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UNCLASSIFIED QUARTERLY REPORT OF THE
REACTOR ENGINEERING DIVISION

January 1, 1955 through March 31, 1955

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I. HEAT TRANSFER

A. Effect of Channel Geometry on the Power Density of a Natural Circulation Boiling Channel at 300 psia - P. A. Lottes

Calculations were made to study the effect of changing either height or width of a boiling channel on the power density of the channel. The following assumptions were made:

1. Steam to water velocity ratio = $1 + (3/V_{in})$ (for 300 psia)
2. Friction factor multiplier = $1 + 100x$
where x = steam weight flow fraction
3. Saturated water at inlet
4. No entrance or exit losses
5. Constant heat flux with channel length.

Assumption 1 is an approximation of Argonne data reported in ANL-5371.¹

Assumption 2 is an approximation of Martinelli-Nelson type friction factor multipliers.² Assumption 4 was made to simplify the calculations; inclusion of entrance and exit losses would show even less effect of height, since these losses can be expressed in terms of increased friction or increased L/D of the channel.

Calculations covered the following ranges of variables:

Channel height, ft	2 to 6
Channel width, in.	1/4 to 1/2
Average volume fraction of steam	0 to 0.3

¹Reactor Engineering Division Quarterly Report, ANL-5371 (January 15, 1955).

²R. C. Martinelli, D. B. Nelson, "Prediction of Pressure Drop During Forced Circulation Boiling of Water," Trans. ASME, 70, 695-702 (1948).

The results are given in Figs. 1 to 4. Over the range of steam volume fraction considered, it was found that:

1. For a given value of average steam volume fraction, the total power output of a natural circulation boiling channel is independent of channel height.
2. For a given value of average steam volume fraction, the power density of a natural circulation boiling channel increased slightly with increased channel spacing.

B. Effect of Preferred Void Distribution on Void Measurements -
W. H. Cook, R. R. Rohde

An experimental determination of the effect of preferential void distribution and geometry on void measurements in channels has been made with a thulium source. The experiment was performed to investigate the effect of preferential void distributions on void measurements to check the assumption that the gamma rays are exponentially attenuated, and to establish necessary corrective measures and insure dependable void data.

Channel configurations were constructed with a single and double channel geometry with spacings of 1/4 and 1/2 in. between plates. Lucite blocks of a known size were inserted, as shown in Fig. 5, to simulate water in the channels and to introduce known void fractions into the channel. The expression for the channel voids as a function of the Lucite thickness is given by:

$$x = 1 - \frac{t}{d}$$

where

x = channel voids

t = Lucite thickness, in.

d = channel width, in.

Figure 6 depicts the geometries involved in the study. Typical curves showing the variations encountered appear in Fig. 7. The data are listed in Table I. The dashed curve in Fig. 7 represents the average of per cent error in void fraction for cases 1 to 4 if preferential void distributions are not stable situations.

To check the assumed exponential attenuation of the gamma rays from the thulium source, a tank was filled with water, in graduated amounts, as shown in Fig. 8. Sample data for this study are identified as Runs No. W-8, W-10, and W-11 in Table II. The error curves are shown in Fig. 9. This phase of the experiment also served to substantiate the Lucite block investigation and to check the effect of spacing of the channel walls.

FIG. 1
EFFECT OF CHANNEL HEIGHT ON
INLET VELOCITY FOR 1/4-inch CHANNEL

FIG. 2
EFFECT OF CHANNEL WIDTH ON POWER DENSITY
AT CONSTANT AVERAGE STEAM VOLUME FRACTION

RE-7-15931-A
P.A.LOTTES:V.H., 5-16-55

FIG. 3
EFFECT OF CHANNEL HEIGHT ON
POWER DENSITY FOR 1/4-inch CHANNEL

FIG. 4
EFFECT OF CHANNEL HEIGHT (2, 4, AND 6 ft)
ON TOTAL POWER FOR 1/4-inch CHANNEL

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P.A.LOTTES:V.H.,5-16-55

FIG. 5
SCHEMATIC OF VOID DISTRIBUTION
APPARATUS (PLAN VIEW)

