helium alone would not provide sufficient insulation. A preliminary analytical investigation of the free convection heat transfer characteristics of helium in an annulus verified these data. The maximum capacity of the heater in the loop dictated that, for reliable continuous operation, the maximum tolerable heat loss would be approximately 1.050 kw per foot of pipe at a temperature difference of 1200°F with lower values desirable.

The most practical material to be inserted into the annulus appeared to be laminations of stainless steel shim stock and/or steel wool. As no reliable heat transfer data were available for these types of configurations, a heat loss test stand was fabricated for the determination of a suitable insulating configuration and its thermal characteristics. All sections of the loop will contain insulating annuli of either 1-5/16 inch or 1/4 inch depth with only minor variations in geometry. The assembly tested contained a 1-5/16 inch annulus between concentric sections of 2" and 5" schedule 40 stainless steel pipe. Similar tests with a 1/4 inch annulus are presently being conducted.

The authors wish to acknowledge the invaluable assistance rendered by W. H. Kelley, Jr. and E. Storto in suggesting insulation configurations and editing this memorandum. The earnest cooperation of all craft forces resulted in a material reduction in time required to fabricate and install each new insulation configuration, thus greatly expediting the test program.

II. Heat Loss Test Assembly

The heat loss test section shown in Figure 1 consists basically of a ten foot length of concentric sections of 2 inch, 5 inch, and 8 inch schedule 40 stainless steel pipe. The 2 inch pipe is the heater tube and contains four 3 kw calrod heaters immersed in sodium. The annulus between the 2 inch and 5 inch pipe is the 1-5/16 inch insulating gap while the annulus between the 5 inch and 8 inch pipe contains circulating cooling water. Helium connections are provided to maintain a pressure of 400 psig in the heater tube and the insulating annulus. Twelve thermocouples are attached to each of the outer surfaces of the 2 inch and 5 inch pipe to determine, respectively, the average hot and cold surface temperatures. A schematic of the Pressure Control System is shown in Figure 2 and thermocouple locations are shown in Figure 3.

The test stand, upon which the heat loss test section is mounted, is constructed in such a manner as to permit orienting the test section in either a vertical or horizontal position. This is predicted by the fact that both positions are assumed by the actual loop piping.

III. Description of Insulation

Heat loss vs. temperature difference data were obtained with six different types of insulation. In each case the insulating annulus was filled with helium maintained at a pressure of 400 psig. The six configurations for the annulus are shown in Figure 4 and described in detail in the following paragraphs.

- A. The annulus contained only helium.
- B. The entire annulus was filled with stainless steel wool.
- C. Twelve inch long pieces of 1/16 inch diameter stainless steel wire were tack welded at one inch intervals to a 12 inch wide by 48 inch long section of 0.005 inch stainless steel shim stock. Ten of these assemblies were wrapped, end to end, around the 10 foot heated length of the inner tube. In order to reduce convection currents, the wraps were separated by radial baffles of 0.0025 inch shim stock extending to the outer wall of the annulus. This, in effect, produced five laminations of shim stock, separated by 1/16 inch gas gaps.

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PHOTO 34776

Figure 1. Photo of Test Stand

FIG. 2. PRESSURE RISE TEST (LEAK TEST)
HEAT LOSS EXPERIMENT

DESIGNATION ON
DWG. NO. D-7841,
D-7840
POSITION ON
SWITCH
SWITCH
POINT ON
RECORDER

RECORDER POINTS 11,12,
READ ROOM TEMP.

FIG. 3. THERMOCOUPLE LEAD CHANGE, HEAT LOSS EXPERIMENT

-8-

FIG. 4.A. CONFIGURATION OF INSULATIONS TESTED

-9-

FIG. 4.B. CONFIGURATION OF INSULATIONS TESTED

-10-

FIG. 4.C. CONFIGURATION OF INSULATION TESTED

- D. On the outside of the five laminations described in paragraph C were wrapped five more laminations of alternate layers of flat, 12 inch wide, 0.005 inch stainless steel shim stock and 0.005 inch stainless steel shim stock corrugated to a depth of 1/16 inch.
- E. The entire annulus was filled with approximately ten laminations of alternate layers of 0.005 inch, 12 inch wide, flat stainless steel shim stock and 12 inch wide, 0.003 inch stainless steel shim stock corrugated to a depth of 1/8 inch.
- F. The entire annulus was filled with approximately ten laminations of alternate layers of 12 inch wide, flat 0.003 inch stainless steel shim stock separated by three, one inch wide strips of 0.002 inch stainless steel shim stock corrugated to a depth of 1/8 inch.

