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KER LOOP 1 TUBE TEMPERATURES

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KER LOOP 1 TUBE TEMPERATURES

J. D. Agar
Reactor Design Analysis
NPR PROJECT

October 1, 1962

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October 1, 1962

KER LOOP 1 TUBE TEMPERATURESINTRODUCTION

The KER inpile test loop 1 has been operated for some time at conditions closely approaching those anticipated for Phase I operation of the NPR. This loop is one of four inpile, high pressure, high temperature recirculating test loops installed in KE Reactor. The process tubes associated with the four loops are located in enlarged, front to rear process channels close to the high flux region of the reactor.

The operating history of loop 1 can be categorized into two phases, each phase associated with a different Zircaloy-2 process tube of 2.40" O.D. The first phase of operation was from January, 1958 to April, 1960 and the second was from April, 1960 to the present date. The 0.311" wall process tube of phase 1 was replaced with the presently installed Zircaloy-2 process tube which has a 0.370" wall thickness.
 0.156" 0.185"

Maximum tube temperatures attained during the second phase of operation are of immediate interest. These temperatures will have some bearing on whether or not the tube will be removed for metallurgical examination. The purpose for such an examination would be to ascertain the expected metallurgical condition of the NPR process tubes after a given length of operating experience.

SUMMARY

Basic heat transfer calculations were performed with the aid of the IBM 7090 to determine the effect of varying system parameters on process tube temperatures and associated graphite temperatures of KER loop 1. A maximum tube wall temperature of ~~375-6-70897~~ 630°F was calculated for specific operating data depicting stringent conditions. This temperature can be compared to the predicted maximum tube wall temperature of 630°F to 730°F for NPR Phase I operation.(1)

332 388
 The important system parameters affecting tube wall temperatures were determined to be heat generation rates and sink temperature or water coolant temperature. Other parameters such as gas composition, that are applicable to KE Reactor, were found to be of small importance. Variations of position on the tube periphery did not affect the calculated temperatures significantly. All results are shown graphically and are tabulated in the appendix.

The curves in Figure IIIa through IIIId show the calculated outside tube wall temperature of tube #2 as a function of distance around the tube periphery, heat generation rate and sink temperature.

Heat generation rates for Zircaloy-2 and for graphite as a function of distance from the tube inlet were calculated for the two distinct flux distributions that were prevalent in KE reactor during the two operating phases of loop 1. The results are shown in Figures IV and V.

A crossplot was made of the temperature at the bottom position of the tube periphery versus heat generation rate, with sink temperature as a parameter; the results are presented in Figure VI.

(1) HW-63953, "NPR Process Tube Operating Temperatures," F. J. Mollerus, Jr., February 22, 1960.

Operating data was obtained for a severe operating period of phase 2 operation of loop 1. These data are presented in Figure VII along with a curve presenting the calculated maximum tube wall temperature as a function of distance from tube inlet. The present tube was maintained at these temperatures for about four months of operation. Other operating periods may have resulted in temperatures as severe as these but it is doubtful that a more severe operating period was maintained during either phase 1 or phase 2.

A plot of graphite temperature versus distance from the tube inlet is shown in Figure VIII. These temperatures represent node #24, shown on Figure II, and are maximum temperatures for a given position along a line of motion parallel to the tube axis.

DISCUSSION

The inpile geometry of the KER loop 1 complex is slightly different than that associated with the normal front to rear process tubes and graphite channels in KE Reactor. One main difference is the method of longitudinal support of the tube. The normal process tube in the K reactors, ideally, is supported in a concentric position relative to the graphite channel with the aid of trunnion blocks. The KER tube, on the other hand, is supported eccentrically on the graphite channel bottom. The other principal difference is the absence of both front and rear channel coring in the KER loop 1 graphite channel. Figure II is a descriptive sketch of the system model that was used. The dimensions of the associated graphite lattice are shown in Figure I.