CASE	RUN NO.	NO. OF CHANNELS	CHANNEL WIDTH, in.	SOURCE DISTANCE, in.
R AND C	1	1	1/2	6
	2	1	1/4	6
	3	1	1/2	15
	3a	1	1/2	15
	4	1	1/4	15
1, 2, 3	5	2	1/2	15
1, 2, 3	6	2	1/4	15
1, 2, 3	7	2	1/4	6
4	8	2	1/2	6
4	9	2	1/2	15

FIG. 6
CHANNEL GEOMETRIES USED IN
VOID DISTRIBUTION STUDY

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R.R.ROHDE:H.S., 5-11-55

FIG. 7
DEVIATION OF VOID FRACTION
IN RUNS NO. 5 AND NO. 8

Table I

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VOID DISTRIBUTION TEST - RUNS NO. 5 AND NO. 8

<u>Source Distance = 15 in.</u>			<u>Number of Channels = 2</u>			<u>Width of Channel = 1/2 in.</u>		
<u>Run No.</u>	<u>Case</u>	<u>Void Fraction</u>	<u>Void Intensity Reading</u>	<u>Full Channel</u>	<u>Empty Channel</u>	<u>Calc. Void Intensity Reading</u>	<u>Per cent Error in Void Intensity Reading</u>	<u>Per cent Error in Void Fraction</u>
				<u>Void Intensity Reading</u>	<u>Void Intensity Reading</u>			
5	1	0.136	0.330			0.381	-13.4	-93.
	2	.136	.405			.381	+6.3	+43.6
	3	.136	.370			.381	-2.9	-20.
	1	.260	.367			.434	-15.5	-56.
	2	.260	.508			.434	+17.1	+62.
	3	.260	.440	0.330	0.955	.434	+1.3	+4.7
	1	.508	.538			.565	-4.8	-8.9
	2	.508	.690			.565	-22.1	+41.
	3	.508	.620			.565	+9.8	+18.
	1	.747	.760			.730	+4.1	+5.2
	2	.747	.890			.730	+22.0	+27.8
	3	0.747	0.830			0.730	+13.7	+17.3
8	4	0.168	0.370			0.392	-5.6	-31.6
	4	.265	.420	0.328	0.942	.433	-3.0	-10.8
	4	.498	.540			.554	-2.5	-4.8
	4	0.741	0.730			0.716	+1.95	+2.5

Result of averaging the per cent error in void fraction for Cases 1, 2, 3, and 4 for constant void fraction if preferential void distribution are not stable situations:

0.136	-3.8	-27
.260	-0.9	-2.0
.508	+6.8	+6.5
0.747	+11	+11.0

FIG. 8
 APPARATUS USED TO INVESTIGATE
 ATTENUATION OF GAMMA RAYS (ELEVATION)

