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PILE HEAT EXCHANGER SYSTEM

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Abstract

Some considerations on optimum design of a pile heat exchanger circuit are presented. The power transfer possibilities are found to be quite good. The work was done with a homogeneous pile in mind.

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PILE HEAT EXCHANGER SYSTEM

G. Young

In the following, we set down some considerations regarding the design and performance of a pump and heat exchanger circuit for the homogenous and heavy water cooled piles. Essentially two kinds of idle holdup will be introduced: that in the pump, which will be regarded as proportional to the total rate of flow; and that in the piping, exchanger heads, etc., which will be regarded as equivalent to an extra length of non-functioning heat exchanger.

Denote

A = total cross-section area of the exchanger tubes in which the pile liquid flows.

v = velocity of pile liquid in the tubes.

mAv = volume holdup in pump. Note that m is the length of time the liquid spends in going through the pump.

L = active length of exchanger tubes.

AL_o = volume holdup in external system apart from that in the pumps and active exchanger. L_o is thus the equivalent length, in terms of the exchanger cross-section, of the piping, heads, etc. Note that $n = \frac{L_o}{v}$ is the time spent by the liquid in going through these parts of the circuit.

r = inner radius of exchanger tubes.

h = overall coefficient from the pile liquid inside the tubes to the cooling water outside, based on the inside area of the tube.

T_1 = temperature at which pile liquid enters exchanger.

T_o = temperature at which cooling water enters exchanger.

V = volume of pile liquid in entire outside circuit.

P = power output.

t = temperature decrease of pile liquid through exchanger.

at = temperature rise of cooling water through exchanger.

ΔT = temperature difference between pile liquid and the cooling water across the tube wall from it.

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$\overline{\Delta T}$ = effective average value of ΔT along the exchanger tube.

C = heat capacity of pile liquid per unit volume at average exchanger conditions.

We have at once,

$$V = A\,(L + L_o + mv) \qquad (1)$$

$$P = LA\,\frac{2h}{r}\,\overline{\Delta T} \qquad (2)$$

and upon eliminating A between these,

$$P = V\,\frac{2h}{r}\,\frac{1}{1 + \dfrac{L_o + mv}{L}}\,\overline{\Delta T} \qquad (3)$$

<u>Equal and Opposite Flow of Cooling Water</u>. The simplest case is that with equal counter flow of the cooling water, since then a = 1 and ΔT is constant and equal to $\overline{\Delta T}$ all along the tube. We then find,

$$t = \frac{2h}{rc}\,\frac{L\,\Delta T}{v} \qquad (4)$$

$$\Delta T = T_i - T_o - t \qquad (5)$$

from which,

$$\Delta T = \frac{T_i - T_o}{1 + \dfrac{2hL}{rcv}} \qquad (6)$$

and substituting this for $\overline{\Delta T}$ in (3), gives,

$$P = \frac{V\,(T_i - T_o)}{\left(\dfrac{r}{2h} + \dfrac{L}{vc}\right)\left(1 + \dfrac{L_o + mv}{L}\right)} \qquad (7)$$

This vanishes for $L = 0$ and $L = \infty$ and is maximum for,

$$L^2 = \frac{rvc}{2h} (L_o + mv) , \qquad (8)$$

which substituted into (7), gives,

$$P_{max} = \frac{V (T_1 - T_o)}{\left[\left(\frac{r}{2h}\right)^{\frac{1}{2}} + \left(\frac{L_o}{vc} + \frac{m}{c}\right)^{\frac{1}{2}}\right]^2} \qquad (9)$$

Thus it is seen that v and h should be as large as possible, while r, L_o, and m should be as small as possible, and that L should be as given by (8) in terms of the other quantities. Note that making v large and r small does in fact increase h, so that these requirements are consistent.

Expression (9) may also be written more directly in terms of hold-up times as,

$$P_{max} = \frac{V (T_1 - T_o)}{\left[\left(\frac{r}{2h}\right)^{\frac{1}{2}} + \left(\frac{n + m}{c}\right)^{\frac{1}{2}}\right]^2} \qquad (10)$$

<u>Numerical</u>. Figures obtained by Chapin on slurry pumps are,

gal. per min.	hold-up in tons	m^3/sec.	hold-up in m^3	m in sec.
4000	.6	.25	.54	2.2
8000	.9	.5	.82	1.6

According to Chilton and Vernon, we may consider tube walls as thin as 18 gauge = .124 cm, which with 18.8 stainless steel of heat conductivity .0615 cal, etc., give an h value for the tube wall alone of .5 cal, etc.

It is not known how high v may be without erosion troubles. According to Chilton, values of r down to .2 cm are not impossible to achieve. If $v \cong$ 300 cm per sec and $r \cong 1/3$ cm, we get an h on the slurry side of .6.

To obtain a definite example we take,

$m \cong$ 2 sec

$L_0 \cong$ 300 cm)
) which make $n \cong 1$ sec
$v \cong$ 300 cm/sec)

$c \cong 1$

$r \cong 1/3$

$h \cong$ 1/6 which may be regarded as arising from $h \cong \frac{1}{2}$ for each of the transfers from slurry to wall, through wall, from wall to cooling water.

$T_1 - T_0 \cong 150^\circ$ C.

$V \cong 10^7$ cm^3 ~ 10 tons heavy water hold-up outside pile.

With these values, (10) becomes,

$$P_{max} \cong \frac{V(T_1 - T_0)}{7.5} \cong 2 \times 10^8 \text{ cal per sec} \cong 840{,}000 \text{ kw.}$$

Something like 47 tons are needed for the entire system in this case (37 in pile + 10 outside), so that the above figure is about 18,000 kw. per ton.

The above values substituted in (8) give $L \cong 300\sqrt{3}$, while (4) becomes $t \cong \sqrt{3}\,\Delta T$, and (6) becomes $\Delta T \cong \frac{T_1 - T_0}{1 + \sqrt{3}}$. Thus we see that the hold-up times are,

2	sec in pump
1	sec in piping, etc.
$\sqrt{3}$	sec in exchanger
4.73	sec total

The total flow is thus $\frac{10}{4.73} = 2.12\ m^3/sec$ which requires 4 + of the larger size pumps contemplated above. The temperature difference is $\Delta T = 55^\circ$, and the temperature change through the exchanger is $t = 95^\circ$ for both the slurry and cooling water.

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