IV. Test Procedure

At the start of each test, with the assembly in a vertical position, the annulus was alternately purged and filled with helium five or six times to insure adequate removal of all air, moisture, oil and other contaminants. Power was then applied to the calrods and circulation of the cooling water was started. For each configuration the approximate maximum power, 12 KW, was applied to the calrods to determine the maximum temperature difference attainable with the installed insulation. When thermal equilibrium was reached, readings of all thermocouples and calrod outputs were read to evaluate the temperature difference as a function of heat loss. As soon as it was definitely established that a temperature difference of 1200°F could not be reached, the test was discontinued and the next insulating configuration installed.

When insulation "F" indicated a temperature difference of 1304°F corresponding to a heat loss of 1.172 KW per foot, the power to each calrod was reduced to produce incremental changes in temperature difference of approximately 200°F. Thus data was obtained for the test assembly in the vertical position. The test section was then oriented in a horizontal position and the above procedure repeated.

V. Test Results and Calculations

The temperature differences across the insulating annulus attainable with maximum power input for all configurations are shown in Table I. The variations

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FIG. 4D. CONFIGURATION OF INSULATION TESTED

FIG. 4E. CONFIGURATION OF INSULATION TESTED

-14-

FIG. 4F. CONFIGURATION OF INSULATION TESTED

TABLE 1. TEMPERATURE DIFFERENCES ATTAINABLE
WITH INSULATIONS IN $1\frac{5}{16}$ INCH HELIUM
ANNULUS @ 400 PSI

INSULATION				HEAT LOSS KW/FT.	TEMPERATURE DIFFERENCE °F
DESIGNATION	CONSTRUCTION				
	NUMBER OF LAMINATIONS	SPACING OF LAMINATIONS	METHOD OF SEPARATION		
A	NONE	NONE	NONE	1.120	432
B	STAINLESS STEEL WOOL			1.062	844
C	5	$\frac{1}{16}$	AXIAL LENGTH OF $\frac{1}{16}$ DIA. SST. WIRE	1.234	969
D	10	$\frac{1}{16}$	5 LAMINATIONS SEPARATED BY FULL LENGTH CORRUGATED SHIM STOCK ADDED TO "C" INSULATION	1.155	1156
E	10	$\frac{1}{8}$	FULL LENGTH CORRUGATED SHIM STOCK	1.196	1183
F	10	$\frac{1}{8}$	THREE 1" CORRUGATED STRIPS PER FOOT OF TUBE	1.172	1304

in power input are due to unavoidable end losses from the test section, and the method of correction for these losses is explained in the sample calculations below.

The results of the heat loss test of insulation "F" are presented in Fig. 5. It is seen that the orientation of the test assembly has a negligible effect on the results.

Sample Calculations

Results of first tests indicated that despite external insulation considerable axial heat flow along the heated tube existed. This is evidenced by the typical temperature distribution curve shown in Figure 6. It was decided to consider only the power input to the two center calrods and, knowing the temperature gradients at the extremities of the center section (30 and 90 inches from the top, respectively), calculate the end losses to be applied to the gross power input.

For the test shown in Figure 6, the slopes of the temperature curve at 30 and 90 inches from the top are 35.6 and 42.7 °F/ft respectively.

