CLASSIFICATION CHANGED TO:

BY AUTHORITY OF:

BY:

Unclassified
E J Murphy 11-26-56
M. Shirley

OFFICIAL USE ONLY

ORNL
CENTRAL FILES NUMBER
55-5-142

Date: May 23, 1955

Copy No. 21

To: T. E. Cole

From: J. P. Sanders

Subject: OPERATING CONDITIONS OF THE ORR COOLING SYSTEM AT 20 MW

DISTRIBUTION

1. F. T. Binford	11. S. H. Hanauer
2. R. E. Briggs	12. J. A. Lane
3. J. B. Brown	13. N. F. Lansing
4. C. D. Cagle	14. J. P. Sanders
5. L. H. Chase	15. J. A. Swartout
6. T. E. Cole	16. H. W. Watts
7. J. A. Cox	17. A. M. Weinberg
8. J. E. Cunningham	18. C. E. Winters
9. W. R. Gall	19-23. Laboratory Records
10. J. P. Gill	24. ORNL RC
	25. Central Research Library

OFFICIAL USE ONLY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT:

The calculation of the flow requirements in the main reactor cooling loop of the ORR has been revised and corrected. The present requirements assume an inlet water temperature of 120°F and a maximum heat flux of 6×10^5 Btu/hr-ft² for 30 Mw operation and 4×10^5 Btu/hr-ft² for 20 Mw. A gap width of 0.116 inches was used in these calculations.

A graphical representation of the maximum surface temperature which is to be expected in the reactor lattice as a function of the total flow in the main reactor cooling loop is presented in this report. Separate curves give this representation both for 20 Mw and 30 Mw operation. For the following maximum allowable surface temperatures these total flow requirements are shown:

Power Level (Mw)	Maximum Allowable Surface Temperature (°F)	Required Total Flow Rate (gpm)
20	210	11,000
20	204	12,000
20	200	12,750
30	220	15,600
30	210	17,800
30	209	18,000

OPERATING CONDITIONS OF THE
ORR COOLING SYSTEM AT 20 MW

INTRODUCTION:

The basis for the calculation of the heat transfer rates and the required coolant velocities has been established in a previous memorandum⁽³⁾. In a subsequent report⁽⁴⁾ the maximum heat flux was established as a function of the reactor power level, and the assumptions necessary to determine the total coolant flow in the main circulating loop were listed. These previous calculations⁽⁴⁾ were listed for proposed reactor power levels of 5, 10, and 30 megawatts and were based on the dimensions of a fuel section similar to the one in use in the MTR at that time. In addition, contrary to the established basis the gap width was used as the equivalent diameter in calculating the heat transfer coefficient rather than twice the gap width.

These calculations have been corrected and revised on the basis of the present design power level of the ORR of 20 megawatts and an extended power of 30 megawatts and also for the dimensions of the modified fuel sections now planned for use in the ORR. These calculations and results are given in this report.

CALCULATION OF COOLANT FLOW RATE AT 20 MW:

In the report, ORNL CF 54-3-169⁽⁴⁾, the maximum heat flux, Q_0 , in the reactor for 30 megawatt operation is 600,000 Btu/hr-ft², and this flux may be assumed to be proportional to the total power over the range from 5 to 30 megawatts. Therefore the expected maximum heat flux for

20 megawatts is 400,000 Btu/hr-ft². Economic studies have indicated that 120°F is a reasonable outlet temperature from the air-cooled heat exchangers which have been specified for the ORR cooling system; therefore, this temperature has been established as the inlet reactor temperature, T_{W1} .

Continuing with the nomenclature established in ORNL CF 54-3-57⁽³⁾, the total heat flow per unit width of plate for 20 Mw operation is

$$\begin{aligned} H &= 3.241 \times 10^{-4} Q_o L \\ &= (3.241 \times 10^{-4})(4.0 \times 10^5)(2.781) \\ &= 360.5 \text{ Btu/ft-sec.} \end{aligned}$$

The change in temperature of the coolant passing through this channel is therefore

$$\Delta T = H/G = 360.5/G \text{ } ^\circ\text{F}$$

where G is the coolant flow rate per unit width of plate in pounds/ft-sec.

The average temperature of the water in the channel is thus

$$\begin{aligned} t &= T_{W1} + \Delta T/2 \\ &= 120 + 180.3/G \end{aligned}$$

where t is in °F.

