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PRELIMINARY STUDY OF THE PILE EFFLUENT PIPING SYSTEM **300 AREA
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I. INTRODUCTION

In order to carry out the program of increased pile operating levels either tube outlet temperatures or the water flows must be increased. This program proposes a considerable increase in both the pile effluent water flow and temperature. Consequently, an investigation was started of problems that might be encountered in the pile effluent system. Later, a decision was made that the portion of this investigation dealing with the effects of increased water flow would be handled by the Pile Materials Unit. Therefore, this report serves to present the results of a preliminary investigation of the effects of increased water flow and temperatures. A report indicating the actual outlet water temperatures limits based upon the effluent system will be presented separately.

II. SUMMARY

An analysis was made of the D Pile effluent system in order to obtain an estimate of the effects of the proposed changes in water flow and temperature. This detailed analysis of D Pile was then extended, by estimate, to the other operating piles. The B and D Pile effluent systems are now operating at flow rates 20 to 50 percent, respectively, above their design capacity. The other piles are operating at or below this design effluent capacity. In addition, the H, DR, and C Piles all have double downcomers and can change quickly from one to the other in case of a downcomer failure. The F Pile has only one downcomer but it is an H Pile prototype and its operation may be judged by the operation at H. Because of the possible hazards to personnel and the pile building which would result from the failure of the B or D downcomers it is recommended that they be revised or preferably replaced before the proposed increases in water flow and outlet temperatures are made. The radiation problem of the entrained air in the effluent water:

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is discussed and several suggestions towards alleviating this problem are included.

III. DISCUSSION

As shown in Table I the water flow through the pile effluent system considerably exceeds the designed capacity at the B and D piles. Further increases in water flow and temperature, as proposed in the water plant expansion program, ⁽¹⁾ could cause piping failures or other difficulties in this system. For example, an increase in outlet water temperature that would cause boiling in the piping might cause the following operating difficulties:

1. Irregular flow through the pile produced by the surging effect of unsteady steam formation.
2. Increased corrosion and erosion in the piping caused by the increased temperatures and the cavitation and impingement effects produced by the steam formation.
3. The formation of pressure surges in the system that would cause piping failures.

If the water flow were increased without any boiling in the outlet system the increased flow might cause excessive stresses which would lead to the rupture of the downcomer or other weak spots in the effluent system.

A. Problems of Downcomer Failure

At the H, DR, and C Piles there are two downcomers with the effluent water flowing through one of them. In the unlikely event of a downcomer failure, the flow could be carried by the second downcomer. At F Pile there is only one downcomer but it is a new unit with a capacity proved by the operation of the DR and H Piles. At the B and D Piles, however, there is but one downcomer that is now operating at 25 to 50 percent over capacity. There has been a gradual increase in power level (produced by increased water flow and outlet temperatures) to twice the original value with no corresponding increase in the design capacity of the outlet piping system. Stiffeners have been placed at several points around the B and D downcomers to eliminate the severe vibration that was observed, ⁽²⁾ but no other significant increase in strength has been made.

A natural question that arises is whether there are sufficient hazards involved in a failure in the outlet piping system to warrant a possible restriction of the pile operating level. It is the writer's opinion that these hazards are considerable and that some changes in downcomer construction should be made at the B and D Piles. The negative pressure in these downcomers, with respect to atmospheric pressure, is nearly twice that calculated as a safe design value, and there is a constant pressure pulsation that is sufficient to cause a "breathing" motion to the downcomer. These effects indicate that the B and D downcomers could fail by collapsing inwards with a consequent blocking

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- (1) Richards, R. B., "Water Plant Expansion - Technical Basis", HW-23426, June 22, 1953
 - (2) Drawing H-1-3121 Bracing Details 105-B.

