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December 15, 1954

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SUMMARY OF DATA ON BOILING FLOW FROM THE 189-D TUBE MOCK-UPS

INTRODUCTION

During 1954 interest was maintained in the problem of cooling-by-boiling in a geometry similar to that of a Hanford pile. Operation of present piles and the design of future piles will benefit from basic knowledge of boiling flow.

This report presents a brief compilation of data for boiling flow taken during the year on the full scale and short process tube mock-ups in 189-D.

SUMMARY

Data reported herein consists of burnout conditions for a uniform heat flux in a 'C' annulus and a standard annulus and data taken with full cosine and part cosine power distribution. The data for non-uniform power distribution is meager and was taken primarily to obtain an indication of the validity of extrapolating data with uniform heat flux to conditions of non-uniform flux distribution.

DISCUSSION

Some conditions at burnout and boiling curves of flow vs pressure drop have been recorded previously. (1,2) Nevertheless, a few numbers from these reports are repeated

- (1) McNutt, C. R., "Data on Boiling Flow in a 'C' Annulus with Uniform Tube Powers Up to 600 KW", HW-32009, June 2, 1954.
- (2) Gilbert, W. D., McNutt, C. R., Neidner, R., "Permissible Steam Qualities in Hanford Type Process Tubes", HW-33127, September 9, 1954.

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here to have a concise summary of essentially all burnout data taken to date at HAPO.

Tables 1, 2 and 3 list the conditions when overheating or burnout of the heater tube (simulated slugs) with uniform heat flux would occur. On the 23.5 ft. tube the location of burnout with uniform heat flux is known to occur within the last three feet of the exit in all cases. The exact pressure at burnout is unknown, but P_{30} in Table 1, which was read 30 inches upstream of the exit of the heated annulus, is an approximation of the pressure at burnout. Operating techniques were described in HW-32009.

Figures 1 and 2 are boiling curves taken with a 500 psig rear header pressure and tube powers of 250 KW and 400 KW, respectively. A comparison with boiling curves reported at lower pressures indicates that pressure drop decreases with increasing static pressure for constant values of power, inlet water temperature and exit quality.

Figure 3 shows the power distribution of one run with a full length "cosine" heater tube. Figure 4 gives the boiling curves for both a uniform flux and the cosine flux distribution of Figure 3 for a total tube power of 250 KW, rear header pressure of 100 psig and an inlet temperature of 50 F. At a given flow rate comparison of the pressure drops between the cosine and uniform power distribution indicates that the cosine tube always has a greater static pressure loss over the same length of heated section. It should also be mentioned that no burnout point is indicated on the curve for the cosine flux. The absence of indicated burnout conditions was caused by inadequate monitoring of temperatures and voltage drops along the tube. New tube design is expected to overcome this difficulty.

Figure 5 indicates the monitored pressures and temperatures of a cosine heater tube as a function of tube length. Calculated values of cumulative enthalpy and exit quality are also shown for this run.

Figures 3, 4 and 5 show data for the only full length cosine heater tube used in 1954. However, some tests were run with a part uniform and part non-uniform flux distribution. A typical flux pattern is shown in Figure 6 for a tube run at 450 KW. In addition to the run made at 600 psi (Figure 6) there were other runs made at a rear header pressure of 300 psi. These runs are tabulated in Table 2. Furthermore, these runs were satisfactory experimental checks for the prediction of safe operation close to burnout in a non-uniform heater tube as based on data from a uniform tube. The complexity and expense of fabricating heater tubes with a non-uniform power distribution precludes extensive testing with cosine or part cosine heat fluxes.

Continued testing with boiling flow is anticipated during the first months of 1955. A mock-up suitable for tests with static pressures up to 1500 psi will be run. Hanford-type geometries will be used with inlet temperatures up to 300 F at a maximum flow of 20 gpm.