The mass flow rate per unit width, G, appears to be a convenient quantity in which to express the other variables, and the conventional mass flow rate, G', in pounds/ft²-sec may be found in terms of G by dividing by the flow area per unit width of plate. For the proposed assemblies the gap width is 0.116 inches and thus the flow area per foot of width is 0.00967 square feet. G' is found to be

$$G' = G/0.00967 = 103.4 G.$$

The heat transfer coefficient, h , was obtained from the empirical equation given in McAdams⁽²⁾. This is the same empirical equation used in previous computations. The equation is

$$h = 5.6 (1 + 0.011 t)(G')^{0.8}/(D')^{0.2}$$

The symbol, D' , designates the equivalent hydraulic diameter in inches; the heat transfer coefficient, h is in Btu/hr-ft²-°F. In terms of the mass flow rate per unit width, G , the quantities are

$$1/(D')^{0.2} = 1/(2 \times 0.116)^{0.2} = 1.339$$

$$(G')^{0.8} = (103.4 G)^{0.8} = 40.89 G^{0.8}$$

$$1 + 0.011 t = 1 + 0.011 (120 + 180.3/G)$$

$$= 2.320 + 1.983/G$$

$$h = (5.6)(1.339)(40.89 G^{0.8})(2.320 + 1.983/G)$$

$$= 306.7 G^{0.8} (2.320 + 1.983/G).$$

As described in the previous report⁽³⁾, the point of maximum surface temperature, x , may be determined from

$$\tan \pi x/L = - 3600 \pi C_p G/2 h L$$

$$= - 2033 G/h.$$

From this value of the tangent the value of $\sin \pi x/L$ and $\cos \pi x/L$ may be read from the tables⁽¹⁾ and the maximum temperature of the surface in contact with the coolant, T_m , is found

$$T_m = T_{w1} + \frac{2 Q_o L}{3600 G C_p \pi} (0.9165 - \cos \pi x/L) + (Q_o/h) \sin \pi x/L$$

$$= 120 + 4 \times 10^5 \left[(0.9165 - \cos \pi x/L)/2033 G + (1/h) \sin \pi x/L \right].$$

The liner velocity, V , in ft/sec is given in terms of the mass flow rate

per unit width, G, by

$$V = 103.4 G S$$

where S is the specific volume of the coolant in ft^3/pound .

It is assumed, as in ORNL CF 54-3-169⁽⁴⁾, that the maximum loading will include 24 standard fuel assemblies and 4 shim rod fuel assemblies, and that this total number is equivalent in flow requirements to 27 regular fuel assemblies. The fuel elements which are, at present, proposed for use in the ORR have 18 gaps which are 0.116 inches by 2.621 inches. The flow area inside the fuel assembly is thus 5.47 square inches or 0.0380 square feet. For a linear velocity through the fuel assembly of V, the total flow through the fuel assemblies, F, in gal/min is

$$\begin{aligned} F &= (27)(0.0380)(7.481)(60) V \\ &= 460.5 V \end{aligned}$$

where 7.481 is the number of gal/ft^3 and 60 is sec/min .

Based on the ratio of flows in the MTR, as in ORNL CF 54-3-169⁽⁴⁾, it is assumed that flow outside of the fuel assemblies and through external by-passes is 20 percent of the flow through the assemblies. Thus the total flow in the main reactor cooling loop is F_T as found by

$$F_T = (1.2)(460.5) V = 552.6 V$$

where, as before, V is the linear velocity in the fuel assemblies in ft/sec .

Various values of G have been assumed and the corresponding values of T_m and V and F_T have been calculated and recorded in Table No. 1.

TABLE NO. 1

CALCULATION OF COOLANT FLOW RATE AT 20 MW

Quantity*	Value						
G	6	8	10	12	14	16	18
$G^{0.8}$	4.19	5.28	6.30	7.30	8.26	9.19	10.09
t	150.0	142.5	138.0	135.0	132.9	131.3	130.0
h	3406	4158	4866	5564	6237	6889	7520
$\tan \pi x/L$	- 3.581	- 3.911	- 4.178	- 4.385	- 4.563	- 4.722	- 4.866
$\sin \pi x/L$	0.9631	0.9688	0.9725	0.9750	0.9768	0.9783	0.9795
$\cos \pi n/L$	- 0.2689	- 0.2477	- 0.2328	- 0.2223	- 0.2141	- 0.2072	- 0.2013
$0.9165 - \cos \pi x/L$	1.1854	1.1642	1.1493	1.1388	1.1306	1.1237	1.1178
$(2033.4 \text{ G}) 10^{-4}$	1.2200	1.6267	2.0334	2.4401	2.8468	3.2534	3.6601
$[(0.9165 - \cos \pi x/L)/2033.4 \text{ G}] 10^4$	0.972	0.716	0.565	0.467	0.397	0.345	0.305
$(1/h)(\sin \pi x/L) 10^4$	2.828	2.330	1.999	1.752	1.566	1.420	1.303
$S(10^2)^{**}$	1.634	1.631	1.628	1.627	1.626	1.625	1.625
T_m	272.0	241.8	222.6	208.8	198.5	190.6	184.3
V	10.14	13.5	16.8	20.2	23.5	26.9	30.2
F_T	5603	7460	9284	11163	12986	14865	16688

* These symbols are as defined in the preceeding paragraph

** These values of the specific volume are given for the value of "t" as listed in Keenan, J. H., and Keyes, F. G., Thermodynamic Properties of Steam, 1st Edition, John Wiley & Sons, Inc. (1936).