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TABLE I
DESIGN CAPACITY OF THE PILE OUTLET RISERS AND DOWNCOMERS

Pile	Maximum	Maximum Internal		Minimum Internal		Maximum Water Outlet Temperature, °C
	Water Flow	Pressure		Pressure		
	gpm	Riser	Downcomer	Riser	Downcomer	
		psig	psig	psig	psig	
<u>Design Capacity - See Appendix C</u>						
B	30,000	17	17	-2.3	-1.4	—
C	80,000	—	—	—	—	80
D	30,000	17	17	-2.3	-1.4	—
DR	50,000	—	—	—	—	84
F	50,000	—	—	—	—	84
H	50,000	—	—	—	—	84

Present Operating Conditions (October, 1953)

B	39,000	19	2	-1.9**	-2.0**	77
C	73,000	25	3	-0.4**	-0.6**	74
D	47,000	20**	2	-2.6**	-2.8**	72
DR	43,000	20	2	-0.5	-0.6	66
F	39,000	18**	3	-0.5	-0.6	79
H	52,000	20	2	-0.5	-0.6	78

* Measured in downcomer.

** Calculated from measured riser pressures, all other values were estimated.

of the entrance to the cushion chamber. This would send as much as 30,000 to 40,000 gallons of water per minute through the doorway to the riser room and thence to the storage basin via the rear face. In just a few minutes this water would be pouring into the far side X-sample room, cushion corridor, monitor room, and on to the control room. It would be an exceedingly wet affair and might occur without causing sufficient back-pressure to trip a Panellit alarm. Consequently, the pile would not be shut down until someone observed the flood and made contact with the control room. It seems very important therefore that downcomer failure be prevented from flooding the pile building. Some of the things that might be done to reduce the hazards of the present condition are:

- Install a monitor system in the downcomer room to scram the pile and the 190 electric pumps in the event of a downcomer failure.
- Make the downcomer room a secondary downcomer by closing the door into the riser room and replacing the concrete floors between the downcomer room and the cushion chamber with open steel grill work.
- Close the riser room door to the downcomer and run an alternate line off the top of the present downcomer and down through a new downcomer room just outside of the pile building.

The adoption of some means of ensuring continued effluent water flow to the cushion chamber will prevent a downcomer failure causing a possible loss of life, serious building contamination, and/or destruction of pile building equipment. However, this will

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not increase the capacity of the B and D downcomers and there is little reason to believe that the water flow can be safely increased much above the present level of 47,000 gpm at the D Pile. The failure of the D or B downcomers would require about a months downtime, even after the changes to prevent flooding had been made. Therefore, it is recommended that immediate study be given to the replacement of the B and D downcomers. The importance of multiple exit water flow paths has been emphasized, (3) and it is suggested that dual-flow high capacity and high temperature downcomers be installed as replacements for the present B and D downcomers. This work could be done during the proposed extended shutdown for pile water plant modification.

B. Vaporization in the Piping

If boiling or flashing were to occur in the system, various problems would be introduced. For instance, recent tests (4)(5) indicate that boiling is occurring at many of the Parker fittings of the D Pile. These laboratory tests have shown that there is no appreciable pressure build-up (less than 7 psi) for tube water flows of less than 30 gpm and outlet temperatures less than 100°C. Thus pressure drop effects are not a problem up to 100°C outlet water temperature or up to the saturation temperature of the cross-header. The corrosion effect in these fittings is not known but there is reason to believe that cavitation may be occurring. (6)(7)(8) Therefore, a program of inspecting the outlet Parker fittings on some of the hottest tubes of D Pile is suggested. These Parker fittings are of sufficient strength that the effect of any induced stresses should be negligible, and only the severe erosion that can be produced by cavitation would be a problem.

The next point in the effluent system where boiling is apt to occur is at the top of the downcomer or in the cross-over between it and the risers. Here the system is atmospheric pressure or below, which is the lowest pressure in the effluent system except at the Parker fitting constriction. Boiling at this location could lead to increased corrosion problems, increased stresses caused by pressure fluctuations and greatly increased radiation problems.

C. Radiation Problems

The cooling water flowing through the pile contains an air concentration that is probably close to saturation. The radio argon produced by the irradiation of the natural argon in this air is the chief radiation hazard in the gas and vapor escaping from the outlet system. (9) The air that is sucked into the top of the downcomer and riser serves

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- (3) Woods, W. K., "Downcomers for 105-EW and KE", HW-25975, October 20, 1952.
 - (4) Recht, R. F., "Private Communication of Tests Conducted on Full Scale Process Tube Mock-Up - June - July, 1953".
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to dilute the radio argon that escapes from the water at the cushion chamber but at the same time removes more of the radio argon from the water.