The primary goal of this study was the determination of various temperature distributions in the KER process tube wall and surrounding graphite during phase 2 operation. The temperature distributions accompany given system parameters. The heat transfer calculations were performed with the aid of the IBM 7090. The FORTRAN heat transfer program that was used was written by F. J. Mollerus, Jr.⁽²⁾

Normally a three dimensional heat transfer problem such as would encompass the KER loop 1 system is difficult and time consuming to solve. The method of approach to this problem was to reduce it to one of two dimensional heat transfer. The model of the system was reduced to a very thin slab in the longitudinal or axial direction. The slab was reduced in thickness to the point at which no appreciable heat transfer occurred in the longitudinal direction. The outer surfaces of the model were so established as to remain essentially adiabatic, thus reducing the direction and sense of heat transfer to two dimensions; in an inner radial direction to a single heat sink and in a peripheral direction. The resulting temperature distributions are functions of system parameters such as heat generation rates, pile gas compositions, coolant water temperature, and physical constants such as thermal conductivity, emissivity, and area factors.

(2) HW-73668, "User's Manual for STEHP - A Steady State Heat Transfer Program for the IBM 7090 Computer," F. J. Mollerus, Jr., May, 1962.

KER LOOP 1

LATTICE DIMENSIONS

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1.724 ± 0.05 ID
1.510 - OD
1.635 - 120°
5.20

KER LOOP 1
TEMPERATURE NODE DESIGNATION

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NOTE:

"A" = 2.089" FOR TUBE #1

"A" = 2.030" FOR TUBE #2

The two dimensional heat transfer slab was divided into appropriately spaced temperature nodes as is shown in Figure II. The standard relaxation method was used to solve for the temperatures of the nodes. The variation of tube and graphite temperatures with distance from the tube inlet towards the tube outlet were handled by making cross plots of a series of curves showing the variation of tube and graphite temperature with sink temperature and heat generation; the heat sink is the water coolant flowing through the tube. The cross plots were made with the aid of calculated heat generation rate curves and coolant temperature data. The coolant temperature data was measured during a previous operating period of phase 2 operation that was designated as one of the most severe with regards to maximum coolant temperature and flux location.

The following tables are lists of physical constant values used during the series of calculations.

TABLE I

PHYSICAL CONSTANTS

<u>Items</u>	<u>Value</u>	<u>Units</u>
Contact coefficient of tube block	500	Btu/hr-ft ² -°F
Emissivity of graphite	0.98	
Emissivity of Zircaloy-2	0.50	
Heat transfer coefficient - water side	∞	Btu/hr-ft ² -°F
Thermal conductivity of Zircaloy-2	6.5	Btu/hr-ft ² -°F/ft

TABLE II

GRAPHITE THERMAL CONDUCTIVITY

Btu/hr-ft²-°F/ft

<u>K</u>	<u>T°F</u>
2.10	140
4.60	356
7.00	464
7.98	572
8.61	662
8.96	752
8.84	842
8.33	1,110
6.44	2,160

TABLE III

PILE GAS THERMAL CONDUCTIVITY - 100% He

Btu/hr-ft²-°F/ft

<u>K</u>	<u>T°F</u>
.081	32
.103	261
.137	621
.171	981

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RESULTS

The results of the study are presented in graphical form on Figures III through VIII and in tabular form in the appendix. The tabulated results are for the convenience of those who would require a different set of cross plots than those presented in the body of the report.

Figures IIIa through IIIId show the effects of the significant system parameters on tube surface temperature. These curves represent the bases for additional cross plots. The geometry of the graphite stack prevents a large temperature gradient around the tube periphery, although such a temperature gradient is more pronounced at the higher heat generation rates.

Figures IV and V are graphical representations of calculated heat generation rates at the KE reactor based upon operating flux distribution history. The values for the curves have been calculated in the form of heat generation rates in the graphite moderator and in the Zircaloy-2 process tube walls to facilitate expressing the final results in usable form.

Figure VI is a cross plot of the data represented in Figure III. The outer surface temperature of the tube wall, at the bottom contact point, is plotted versus Zircaloy-2 heat generation rate with sink temperature as a parameter. The temperature of the tube surface at any position can be plotted readily by extrapolation of the calculated nodes shown in Figure II. Because of the geometrical symmetry of the system, this extrapolation can be done with reasonable accuracy. Although Zircaloy-2 heat generation rate is plotted on the abscissa, reference can be made to heat generation of either substance, Zircaloy-2 or graphite, because of the symmetry of the representative operating flux curve.