Assuming the 2.375 inch O.D. tube to represent a shaft of liquid sodium having a thermal conductivity of 40 Btu/hr ft °F, the total end losses are

$$kA \frac{\Delta t}{\Delta x} \quad \text{or} \quad \pi / 4 \left(\frac{2.375}{12} \right)^2 \frac{40}{3413} (35.6 + 42.7) = 0.0003605 (35.6 + 42.7) = 0.028 \text{ KW}$$

The total power input is

$$1.436 + 1.219 = 2.655 \text{ KW}$$

therefore the net power input is

$$2.655 - 0.028 = 2.627 \text{ KW or } 0.525 \text{ KW/ft}$$

Values of the temperature difference were read from the curves of Figure 6 at 10 inch intervals to produce the following values:

<u>Distance from top, inches</u>	<u>Temperature Difference, °F</u>	
30	721	
40	740	
50	747	
60	761	Average = 763°F
70	789	
80	805	
90	787	

Data sheets, temperature distribution curves and calculations for the remaining points of Figure 5 are included in the appendix, pages to .

VI. Conclusions and Recommendations

The heat losses from a 1-5/16 inch helium annulus filled with ten laminations of shim stock spaced 1/8 inch apart are tolerable but barely so. The assembly which will be used to determine heat loss data for a 1/4 inch helium filled annulus may easily be reworked to provide a 1-5/16 inch annulus. Inasmuch as the insulation tested filled the annulus with 1/8 inch gaps, it is recommended that, at the conclusion of the test of the 1/4 inch annulus, the assembly be modified to 1-5/16 inch annulus and test conducted of insulation with up to 20 laminations of shim stock spaced 1/16 inch apart.

FIG. 6. TYPICAL TEMP. DISTRIBUTION AND HEAT LOSSES
FOR INSULATION "F"

FIG. 6. DIST FROM TOP OF
HEATED TUBE - INCHES

VII. References

1. General Electric Company, Vallecitos Atomic Laboratory, Progress Report No. 10, GCPR-Prototype Fuel Irradiation Program, May 18 to June 18, 1959, Contract No. ORNL-1350.
2. Battelle Memorial Institute, Report No. 1290, An In-Pile Gas-Cooled Loop Installed at the Battelle Research Reactor, Sept. 16, 1958.

VIII. Appendix

A. Data Sheets

B. Temperature Distribution Curves

INSULATION
ORIENTATION A
VerticalDATE 6/9/59 TIME 1350
DATA BY R.B.K.

DISTANCE FROM TOP OF TEST SECTION	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES													CALROD NUMBER	VOLTAGE	CURRENT	POWER	
	RECORDER POINT NUMBER	OUTER (COLD) SURFACE				RECORDER POINT NUMBER	INNER (HOT) SURFACE				INNER SURFACE AVERAGE	OUTER SURFACE AVERAGE	DIFFERENCE					GRADIENT
		0° °F	90° °E	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F								
inches		°F	°E	°F	°F		°F	°F	°F	°F	°F	°F	°F	°F/ft		Volts	Amps	KW
0	1 (7)	120	120	120	(120)	4 (10)	530	580	550	(560)	555	120	435		#1	248	22.6	5.600
10																		
20																		
30																		
40																		
50																		
60	2 (8)	100	100	100	(100)	5 (11)	510	540	540	(520)	527.5	100	427.5		#2	253	21.05	5.340
70																		
80																		
90																		
100																		
110																		
120	3 (9)	80	75	80	(80)	6 (12)	160	160	150	(160)	157.5	79						
													AVERAGE =	431				

FOR UPPER HALF OF TUBE (Neglecting Axial Heat Flow)

NET KW = 5.600 KW or 1.120 KW/ft

Average Temperature Difference = 431°F

[illegible]

FOR UPPER HALF OF TUBE (Neglecting axial heat flow)

$$\text{NET KW} = 4.360 \text{ KW or } 0.872 \text{ KW/ft}$$

Average Temperature Difference = 352°F

INSULATION A
ORIENTATION Vertical

DATE 6/10/59 TIME 0810
DATA BY RBK

[illegible]

FOR UPPER HALF OF TUBE (Neglecting axial heat flow)