The total activity escaping from the effluent system will increase with the following conditions:

1. Increased pile operating level.
2. Decrease in inlet water temperature since the dissolved argon concentration should increase.
3. Increase in water flow.
4. Increase in pile outlet water temperature.
5. Decrease in suction pressure at the top of the downcomer by means of increased riser and downcomer vent openings.

Radioactivity will probably be a problem at the B and D Piles during the winter months. The amount of effluent gas could be reduced by reducing the opening in the downcomer and riser vents but this is not recommended for the B and D Piles because they are already operating at minimum pressures below the design values.

The radiation hazard from the venting of excessive amounts of gas and vapor from the top of the downcomer and the far riser can be handled by changing the open vents to pressure relief valves. These could be adjusted to open both at 5 psi positive pressure and 0.5 psi negative pressure. This would prevent the escape of radioactive gas from these vents at high outlet water temperatures and positive pressures of less than 5 psi and at the same time prevent excessive negative pressures from occurring. It would prevent the formation of a vacuum leg in the downcomer that might draw water from the pile.

The problem of the escape of radioactive gas and vapor from the effluent line leading from the downcomer will remain and will increase with increased outlet temperatures. This can be handled by better sealing of this system and by the use of a liquid gas separator with a vent line leading to the radioactive exhaust system that goes to the stack.

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APPENDIX A

Nomenclature

- A - cross section area for water flow - sq. ft.
- C - corrosion allowance for pipe wall - in. - .065" for welded steel pipe over 20" in diameter.
- D - pipe diameter (inside) - ft.
- d - pipe diameter (outside) - in.
- E - modulus of elasticity - 29×10^6 psi for stainless steel. (10)
- e - neperian logarithm base.
- f - Reynolds number obtained from Figure 125. (11)
- f_s - outlet temperature reduction factor to allow for electrical outages or single pump failures.
- Q - water flow gallons per minute.
- g - acceleration due to gravity - ft./sec., sec.
- N - total equivalent length of piping - ft.
- Q - heat output from tube, KW.
- P - pressure in piping system at any point - lbs./sq.in. gauge.
- Pd - design working pressure - psi.
- ΔP - pressure increase in going upstream from point x to point y psi in piping system - psi.
- ΔP_p - pressure increase between the cross-header and outlet nozzle flange - psi.
- R_1 - ratio of maximum tube outlet temperature on a cross-header to the cross-header temperature.
- S - recommended maximum allowable working stress lbs./sq.in. - for type welded stainless steel pipe. (12)
- t - water temperature - °C.
- τ - thickness of pipe - in.
- u - water velocity - ft. per sec.
- u_e - water velocity in expanded section - ft. per sec.

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u_0 - maximum water velocity along header with side streams - ft. per sec.

ΔX - increase in elevation between downstream and upstream positions in the piping system - ft.

Δt - increase in water temperature going through the pile - C.

β - poisons ration - 0.3 for wrought steel.⁽¹³⁾

ρ - water density - lbs./cu.ft.

E - welded joint efficiency - 70%.⁽¹²⁾

μ - fluid viscosity - lbs./ft.sec.

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APPENDIX B

Water Flow and Pressures in Outlet Piping

Assuming that the pressure at the top of the downcomer is atmospheric or zero pounds gage, then the pressure at various points in the system may be computed from the water flow and the known static heads. The flow is assumed to be isothermal and any kinetic energy losses due to flow pulsations are neglected. The general equations used were:

$$\Delta p = \frac{\rho}{144} \left[\Delta X + \frac{2 u^2 N f}{g D} + \frac{(u - u_c)^2}{2 g} \right] \quad (1)$$

giving the pressure drop along a single pipe containing various terms and fittings, and:

$$\Delta p = \frac{\rho}{144} \left[\frac{u_c^2}{2 g} \left(\frac{1.43 N f}{D} + 2 \right) + \Delta X \right] \quad (2)$$

which gives the pressure drop along a header with many side streams.⁽¹⁴⁾ This equation was used to determine the pressure drop along the risers in the cross-header section and the pressure drop in the cross-headers in the section receiving water from the process tubes.