CALCULATION OF COOLANT FLOW RATE AT 30 MW:

The flow required for 30 Mw operation was recalculated for the new fuel elements and an inlet water temperature, T_{W1} , of 120°F. The maximum heat flux, Q_o , is 600,000 Btu/hr-ft². The total heat flow per unit width of plate is

$$H = 3.241 \times 10^{-4} Q_o L = 540.7 \text{ Btu/ft-sec.}$$

The change in temperature of the water flowing past the plate, ΔT , and the average temperature, t , are found in terms of the mass flow rate per unit width, G , as

$$\Delta T = 540.7/G$$

$$t = T_{W1} + \Delta T/2 = 120 + 270.3/G.$$

For a gap width of 0.116 inches or 0.00967 feet, G' is related to G as in the previous section by

$$G' = G/0.00967 = 103.4 G.$$

The heat transfer coefficient is thus found

$$h = 306.7 G^{0.8} (2.320 + 2.973/G)$$

As before the relationships of velocity, V , and the quantity, $\tan \pi x/L$, are found in terms of G to be

$$V = 103.4 G S$$

$$\tan \pi x/L = - 2033 G/h,$$

and the maximum temperature, T_m , is

$$T_m = 120 + 6 \times 10^5 \left[(0.9165 - \cos \pi x/L)/2033 G + (1/h) \sin \pi x/L \right].$$

The same assumptions concerning the number of fuel assemblies and the total flow external to the fuel assemblies apply to 30 Mw operation; and, as in the previous calculations, the total flow, F_T , in gal/min is

$$F_T = 552.6 V$$

Various values of the mass flow rate per unit width, G , are now assumed and the corresponding calculated values are reported in Table No. 2.

TABLE NO. 2

CALCULATION OF COOLANT FLOW RATE AT 30 MW

Quantity*	Value						
G	8	10	12	14	16	18	20
$G^{0.8}$	5.28	6.30	7.30	8.26	9.19	10.09	11.00
t	153.8	147.0	142.5	139.3	136.9	135.0	133.5
h	4359	5056	5749	6414	7063	7690	8330
$\tan \pi x/L$	- 3.731	- 4.021	- 4.244	- 4.437	- 4.605	- 4.759	- 4.881
$\sin \pi x/L$	0.9659	0.9705	0.9733	0.9755	0.9772	0.9786	0.9796
$\cos \pi x/L$	- 0.2589	- 0.2414	- 0.2293	- 0.2199	- 0.2122	- 0.2056	- 0.2007
$0.9165 - \cos \pi x/L$	1.1754	1.1579	1.1458	1.1364	1.1287	1.1221	1.1172
$(2033.4 \text{ G}) 10^{-4}$	1.6267	2.0334	2.4401	2.8468	3.2534	3.659	4.067
$[(0.9165 - \cos \pi x/L)/2033.4 \text{ G}] 10^4$	0.723	0.569	0.470	0.339	0.347	0.307	0.275
$(1/h)(\sin \pi x/L) 10^4$	2.216	1.920	1.693	1.521	1.384	1.273	1.176
$S (10^2)^{**}$	1.636	1.633	1.631	1.629	1.628	1.627	1.626
T_m	296.3	269.3	249.8	235.2	223.9	214.8	207.1
V	13.5	16.9	20.2	23.6	26.9	30.3	33.6
F_T	7460	9339	11163	13041	14865	16744	18567

* These symbols are as defined in the preceeding paragraphs

** These values of the specific volume are given for the value of "t" as listed in Keenan, J. H., and Keyes, F. G., Thermodynamic Properties of Steam, 1st Edition, John Wiley & Sons, Inc. (1936).

GRAPHICAL REPRESENTATION OF RESULTS:

Figure No. 1 presents a graphical representation of the total flow required in the reactor system, based on the foregoing assumptions, and the corresponding maximum temperature developed on the surface of the fuel assembly in contact with the coolant.

BIBLIOGRAPHY

- (1) Comrie, L. J., Chambers's Six-Figure Mathematical Tables, Vol. II, Natural Values, D. Van Norstrand Co., Inc., New York (1949). Table IIc.
- (2) McAdams, W. H., Heat Transmission, 2nd Ed., McGraw-Hill Book Co., Inc., New York, (1942), P. 183, Equation (9).
- (3) Sanders, J. P., "Heat Transfer and Pressure Loss in Proposed ORR Fuel Assemblies", ORNL CF 54-3-57, March 11, 1954.
- (4) Sanders, J. P., "Operating Conditions of the ORR Cooling System", ORNL CF 54-3-169, March 19, 1954.