The data for the coolant temperature curve shown on Figure VII was obtained from measured experimental data for an operating run for KEER loop 1 of four months duration. This operating run, from December, 1960 to April, 1961, represents one of the most severe during phase 2 operation with regards to maximum coolant temperature and flux peak location. The curve representing the calculated tube wall surface temperature, at the bottom contact point, versus position from the tube inlet was determined from the previous cross plot of Figure VI, the coolant water temperature curve of VII and the appropriate heat generation rate curve of Figure IV. A maximum tube wall temperature of 703°F was calculated for a point 294" from the tube inlet. This temperature falls in the range of predicted tube wall temperatures calculated for NPR Phase I operation. The temperature range, 630° to 730°F , was calculated by F. J. Mollerus, Jr. with the aid of the same FORTRAN program that was used for this study.

The curve of maximum graphite temperature versus position in Figure VIII was produced in a similar manner as the tube wall temperature curve of Figure VII. This maximum temperature occurred at node 24 in all cases.

Finally, calculated temperatures for all nodes shown on Figure II are included in the Appendix. Cross plots of other temperature nodes may be accomplished in a like manner described above. The presented plots were chosen to show maximum temperatures of both the graphite moderator and the tube wall.

J. D. Agar

Reactor Design Analysis
NPR PROJECT SECTION

JD Agar:bsm

FIGURE III a
TUBE OUTER SURFACE
KER-LOOP 1
TUBE # 2

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10-10-10 100 10 350 14

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FIGURE III c
TUBE OUTER SURFACE
KER LOOP 1
TUBE " 2

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ZIRCALOY-2 HEAT GEN: 90 BTU
HR-FT²

FIGURE III a
TUBE OUTER SURFACE

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KER LOOP 1
TUBE # 2

ZIRCALOY-2 HEAT GEN = 12.9 ^{137U} MW/IN²
PARAMETER (SINK TEMP)

FIG. 10X10 - 35914

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FIGURE IV
HEAT GENERATION RATE
KE REACTOR
KER LOOP I
(APR 1960 - OCT 1961)

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FIGURE IV
HEAT GENERATION RATE
KE REACTOR
KER LOOP 1
(OCT 1967 - AUG 1968)

FIGURE VI

TUBE OUTER SURFACE TEMP
(BOTTOM POSITION)
KER LOOP 1
TUBE # 2

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FIGURE VII
COOLANT WATER TEMPERATURE

FIGURE VIII

KEP LOOP 1
TUBE #2

CALCULATED MAXIMUM GRAPHITE TEMPERATURES

100% He

NOTE:

THESE CALCULATED DATA
CORRESPOND TO THE
MEASURED WATER
COOLANT AND FLUX
DATA OF FEB. 1961

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APPENDIXTABLE ICALCULATED NODE TEMPERATURES**DECLASSIFIED**Parameters:Zirc-2 Heat generation 24 Btu
Tube #2 hr-in³