Table II
VOID MEASUREMENTS IN WATER TESTS

Run No.	Void Fraction	Void Intensity Reading	Calc. Void Intensity Reading	Per Cent Error in Void Intensity Reading	Per Cent Error in Void Fraction	Source Distance, in.	Number of Channels	Width of Channels, in.
W-8	0	0.300	0.300	0	0	6	No channels	
	0.092	.325	.333	-2.4	-22.8			
	.182	.360	.369	-2.4	-11.6			
	.273	.400	.410	-2.4	-7.7			
	.364	.440	.470	-6.4	-15.4			
	.455	.487	.504	-3.4	-6.6			
	.545	.538	.558	-3.6	-5.8			
	.636	.600	.621	-3.4	-4.7			
	.728	.668	.688	-2.9	-3.5			
	.818	.743	.762	-2.5	-2.7			
	0.909	.835	.876	-4.7	-4.5			
	1.00	0.940	0.940	0	0			
	0	0.280	0.280	0	0			
	0.044	.298	.296	+0.68	+12.8			
	.130	.325	.328	-0.92	-5.8			
	.217	.360	.364	-1.10	-4.2			
W-10	.305	.398	.405	-1.70	-4.6	6	2	1/4
	.391	.442	.450	-1.78	-3.8			
	.478	.490	.500	-2.00	-3.5			
	.565	.540	.555	-2.70	-3.9			
	.652	.605	.615	-1.63	-2.1			
	.739	.672	.686	-2.04	-2.3			
	.826	.750	.760	-1.30	-1.3			
	0.913	.837	.845	-0.95	-0.9			
	1.00	0.940	0.940	0	0			
	0	0.299	0.299	0	0			
	0.092	.328	.332	-1.2	-11.4			
	.182	.362	.369	-1.9	-9.1			
	.273	.400	.408	-2.0	-6.2			
	.364	.443	.454	-2.4	5.8			
	.455	.493	.504	-2.2	-4.2			
	.545	.543	.558	-2.7	-4.3			
W-11	.636	.610	.620	-1.6	-2.2	6	2	1/2
	.728	.680	.688	-1.2	-1.44			
	.818	.760	.762	-0.26	-0.28			
	0.909	.843	.875	-3.6	-3.45			
	1.00	0.94	0.940	0	0			
	0	0.315	0.315	0	0			
	0.125	.360	.361	-.28	-2.06			
	.250	.409	.414	-1.21	-4.44			
	.375	.467	.475	-1.69	-4.13			
	.500	.538	.544	-1.11	-2.04			
	.625	.617	.624	-1.12	-1.65			
	.750	.705	.715	-1.40	-1.71			
	0.875	.818	.820	-.24	-.25			
	1.00	0.940	0.940	0	0			
	0	0.312	0.312	0	0			
P-4A	.125	.359	.358	+4.2	+3.06			
	.250	.407	.410	-.73	-2.66			
	.375	.465	.471	-1.28	-3.10			
	.500	.533	.541	-1.48	-2.70			
	.625	.613	.621	-1.29	-1.88			
	.750	.705	.711	-.84	-1.02			
	0.875	.810	.817	-.86	-.90			
	1.00	0.938	0.938	0	0			
	0	0.312	0.312	0	0			
	.125	.359	.358	+4.2	+3.06			
	.250	.407	.410	-.73	-2.66			
	.375	.465	.471	-1.28	-3.10			
	.500	.533	.541	-1.48	-2.70			
	.625	.613	.621	-1.29	-1.88			
	.750	.705	.711	-.84	-1.02			
	0.875	.810	.817	-.86	-.90			
	1.00	0.938	0.938	0	0			

Average of Run No. P-4A and P-4B:

0	0	0
0.125	+1.14	+5.51
.250	-1.94	-3.54
.375	-1.49	-3.66
.500	-1.30	-2.37
.625	-1.20	-1.75
.750	-1.12	-1.37
.875	.55	-5.58
1.00	0	0

FIG. 9
DEVIATION OF VOID FRACTION IN WATER TESTS

As a further check on the effect of geometry, the pressure vessel designed for the 600-psi Boiling Density Experiment was used to verify the assumption that the gamma rays are exponentially attenuated. A container was positioned in the vessel, as shown in Fig. 10, and water was introduced to produce a known void fraction. The per cent deviation, identified as curve P-4 in Fig. 9, is the average of Runs No. P-4A and P-4B listed in Table II.

The Lucite data has shown that if preferential void distributions are stable phenomena then the error in measuring the void fraction can vary considerably, depending on the configuration of the distribution. As shown in Fig. 7, Case 1, Run No. 5, resulted in an error of -93% at a void fraction of 0.136. Dengler³ has noted that he never observed preferential void distributions in his study of flow in heated, vertical channels during natural circulation. If preferential void distributions do not occur in the channels, then it is concluded that the maximum error in the local boiling region of voids from 0 to 0.25 was about -27%, and the maximum error in the steam region of voids from 0.10 to 0.60 was approximately +8%.