In the case of the pressure drop across the outlet pigtails to the pressure tap in the outlet flange the experimental data reported by R. G. Vandewater⁽¹⁵⁾ were used. These results were obtained at 14°C therefore, a viscosity correction was made, according to the equation below, to obtain pressure drop values at the water outlet temperature.

$$\Delta p_{p_t} = \Delta p_{p_0} \frac{(\mu_c)^{0.2}}{(\mu_0)^{0.2}} \left(\frac{\rho_0}{\rho_c} \right)^{1.2} \quad (3)$$

The density effect is negligible with respect to the viscosity factor and is neglected.

A portion of this pressure drop across the pigtail assembly occurs in the Parker fitting where the pigtail is attached to the cross-header. The reduction in cross section at this point produces a high velocity low pressure point in the system. Whenever the pressure at this point falls below the saturation pressure, flash vaporization will occur. This will cause an increase in the outlet nozzle pressure and probably some cavitation erosion of the fittings. Laboratory tests have indicated that this is not sufficient to cause a panellit alarm or any instability in the water flow at outlet temperatures below 100°C and water flows up to 30 gpm,⁽⁴⁾⁽⁵⁾ with rear cross header pressures of not less than 7 psig. An important observation from these tests is that at constant flow the saturation pressure in the Parker fitting appears nearly independent of cross-header pressure. Thus, for cross-header pressures of 2 to 20 psig and 25 gpm water flow the saturation pressure in the fitting is 5-6 psia. This means that boiling will occur in these Parker fittings at outlet water temperatures as low as 72°C.⁽⁴⁾

The actual pressure at the top of the downcomer was measured by inserting a line in the opening in the air recirculating line at the top of the downcomer and reading the observed static pressure as this line was lowered into the cushion chamber. As shown in Figure 1, there was a negative pressure at the top of the downcomer of 2.8 psi. The water level in the downcomer appeared to be at the 25 foot level. This water column contained considerable air which apparently escaped in the cushion chamber as indicated by the sudden increase in fluid density at this point. The amount of air in the water

FIGURE 1

PRESSURE TRAVERSE OF D- DOWNCOMER

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can be estimated from the slope of the water pressure curve below the 25 foot level. The increase in pressure for a foot of elevation is .099 pounds per square inch compared with 0.433 pounds per sq. in. for water alone.

The average density of the air would be:

$$P_a = \frac{29.9}{359 \left(\frac{341}{273} \right) \left(\frac{14.7}{13.2} \right)} = 0.06 \quad (4)$$

and the volume percent water is obtained from the equation

$$144 \Delta p = \frac{.06(100-W) + 62.4W}{100} \quad (5)$$

$$W = 23\% \text{ H}_2\text{O by volume.}$$

This would indicate a gas flow of 20,600 cfm. The highest air entrainment value previously reported was 7,400 cfm at 30,000 gpm water flow. (16)(17) Tests on a downcomer mock-up showed the entrainment to be proportional to the water flow (18) and this would indicate a maximum current entrainment of 11,000 cfm. Evidently the fluid flow in the downcomer is not homogeneous. This has been substantiated by the observation of flow through a transparent small scale model.

Table II shows a comparison of theoretical and measured pressures at various locations of the D Pile effluent system. There is close agreement between the experimental and the measured values.

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TABLE II
FLOW AND TEMPERATURES IN OUTLET CROSS-HEADERS D PILE MAY, 1953