NET KW = 3.510 KW or 0.702 KW/ft

AVERAGE TEMPERATURE DIFFERENCE = 284°F

DISTANCE FROM TOP OF TEST SECTION inches	TEMPERATURE DATA														HEAT DATA			
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE Volts	CURRENT Amps	POWER KW
	OUTER (COLD) SURFACE					INNER (HOT) SURFACE					INNER SURFACE °F	OUTER SURFACE °F	DIFFERENCE °F	GRADIENT °F/ft.				
	RECORDER POINT NUMBER	RADIAL ORIENTATION				RECORDER POINT NUMBER	RADIAL ORIENTATION											
	0° °F	90° °F	180° °F	270° °F	0° °F	90° °F	180° °F	270° °F										
0	1	90	115	145	115	4	650	780	850	755	750	120	630	220	1	248.0	22.8	5.650
10						5	970				980	117	863					
20						6	1045				1060	113	947					
30																		
40															2	248.0	20.5	5.085
50																		
60	2	90	102	135	105	7	1060		1100		1080	110	970					
70						8	1050				1060	107	953					
80															2	248.0	20.5	5.085
90																		
100						9	945				970	103	867					
110																		
120	3	90	92	105	95	10	830		845		840	100	740	85				
												AVERAGE =		853	TOTAL = 10.735			

Total end losses = $0.0003605 (220 \div 85) = 0.110$ KW

Net KW = $10.735 - 0.110 = 10.625$ or 1.062 KW/ft

Average temperature difference = 853°F

[illegible]
$$\text{TOTAL END LOSSES} = 0.0003605 (32.5 \times 120) = 0.055 \text{ KW}$$
$$\text{NET KW} = (3.225 - 3.000) = 0.055 = 6.170 \text{ KW or } 1.234 \text{ KW/ft.}$$

AVERAGE TEMPERATURE DIFFERENCE = 969°F

INSULATION D
ORIENTATION VerticalDATE 6/25/59 TIME 1750
DATA BY ES & REH

DISTANCE FROM TOP OF TEST SECTION inches	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE Volts	CURRENT Amps	POWER KW
	OUTER (COLD) SURFACE					INNER (HOT) SURFACE					INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT				
	RECORDER POINT NUMBER	0° °F	90° °F	180° °F	270° °F	RECORDER POINT NUMBER	0° °F	90° °F	180° °F	270° °F								
0	1	130				4	1090											
10																		
20						5	1200								4	*250	*11.5	
30											1236	120	1104	40.0			2.875	
40						6	1265				1265	117	1148					
50											1282	115	1167		1	*250	*11.5	
60	2	110				7	1290				1290	110	1180				2.875	
70											1287	105	1182					
80						8	1280				1280	100	1180		2	250	11.8	
90											1226	93	1133	100.0			2.950	
100						9	1025											
110															3	250	11.2	
120	3	65				10	365										2.800	

AVERAGE = 1156

*Estimated Values

TOTAL END LOSSES = $0.0003605 (40.0 \div 100.0) = 0.050$ KWNET KW = $(2.875 \div 2.950) - 0.050 = 5.775$ KW or 1.155 KW/ft.

AVERAGE TEMPERATURE DIFFERENCE = 1156°F

DISTANCE FROM TOP OF TEST SECTION	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE	CURRENT	POWER
	OUTER (COLD) SURFACE					INNER (HOT) SURFACE					INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT				
	RECORDER POINT NUMBER	RADIAL ORIENTATION				RECORDER POINT NUMBER	RADIAL ORIENTATION											
inches		0° °F	90° °F	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F	°F	°F	°F	°F/ft.	Volts	Amps	KW	
0	1	120	115	120	120	4	1170	1130	1135	1120								
10																		
20						5	1255								4		12.40	
30											1290	115	1175	30				
40						6	1310				1310	113	1197					
50											1315	111	1204		1	*248.5	12.9	
60	2	110	110	105	110	7	1315		1325		1320	109	1211				3.205	
70											1320	107	1213					
80						8	1320				1320	104	1216		2	248.0	11.80	
90											1165	97	1068	390			2.925	
100						9	855											
110																		
120	3	70	70	70	70	10	210		210						3	253.0	11.50	

AVERAGE = 1183

*Estimated Voltage

TOTAL END LOSSES = $0.0003605 (30.0 \div 390.0) = 0.151 \text{ KW}$ NET KW = $(3.205 \div 2.925) - 0.151 = 5.979 \text{ KW or } 1.196 \text{ KW/ft}$ AVERAGE TEMPERATURE DIFFERENCE = 1183°F