Sink Temp	100° C	150° C	200° C	250° C	300° C	350° C
Node	Temperature - °F					
1	231.1	321.3	411.3	501.3	591.1	681.0
2	227.5	317.5	407.6	497.6	587.5	677.6
3	226.3	316.2	406.1	496.1	586.1	676.2
4	246.2	314.5	404.5	494.5	584.6	674.7
5	243.1	333.4	423.5	513.4	603.2	692.9
6	236.7	326.7	416.7	506.7	596.7	686.7
7	234.8	324.5	414.5	504.5	594.5	684.6
8	231.9	321.7	411.7	501.8	591.9	682.1
9	253.4	343.1	432.5	521.8	611.0	700.1
10	260.1	348.3	436.8	525.4	614.2	703.2
11	270.8	357.3	444.7	532.6	620.8	709.3
12	275.3	361.1	448.1	535.7	623.7	712.1
13	267.9	354.1	441.6	529.8	618.3	706.9
14	271.0	356.5	443.6	531.5	619.8	708.4
15	280.6	664.7	456.8	538.0	625.8	714.1
16	283.7	367.5	453.4	540.4	628.1	716.4
17	291.3	372.3	456.9	543.3	630.5	718.4
18	288.2	369.6	454.5	541.2	628.7	716.9
19	296.9	377.3	461.3	547.4	634.5	722.4
20	297.4	378.1	462.2	548.4	635.6	723.6
21	301.0	380.9	464.6	550.6	637.6	725.5
22	391.4	461.3	536.3	614.7	695.1	777.4
23	407.8	475.7	549.6	627.2	707.2	789.6
24	412.1	479.4	553.1	630.8	711.0	793.7
25	301.3	380.7	464.2	550.0	636.9	724.7
26	365.9	438.9	517.5	597.3	679.6	763.4
27	387.1	457.2	533.0	612.4	693.9	777.4
28	292.5	372.9	457.3	543.7	631.0	719.0
29	353.4	427.5	506.3	588.0	671.2	755.7
30	373.7	444.9	521.8	602.2	684.7	768.9
31	337.7	412.3	492.4	575.8	660.7	747.1
32	371.3	441.9	518.9	599.7	682.7	767.7

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TABLE II

CALCULATED NODE TEMPERATURES

Parameters:

Zirc - 2 Heat Generation 42 Btu
Tube #2 hr-in³

Sink Temp Node	100° C	150° C	200° C	250° C	300° C	350° C
	Temperature °F					
1	245.9	330.1	426.1	515.9	605.6	695.2
2	239.4	329.4	419.4	509.5	599.5	689.4
3	237.0	326.9	416.9	506.9	597.0	687.2
4	234.0	324.0	414.0	504.1	594.3	684.6
5	267.4	357.6	447.6	537.2	626.7	716.0
6	255.5	345.5	435.6	525.6	615.6	705.6
7	251.9	341.6	431.6	521.7	611.8	702.1
8	246.9	336.7	426.8	517.0	607.3	697.7
9	285.3	374.3	463.1	551.6	640.1	728.4
10	295.7	382.7	470.2	579.0	645.9	734.1
11	313.1	397.8	483.7	570.2	657.3	745.0
12	320.4	404.3	489.5	575.7	662.6	750.1
13	307.7	392.2	478.2	565.2	652.5	740.2
14	312.3	396.0	481.5	568.1	655.4	743.2
15	327.6	409.6	493.8	579.4	660.0	753.3
16	332.8	414.4	498.3	583.7	670.2	757.5
17	343.5	421.5	503.5	587.9	673.4	760.0
18	338.1	417.0	499.7	584.6	670.7	757.9
19	351.7	429.5	511.2	595.3	680.8	767.8
20	353.0	431.2	513.2	597.3	683.0	770.2
21	358.3	435.7	517.2	601.0	686.6	773.7
22	498.5	562.4	631.4	704.3	780.0	858.6
23	522.5	584.9	652.9	725.4	801.4	880.8
24	528.6	590.9	659.0	731.8	808.6	889.1
25	358.2	435.0	516.0	599.6	684.9	771.7
26	460.8	528.3	600.7	676.6	754.9	835.6
27	491.5	556.5	627.0	701.7	779.6	860.7
28	344.4	422.2	504.2	588.7	674.5	761.6
29	441.5	510.4	584.3	661.7	741.2	822.8
30	470.7	537.1	609.2	685.3	764.3	846.4
31	414.5	485.2	561.9	642.2	724.8	809.9
32	465.6	531.9	604.5	681.5	761.7	845.4

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TABLE III

CALCULATED NODE TEMPERATURES

Parameters:

Zirc. 2 Heat Generation 90 Btu/hr-in³
Tube #2

Sink Temp Node	100°C	150°C	200°C	250°C	300°C	350°C
	Temperature °F					
1	283.0	372.8	462.3	551.6	640.9	730.0
2	269.1	359.1	449.1	539.1	629.1	719.1
3	263.9	353.9	444.1	534.3	624.6	714.9
4	257.9	348.0	438.4	528.8	619.3	709.9
5	327.8	417.4	506.5	595.3	683.9	772.4
6	302.4	392.5	482.6	572.6	662.6	752.6
7	294.5	384.5	474.8	565.2	655.7	746.2
8	284.4	374.7	465.3	556.0	646.9	737.8
9	363.0	450.0	536.7	623.3	709.9	796.6
10	381.1	465.6	550.8	636.5	722.7	809.2
11	413.0	494.4	577.4	661.5	746.5	832.1
12	427.3	507.6	589.9	673.5	755.2	843.6
13	399.5	481.3	564.8	649.1	744.3	820.6
14	407.7	488.8	571.8	656.1	741.6	828.2
15	436.1	515.0	596.3	679.4	763.9	849.9
16	446.9	525.3	606.3	689.2	773.7	859.6
17	457.8	532.6	611.2	692.0	775.1	861.1
18	449.3	525.6	605.4	687.6	772.1	859.2
19	474.8	549.8	628.5	710.0	794.1	880.6
20	479.6	555.0	634.1	715.9	800.3	887.0
21	488.3	563.1	641.7	723.3	807.8	894.8
22	716.9	773.2	824.8	900.4	969.8	1,043
23	759.9	817.1	880.0	947.2	1,018	1,093
24	772.4	830.8	895.5	964.7	1,038	1,115
25	485.1	559.2	637.2	718.3	802.4	889.1
26	657.7	718.3	783.6	852.9	925.9	1,003
27	709.5	769.2	834.9	905.2	979.3	1,057
28	459.3	534.6	613.7	695.6	780.0	867.2
29	625.4	688.0	755.0	826.0	900.5	978.6
30	674.2	735.6	802.9	874.9	950.9	1,031
31	578.7	646.2	719.2	796.6	878.2	963.3
32	664.7	727.5	796.8	871.5	950.9	1,034

TABLE IV

CALCULATED NODE TEMPERATURES

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Parameters:

Zirc-2 Heat Generation 129 Btu/hr-in³
Tube #2

Sink Temp Node	100°C	150°C	200°C	250°C	300°C	350°C
	Temperature °F					
1	316.6	405.7	494.8	583.7	672.6	761.4
2	296.3	386.4	476.4	566.5	656.4	746.4
3	289.0	379.2	469.6	560.0	650.4	740.8
4	280.4	370.9	461.6	552.2	643.0	733.8
5	382.5	471.1	559.4	647.5	735.5	823.4
6	345.8	435.9	526.1	616.2	706.2	796.1
7	334.6	425.0	515.6	606.2	696.9	786.7
8	320.3	411.2	502.3	593.4	684.7	776.1
9	432.0	416.8	601.8	686.9	772.1	857.7
10	456.9	539.6	623.2	707.4	792.0	877.2
11	501.7	581.2	662.3	744.3	827.4	911.2
12	523.1	601.4	681.5	762.8	845.6	929.2
13	478.6	558.6	640.1	723.1	807.7	893.3
14	491.2	570.8	652.3	735.5	820.2	905.8
15	531.8	609.1	688.8	770.3	853.9	938.3
16	548.9	625.6	704.8	785.9	869.5	953.8
17	553.7	627.0	703.6	783.7	867.8	953.5
18	544.9	620.3	699.0	781.0	866.2	952.8
19	582.4	656.4	734.1	815.4	899.8	985.3
20	592.1	666.4	744.4	825.9	910.6	996.3
21	603.9	677.7	755.4	837.2	922.3	1,008
22	888.8	942.1	1,000	1,063	1,131	1,201
23	957.6	1,013	1,073	1,138	1,208	1,280
24	981.6	1,039	1,102	1,170	1,243	1,318
25	595.8	669.1	746.4	827.7	912.4	998.2
26	814.0	871.8	934.3	1,002	1,074	1,149
27	890.9	950.0	1,014	1,083	1,157	1,233
28	558.0	632.5	710.8	792.7	878.2	965.2
29	771.7	831.5	896.1	965.0	1,039	1,115
30	842.9	904.1	970.6	1,042	1,118	1,196
31	716.2	784.3	858.1	93.6	1,020	1,105
32	832.8	897.5	968.4	1,044	1,125	1,208