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TABLE 1
BURNOUT DATA FOR A 23.5 ft. 'C' ANNULUS

$Q \times 10^{-5}$ Btu/hr-ft ² (Uniform Flux)	t_1 , inlet, F	V, Inlet, fps	$G \times 10^{-6}$, Inlet, lb/hr-ft ²	X, Exit, Wt. %	P ₁ , Inlet, psia	P ₃₀ 30" Upstream of exit, psia	P ₀ exit, psia
0.97	51	1.93	0.428	42.2	154	133	124
0.97	205	2.63	0.570	39.6	184	---	139
0.97	293	4.89	1.03	23.9	232	172	155
0.97	52	1.53	0.346	54.5	283	---	275
0.97	200	1.58	0.364	67.8	312	---	275
0.97	292	2.12	0.44	63.1	313	281	270
0.97	81	1.60	0.347	50.3	538	---	521
0.97	214	1.82	0.395	57	549	---	530
1.56	56	3.83	0.857	25.0	189	162	145
1.56	202	5.19	1.12	26.7	245	193	170
1.56	265	7.30	1.54	20.6	284	221	189
1.56	55	3.57	0.809	23.7	299	284	274
1.56	203	4.53	0.98	29.5	340	302	287
1.56	300	6.35	1.31	27.3	381	321	296
1.56	60	2.85	0.641	37.0	541	---	520
1.56	213	3.29	0.710	47.0	586	---	555
1.56	317	4.38	0.895	42.4	670	---	630
2.33	52	5.77	1.30	23.0	239	201	173
2.33	197	8.90	1.97	18.1	315	255	215
2.33	264	10.3	2.17	20.3	385	288	240
2.33	50	5.77	1.30	18.1	333	306	290
2.33	200	8.80	1.91	15.4	381	341	311
2.33	258	9.59	2.01	20.1	425	357	322
2.33	86	4.15	0.94	41.5	655	---	635
2.33	82	4.21	0.95	37.3	670	---	640

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TABLE 2
BURNOUT DATA FOR A 42 inch 'C' ANNULUS

$Q \times 10^{-5}$ Btu/hr-ft ² (Uniform Flux)	t_1 , Inlet, F	V, Inlet, fps	$G \times 10^{-6}$, Inlet lb/hr-ft ²	X Exit, Wt. %	P_o Exit, psia
2.28	170	2.04	0.448	9.1	100
2.28	190	2.00	0.439	11.9	100
4.55	186	4.52	0.990	8.4	100
4.55	224	3.87	0.834	10.8	300
4.55	322	5.62	1.15	10.6	300
4.55	344	3.87	0.782	15.7	600
4.55	344	3.10	0.640	19.7	800
6.82	294	8.90	1.85	5.6	300

TABLE 3
BURNOUT DATA FOR A 23.5 ft STANDARD ANNULUS

$Q \times 10^{-5}$ Btu/hr-ft ² (Uniform Flux)	t_1 , Inlet, F	V, Inlet, fps	$G \times 10^{-6}$, Inlet lb/hr-ft ²	X Exit Wt. %	P_1 , Inlet psia	P_{30} 30" Upstream of exit, psia	P_o exit, psia
1.94	50	6.80	1.53	15.0	216	175	151
1.94	46	4.72	1.06	23.0	335	---	280
1.94	49	5.90	1.33	23.0	236	187	158
1.94	48	4.90	1.10	31.0	309	266	241
1.94	50	4.72	1.06	35.4	341	307	283
1.94	49	4.72	1.06	34.4	391	357	336

TABLE 4
STABLE OPERATING CONDITIONS FOR A 23.5 ft. 'C' ANNULUS WITH UNIFORM AND NON-UNIFORM POWER DISTRIBUTION*

Q_1 , Tube Power, KW	t_1 , Inlet, F	V, Inlet, fps	$G \times 10^{-6}$, Inlet lb/hr-ft ²	X Exit, Wt. %	P_1 , Inlet psia	P_o exit, psia
320	258	4.0	0.85	27.2	373	339
395	290	5.4	1.12	26.5	365	422
380	250	4.3	0.92	32.1	349	398
425	165	5.5	1.22	10.2	440	450

* The shape of the power distribution along the heater tube was similar to the distribution shown in Figure 6

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500 psig, Rear Header Pressure; 400 KW, Uniform Tube Power

FIGURE 2 PRESSURE DROP WITH BOILING IN A 'C' ANNULUS

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250 KW, Tube Power
3.7 gpm

FIGURE 3 SPECIFIC POWER IN A FULL-LENGTH
COSINE HEATER TUBE

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FIGURE 5 PRESSURES, TEMPERATURES, AND CALCULATED QUANTITIES FOR COSINE POWER DISTRIBUTION

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Distance From Upstream Flange, Feet

Upstream Downstream

450 KW, Tube Power 600 psig, Rear Header Pres.

7.0 gpm 295 F Inlet Water

 38% Exit Steam by Weight

FIGURE 6 SPECIFIC POWER IN A HEATER TUBES WITH UNIFORM AND NON-UNIFORM POWER DISTRIBUTION

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