[illegible]

*Thermocouple Inoperative

TOTAL END LOSSES = 0.0003605 (26.0 / 57.0) = 0.030 KW

$$\text{NET KW} = (3.174 / 2.806) - 0.030 = 5.950 \text{ KW or } 1.190 \text{ KW/ft.}$$

AVERAGE TEMPERATURE DIFFERENCE = 12.99°F

DISTANCE FROM TOP OF TEST SECTION	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE	CURRENT	POWER
	OUTER (COLD) SURFACE					INNER (HOT) SURFACE					INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT				
	RECORDER POINT NUMBER	RADIAL ORIENTATION				RECORDER POINT NUMBER	RADIAL ORIENTATION											
inches		0° °F	90° °F	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F	°F	°F	°F	°F/ft.	Volts	Amps	KW	
0	1	85	95	140	90	4	725	870	945	840								
10																		
20						5	1055								1	205.0	10.90	2.234
30											1148	108	1040	28.0				
40						6	1135				1167	107	1060					
50											1183	106	1077		2	221.0	11.40	2.519
60	2	85	105	130	95	7	1170		1230	1172	1202	1057	1097					
70											1280	104	1176					
80						8	1300				1322	103	1219		3	221.0	10.30	2.276
90											1297	102	1195	50.0				
100						9	1210											
110															4	221.0	10.20	2.254
120	3	85	95	125	95	10	*		1115									

*Thermocouple Inoperative

TOTAL END LOSSES = $0.0003605 (28.0 + 50.0) = 0.028 \text{ KW}$ NET KW = $(2.519 + 2.276) - 0.028 = 4.767 \text{ KW}$ or 0.953 KW/ft. AVERAGE TEMPERATURE DIFFERENCE = 1123°F

DISTANCE FROM TOP OF TEST SECTION	TEMPERATURE DATA														HEATER DATA			
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE	CURRENT	POWER
	RECORDER POINT NUMBER	OUTER (COLD) SURFACE				RECORDER POINT NUMBER	INNER (HOT) SURFACE				INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT				
		0°	90°	180°	270°		0°	90°	180°	270°								
inches		°F	°F	°F	°F		°F	°F	°F	°F	°F	°F	°F/ft.		Volts	Amps	KW	
0	1	70	85	125	80	4	650	760	815	730								
10																		
20						5	915											
30											988	96	892	30.0	1	175.0	9.45	1.654
40						6	990				1008	95	913					
50											1027	94	933					
60	2	75	90	110	85	7	1030		1070		1052	94	958		2	198.0	10.00	1.980
70											1089	93	996					
80						8	1130				1143	93	1050		3	199.0	9.00	1.791
90											1138	93	1045	40.0				
100						9	1050											
110																		
120	3	80	80	110	80	10	*		960						4	200.0	9.00	1.800

AVERAGE = 970

*Thermocouple Inoperative

TOTAL END LOSSES = 0.0003605 (30.0 / 40.0) = 0.025 KW

NET KW = (1.980 / 1.791) - 0.025 = 3.746 KW or 0.749 KW/ft.

AVERAGE TEMPERATURE DIFFERENCE = 970°F

DISTANCE FROM TOP OF TEST SECTION inches	TEMPERATURE DATA														HEATER DATA			
	MEASURED WITH THERMOCOUPLE										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE Volts	CURRENT Amps	POWER KW
	OUTER (COLD) SURFACE					INNER (HOT) SURFACE					INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT				
	RECORDER POINT NUMBER	RADIAL ORIENTATION				RECORDER POINT NUMBER	RADIAL ORIENTATION											
		0° °F	90° °F	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F								
0	1	70	80	110	75	4	530	620	640	590								
10																		
20						5	755								1	147.0	8.00	
30											813	92	721	35.6			1.176	
40						6	820				832	92	740					
50											838	91	747		2	169.0	8.50	
60	2	75	85	105	80	7	835		860		852	91	761				1.436	
70											880	91	789					
80						8	880				895	90	805		3	167.0	7.30	
90											871	90	781	42.7	.			
100						9	805											
110															4	170.0	7.50	
120	3	70	75	110	80	10	*		730								1.275	