The validity of the assumed exponential attenuation of the gamma rays from the thulium source was upheld in the test conducted with the 600-psi boiling density pressure vessel (P-4). The error in the void fraction which was noted is well within the readability of the charts employed since the maximum void fraction error was only -3.7% at a void fraction of 0.375. This test also established that the void-measuring device on the 600-psi Boiling Density Experiment is designed correctly.

II. WATER CORROSION OF THERMENOL - C. R. Breden

The Naval Ordnance Laboratory has developed a new, light-weight, high-strength, non-strategic, ferritic-type alloy called Thermenol (nominal composition: 16% Al, 3-1/2% Mo, balance Fe). The alloy can be cold-rolled into thin sheets and reportedly combines heat and oxidation resistance with excellent magnetic properties and high electrical resistivity.

Thermenol appears to hold considerable promise for use in high-temperature water. Two samples have been tested in 500F degassed water for a total of 3,452 hr. The weight change over this period was essentially zero, and there was no evidence of pitting or general attack. Further tests will be made.

³C. E. Dengler, Sc.D. Thesis in Chemical Engineering, Massachusetts Institute of Technology (1952).

FIG. 10
VOID DISTRIBUTION APPARATUS HOUSED
IN PRESSURE VESSEL (ELEVATION)

III. FILTER TESTS - C. Wohlberg, T. Cameron

A series of tests have been completed on a number of "Fulflo" wound cotton thread filters made by Commercial Filters Corporation. The object of these tests was to evaluate the characteristics of this type of filter for the removal of finely-divided magnetite (Fe_3O_4), a major constituent of corrosion products such as are obtained from a turbine. Specifically, the filters were evaluated for:

- (1) Efficiency, i.e., the weight fraction of the Fe_3O_4 removed from the flowing water.
- (2) Increase in pressure drop across the filter due to clogging with solid.
- (3) Increase in pressure drop due to "packing" or compression of fibers as a function of flow rate.

The filter medium consisted of a 10-mesh stainless steel wire cylinder (1 in. diameter), wound with coarse, loose thread. The diameter of the completed cylinder was 2-1/2 in. The thread was wound in a diamond pattern on the core. The higher the first number in the code description of the filters, the tighter was the weave. In this work only two weaves were used, a 15 wind and a 27 wind. These filters (in cotton fiber) are rated as being able to remove particles coarser than 17 microns and coarser than 3 microns, respectively (manufacturer's data). These filters are held in standard, commercial filter canisters.

The different types of filter material that were tested are listed below. All are of the "Fulflo" type with one exception - the Clarite supplied by Croll-Reynolds Engineering Company.

Type	Length, in.	Catalog No.	Material	Number of Samples Tested
Fulflo	10	15R10SV	Cotton	2
	10	27R10SV	Cotton	2
	4	27R10S	Cotton	1
	4	027R10S	Orlon	1
	4	D27R10S	Dynel	1
	4	W27R10S	Cellulose Acetate	1
Clarite	6*		1/8 in. Carbon Coat	1
	6*		1/4 in. Carbon Coat	1

* 3-1/4 in. diameter

The material to be filtered was precipitated magnetite. The ultimate particle size was determined by electron micrography to be 0.02-0.04 micron. The size of the agglomerates was about 5-10 microns. In these tests, roughly 10 or 15 ppm dispersions were used. Each batch was about 205 gal. Initially, the filtration efficiency was measured by a nephelometric technique. However, since it was difficult to keep the particles in adequate suspension, chemical analysis was used to determine the concentration of iron in the water before and after the filter. Since the expected filterable solids content of the EBWR condensate is expected to be of the order of 0.04 ppm, and of unknown, but presumably very small, particle size, major emphasis was placed on the finest filter, the 27 mesh. However, some 15-mesh filters were also used in the expectation that some surface loading would improve its filtering efficiency.

Figure 11 shows that the No. 27 filter (10 in. length) retained approximately its initial gravimetric efficiency, 94% to 86%, for an accumulated loading of 42 gm of Fe_3O_4 . However, the No. 15 filter, instead of retaining its efficiency as the surface became loaded with solids, suddenly permitted a large quantity of accumulated solids to "break through." This behavior quite conclusively demonstrated that the No. 15 filter could not be used even though the pressure drop across this filter was appreciably lower than that of the No. 27 filter. The pressure drop across the No. 27 filter increased almost linearly with pickup of solid.