Header No.	Rear Cross-Header			Maximum Tube			Parker Fittings		
	Flow	Pressure	Temp.	Flow	Temp.	Ratio**	Pressure	Sat.	No. of Tubes
	G gpm	p psia	t °C	G gpm	t °C	R	for Central Tubes psia	Temp. °C	on Header with Temp. Over the Sat. Temp.
46	217	20	48	19	52	1.08	5	72	0
44	641	23	54	18.7	66	1.22	5	72	0
42	863	26	61	22.5	73	1.20	4	68	18
40	939	27	68	23	79	1.16	5	72	35
38	881	28.5	69	23	79	1.15	6.5	79	5
37	376	26	74	27.5	77	1.04	7	81	0
36	641	28.5	64	23.5	80	1.25	5.5	75	12
35	540	30	76	28	81	1.07	5	72	38
34	525	29	65	25	80	1.23	5	72	11
33	552	29	77	27	81	1.05	6	77	23
32	475	29	65	24	76	1.12	5	72	10
31	673	31	77	27	80	1.04	7	81	0
30	406	27	62	28	72	1.16	6	77	0
29	760	32	76	26.5	80	1.05	7	81	0
28	356	27	61	24	72	1.18	5	72	1
27	776	29	78	26	83	1.06	5	72	55
26	356	28	62	27.5	72	1.16	6	77	0
25	795	33	77	27.5	85	1.10	6	77	39
24	292	31	61	24.5	71	1.16	6	77	0
23	743	34	75	27	82	1.09	6	77	26
22-0*									

* Because of increased pressures the lower half would have fewer tubes with boiling in the Parker fittings than the upper.

** Ratio of the maximum tube temperature on a header to the average temperature of this header.

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TABLE III
PRESSURES IN D FILE EFFLUENT SYSTEM MAY, 1953

Location in Outlet System	Water Flow gpm	Water Temperature ° C	Elevation Above Ground Floor ft	Pressure	
				Theoretical psig	Measured psig
1. Top of Downcomer	46,100	68	52	---	-2.8
2. Top of Near Riser	46,100	68	52	-2.6	---
3. 46-1/2 Cross-Header	217	48	35.3	5.4	6
4. 23-1/2 Cross-Header	743	76	19.3	15.0	12.2
5. Tube 2465	26	77	19.5	64	65
6. Tube 2375	27	80	19.1	69	67

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APPENDIX CDesign Strength of the B and D Downcomers

The following information concerning the designed capacity and pressures of the B,D,F downcomers was found in a search of the classified literature. There was a specification in the design drawing D-62038 that the downcomer and riser sections be hydrostatically tested at 25 psig.⁽¹⁹⁾ In general, a pressure vessel is tested at not less than 1.5 times the maximum working pressure⁽²⁰⁾ which would place the allowable working pressure of this system at 27 psig. In two reports on the downcomer problems of the B,D,F Piles by Kumiansky⁽¹⁷⁾⁽¹⁸⁾ the downcomer flow capacity was specified as 30,000 gpm and it was stated that the minimum design pressure at the top of the downcomer was reached under these conditions. Assuming a linear relationship between flow and suction pressure, caused by the syphoning action of the water, this minimum design pressure would be 12.9 psia. This is based upon the value of 11.9 psia pressure measured at the top of the D Pile downcomer with a total flow of 46,000 gpm. See Table III. To supplement this meager information on downcomer pressure limits various design calculations have been made.

Maximum Internal Working Pressure

For large welded pipe the working pressure is given by the equation:⁽²⁰⁾

$$\tau = \frac{d}{2} \left(1 - \sqrt{\frac{S-p}{S+p}} \right) + C \quad (9)$$

where the corrosion allowance C is 0.065 in. Therefore, for the 36 in. diameter risers with 3/16" wall thickness the working pressure is 68 psi. For the downcomer it is 58 psi. Applying the shell equation to this problem:^(20a)

$$\tau = \frac{pd}{2SE - p} + C \quad (10)$$

yields a working pressure of 48 psig for the risers and 41 psig for the downcomer.

Minimum Internal Working Pressure

The collapsing pressure of a long circular tube having a perfectly circular form is:⁽²¹⁾

$$p = \frac{2E}{1-\beta} \left(\frac{\tau}{d} \right)^3 \quad (11)$$

The general effect of eccentricity or ellipticity of the piping on the collapsing pressure is to reduce it considerably. However, at the low strengths obtained for this downcomer this excentric effect is small. From this equation the external collapsing pressure is 5.8 psi for the downcomer and 9.3 psi for the risers. A factor of safety of 2 to 4 is recommended for design purposes.⁽²¹⁾ In this case with the high velocity surging flow the higher safety factor is recommended. Thus, the minimum design pressure for the downcomer is 13.3 psia and for the risers is 12.4 psia or -1.4 and -2.3 psi respectively.

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