*Thermocouple Inoperative

TOTAL END LOSSES = $0.0003605 (35.6 \div 42.7) = 0.028 \text{ KW}$

$$\text{NET KW} = (1.436 - 1.219) - 0.028 = 2.627 \text{ KW or } 0.525 \text{ KW/ft.}$$

AVERAGE TEMPERATURE DIFFERENCE = 763°F

DISTANCE FROM TOP OF TEST SECTION	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE	CURRENT	POWER
	OUTER (COLD) SURFACE				INNER (HOT) SURFACE				INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT						
	RECORDER POINT NUMBER	RADIAL ORIENTATION			RECORDER POINT NUMBER	RADIAL ORIENTATION												
inches		0° °F	90° °F	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F	°F	°F	°F	°F/ft.	Volts	Amps	KW	
0	1	65	70	100	70	4	425	495	495	460								
10																		
20						5	625								1	120.0	6.65	0.798
30											675	85	590	37.0				
40						6	675				689	85	604					
50											694	85	609		2	142.0	7.10	1.008
60	2	70	80	95	75	7	685		700		696	85	611					
70											695	85	610					
80						8	685				687	85	602		3	140.0	6.00	0.840
90											667	85	582	34.9				
100						9	620											
110															4	144.0	6.10	0.878
120	3	65	75	100	75	10	*		550									
													AVERAGE =		601			

*Thermocouple Inoperative

TOTAL END LOSSES = $0.0003605 (37.0 / 34.9) = 0.026$ KWNET KW = $(1.008 / 0.840) - 0.026 = 1.822$ KW or 0.364 KW/ft.AVERAGE TEMPERATURE DIFFERENCE = 601°F

Distance from Top of Test Section inches	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE	CURRENT	POWER
	OUTER (COLD) SURFACE					INNER (HOT) SURFACE					INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT				
	RECORDER POINT NUMBER	RADIAL ORIENTATION				RECORDER POINT NUMBER	RADIAL ORIENTATION											
		0°	90°	180°	270°		0°	90°	180°	270°								
		°F	°F	°F	°F		°F	°F	°F	°F	°F	°F	°F	°F/ft.		Volts	Amps	KW
0	1	60	65	90	65	4	330	375	375	355								
10																		
20						5	485								1	97.0	5.50	0.534
30											526	75	451	25.6				
40						6	535				543	75	468					
50											545	75	470		2	118.0	6.00	0.708
60	2	65	75	85	70	7	535		550		544	75	469					
70											540	75	465					
80						8	520				527	75	452		3	116.0	5.00	0.580
90											505	75	430	33.6				
100						9	465											
110															4	117.0	5.00	0.585
120	3	60	65	90	70	10	*		410									

AVERAGE = 458

*Thermocouple Inoperative

Total end losses = $0.0003605 (25.6 + 33.6) = 0.022 \text{ KW}$

Net KW = $(0.708 + 0.580) - 0.022 = 1.266 \text{ KW or } 0.253 \text{ KW/ft}$

Average temperature difference = 458°F

DISTANCE FROM TOP OF TEST SECTION	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE	CURRENT	POWER
	OUTER (COLD) SURFACE					INNER (HOT) SURFACE					INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT				
	RECORDER POINT NUMBER	RADIAL ORIENTATION				RECORDER POINT NUMBER	RADIAL ORIENTATION											
inches		0° °F	90° °F	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F	°F	°F	°F	°F/ft.		Volts	Amps	KW
0	1	120	115	120	120	4	1180	1120	1110	1190								
10																		
20						5	1245								1	240.0	12.50	3.000
30											1310	109	1201	65.0				
40						6	1355				1355	107	1248					
50											1390	106	1284		2	247.0	12.80	3.162
60	2	100	90	100	100	7	1420		1430		1420	105	1315					
70											1455	103	1352					
80						8	1490				1490	100	1390		3	244.0	11.50	2.806
90											1435	98	1337	235.0				
100						9	1120											
110															4	241.5	11.30	2.729
120	3	90	90	90	95	10	*		355									