Since there was some probability that a "packing" effect due to felting or compression of the filter fibers might be responsible for part of the increase in pressure drop, an experiment was run on a 4-inch, No. 27 filter at a flow rate of 2 gpm, corresponding to a 5 gpm flow rate for the 10-inch filter cartridge. A total of 25,000 gal of water flowed through the filter. Figure 12 shows that there is a definite and almost linear increase in pressure drop from 5 to 39 psi across the filter. It is also apparent from Fig. 11 that the greater the loading, and hence the pressure drop across the filter to force through the water at a given rate, the lower is the efficiency of the filter, beyond a critical loading (of solids). This result suggested that perhaps the packing effect was a function of the rate at which water was put through the filter. Accordingly, a No. 27, 10-inch filter was installed. Clean water totaling 37,000 gal was filtered at a rate of 3.2 gpm. It is evident from Fig. 12 that a much lower rate of increase of pressure drop occurred. It should be stressed that these are single experiments on a possibly variable filter medium, so that the absolute figures should not be taken too literally; however, the indication is very strong that at higher rates of throughput per unit area, the packing effect is appreciable.

Commercial Filters Corporation also makes the Fulflo filters in a variety of synthetic fibers. Since the synthetics should show less packing than cotton (due to the solid structure of the fibers), some 4-inch cartridges of different fibers were tested. As shown in Fig. 13 the Orlon, Dynel, and Cellulose Acetate filters are all considerably less efficient than a similar cotton filter.

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C. WOHLBERG:H.C., 6-15-55

FIG. 11
PERFORMANCE OF 10-inch COTTON FILTERS
(FLOW RATE: 5 gpm)

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FIG. 12
EFFECT OF FLOW RATE ON PRESSURE DROP
ACROSS 4-inch AND 10-inch COTTON
FILTERS AS A FUNCTION OF TOTAL FLOW

FIG. 13
PERFORMANCE OF 4-inch COTTON, SYNTHETIC,
AND CARBON COATED FILTER UNITS
(FLOW RATE: 2 gpm)

Since the pressure drop across the Dynel, Cellulose Acetate, and Orlon filters for corresponding loading (a total weight of Fe_3O_4 picked up by filter) was considerably less than for a cotton filter, one may conclude that they are less subject to packing.

Mention has been made of the well membrane-type filter, the Clarite Filter, made by the Croll Reynolds Engineering Company. The filter consists essentially of a wedged-shaped wire welded onto a number of circularly placed rods. Figure 13 shows the results of one run made with a laboratory model of this filter* coated with a 1/4-inch layer of carbon filter aid supplied by Dicalite Division of Great Lakes Carbon Corporation. It will be noticed that the efficiency of filtration is practically 100%. The pressure drop across the filter increased rather sharply with oxide loading. The disadvantage of this type of filter is its sensitivity to pulsation of flow; the precoat tends to flake off under such conditions. However, other types of filter aids, such as wood fiber or wood fiber-carbon mixtures, should be relatively free of this fault. The advantage of the filter (in addition to its superior filtering ability) is that the filtering surface can be changed easily and automatically without the necessity of disassembly.

The following conclusions are based on the previously described test results:

1. The No. 27 Fulflo filter maintains its efficiency for a larger loading than the No. 15 cotton filter. However, it does let the finer particles through. Therefore, its absolute effectiveness cannot be forecast at this time since the particle size distribution of the corrosion product can not be forecast.
2. Some increase in pressure drop, due to packing of the filter, may be expected across the No. 27 cotton filter, although at the relatively low flow rate of 2 gpm per 10-inch unit, it may be low. Further work on this one aspect would be desirable.
3. Synthetic fiber filters are less effective than cotton filters.
4. The carbon-coated, well-membrane filter showed very high filtering efficiency for magnetite

*Supplied by the local representative, F. M. deBeers Associated.