*Thermocouple Inoperative

AVERAGE = 1304

TOTAL END LOSSES = 0.0003605 (65.0 + 235.0) = 0.108 KW

NET KW = (3.162 + 2.806) - 0.108 = 5.860 KW or 1.172 KW/ft

AVERAGE TEMPERATURE DIFFERENCE = 1304°F

DISTANCE FROM TOP OF TEST SECTION	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE	CURRENT	POWER
	OUTER (COLD) SURFACE					INNER (HOT) SURFACE					INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT				
	RECORDER POINT NUMBER	RADIAL ORIENTATION				RECORDER POINT NUMBER	RADIAL ORIENTATION											
inches		0° °F	90° °F	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F	°F	°F	°F	°F/ft.		Volts	Amps	KW
0	1	110	105	85	105	4	905	990	870	880								
10																		
20						5	1045								1	208.0	11.00	2.288
30											1115	99	1016	80				
40						6	1190				1190	97	1093					
50											1225	96	1129		2	222.0	11.50	2.553
60	2	90	110	95	90	7	1240	1260	1260		1250	95	1155					
70											1270	94	1176					
80						8	1290				1290	93	1197		3	221.0	10.30	2.276
90											1190	91	1099	280.0				
100						9	920											
110															4	222.0	10.20	2.264
120	3	85	85	85	85	10	*		300									
											AVERAGE = 1124							

*Thermocouple Inoperative

TOTAL END LOSSES = $0.0003605 (80.0 \div 280.0) = 0.126 \text{ KW}$ NET KW = $(2.553 \div 2.276) - 0.126 = 4.703 \text{ KW or } 0.941 \text{ KW/ft.}$ AVERAGE TEMPERATURE DIFFERENCE = 1124°F

DISTANCE FROM TOP OF TEST SECTION	TEMPERATURE DATA										HEATER DATA							
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE	CURRENT	POWER
	OUTER (COLD) SURFACE				RECORDER POINT NUMBER	INNER (HOT) SURFACE				INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT					
	RECORDER POINT NUMBER	RADIAL ORIENTATION				RADIAL ORIENTATION												
inches		0° °F	90° °F	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F	°F	°F	°F	°F/ft.		Volts	Amps	KW
0	1	100	100	85	100	4	760	830	740	750								
10																		
20						5	895								1	176.0	9.50	1.672
30											945	93	852	60.0				
40						6	990				986	92	892					
50											1018	91	927		2	197.0	10.00	1.970
60	2	90	105	90	85	7	1035		1055		1043	90	953					
70											1062	88	974					
80						8	1075				1073	87	986	320.0	3	198.0	9.00	1.782
90											950	85	865	320.0				
100						9	660											
110															4	200.0	8.90	1.780
120	3	80	80	80	80	10	*		205									

AVERAGE = 922

*Thermocouple Inoperative

TOTAL END LOSSES = 0.0003605 (60.0 / 320.0) = 0.137 KW

NET KW = (1.970 / 1.782) - 0.137 = 3.615 KW or 0.723 KW/ft.

AVERAGE TEMPERATURE DIFFERENCE = 922°F

DISTANCE FROM TOP OF TEST SECTION inches	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE			CALROD NUMBER	VOLTAGE Volts	CURRENT Amps	POWER KW	
	OUTER (COLD) SURFACE					INNER (HOT) SURFACE					INNER SURFACE	OUTER SURFACE	DIFFERENCE					GRADIENT
	RECORDER POINT NUMBER	0° °F	90° °F	180° °F	270° °F	RECORDER POINT NUMBER	0° °F	90° °F	180° °F	270° °F								
											°F	°F	°F	°F/ft.				
0	1	80	95	80	100	4	600	670	605	600								
10																		
20						5	760								1	148.0	7.80	1.154
30											800	88	712	30.0				
40						6	815				815	88	727					
50											842	88	754		2	170.0	7.45	1.266
60	2	85	100	85	80	7	850		860		855	88	767					
70											857	86	771					
80						8	860				860	84	776		3	168.0	7.45	1.252
90											740	82	658	220.0				
100						9	490											
110															4	172.0	7.60	1.207
120	3	75	75	75	75	10	*		170									
																</		

*Thermocouple Inoperative

TOTAL END LOSSES = $0.0003605 (30.0 \neq 220.0) = 0.090$ KWNET KW = $(1.266 \neq 1.252) - 0.090 = 2.428$ KW or 0.486 KW/ft.

AVERAGE TEMPERATURE DIFFERENCE = 738°F

DISTANCE FROM TOP OF TEST SECTION	TEMPERATURE DATA													HEATER DATA						
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE	CURRENT	POWER		
	OUTER (COLD) SURFACE				RECORDER POINT NUMBER	INNER (HOT) SURFACE				INNER SURFACE	OUTER SURFACE	DIFFERENCE	GRADIENT							
	RECORDER POINT NUMBER	RADIAL ORIENTATION				RADIAL ORIENTATION														
inches		0° °F	90° °F	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F	°F	°F	°F	°F/ft.		Volts	Amps	KW		
0	1	70	80	75	90	4	445	455	435	440										
10																				
20						5	490								1	96	5.5	0.528		
30											523-	78	445	20.0						
40						6	535				535	77	458							
50											533	76	457		2	118	6.0	0.708		
60	2	75	80	75	70	7	510		515		515	75	440							
70											505	74	431							
80						8	470				470	73	397		3	118	5.0	0.590		
90											385	72	313	170.0						
100						9	260													
110															4	118	5.0	0.590		
120	3	70	70	70	70	10	*		125											
													AVERAGE = 420							

*Thermocouple Inoperative

TOTAL END LOSSES = $0.0003605 (20.0 \div 170.0) = 0.068 \text{ KW}$ NET KW = $(0.708 \div 0.590) - 0.068 = 1.230 \text{ KW} = 0.246 \text{ KW/ft.}$ AVERAGE TEMPERATURE DIFFERENCE = 420°F

DISTANCE FROM TOP OF TEST SECTION inches	TEMPERATURE DATA													HEATER DATA				
	MEASURED WITH THERMOCOUPLES										FROM PLOTTED CURVE				CALROD NUMBER	VOLTAGE Volts	CURRENT Amps	POWER KW
	RECORDER POINT NUMBER	OUTER (COLD) SURFACE				RECORDER POINT NUMBER	INNER (HOT) SURFACE				INNER SURFACE °F	OUTER SURFACE °F	DIFFERENCE °F	GRADIENT °F/ft.				
		0° °F	90° °F	180° °F	270° °F		0° °F	90° °F	180° °F	270° °F								
0	1	75	90	75	95	4	500	535	505	510								
10																		
20						5	600							1	121.0	6.80	0.823	
30											646	83	563	40.0				
40						6	680				680	82	598					
50											691	82	609	2	144.5	7.25	1.048	
60	2	80	90	80	75	7	685		695		690	81	609					
70											683	80	603					
80						8	650				650	79	571	3	143.0	6.30	0.901	
90											566	78	488					
100						9	360											
110														4	148.0	6.40	0.947	
120	3	75	75	75	75	10	*		145									
													AVERAGE =	579				

*Thermocouple Inoperative

TOTAL END LOSSES = $0.0003605 (40.0 \neq 160.0) = 0.072 \text{ KW}$ NET KW = $(1.048 \neq 0.901) - 0.072 = 1.877 \text{ KW or } 0.375 \text{ KW/ft.}$ AVERAGE TEMPERATURE DIFFERENCE = 579°F

FIG. 10. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG. II. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG. 12. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG. 13. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG 14. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG. 15. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG. 19. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG. 20. DISTANCE FROM TOP OF HEATED TUBE-INCHES

FIG. 21. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG. 22. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG. 23. DISTANCE FROM TOP OF HEATED TUBE - INCHES

FIG. 24. DISTANCE FROM TOP OF HEATED TUBE-INCHES

FIG. 26. DISTANCE FROM TOP OF HEATED TUBE - INCHES

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