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SUBJECT: HRE-3 Blanket Heat Exchanger as a Feedwater Reactor Rather Than
as a Steam Generator

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FROM: R. C. Robertson

SUMMARY

There may be an advantage to designing the HRE-3 vertical shell and tube slurry heat exchanger as a feedwater heater rather than as a steam generator from the standpoint of space requirement and blowdown problems. This study of the effect of this arrangement on the thermal efficiency of the heat-power cycle indicates that the gross electrical generating capacity of HRE-3 would be reduced by about 500-kw, or about 3 to 4% of the output. It is concluded that, (a) there is sufficient merit in using the exchanger as a feedwater heater to warrant continued study of the concept, and (b) the effect on the thermal efficiency is so small as to not be a major deciding influence.

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Introduction

In preparing conceptual designs of the HRE-3 blanket heat exchanger it has been mentioned that the blowdown problems of a vertical exchanger and the space requirements could be reduced if the blanket power were used for feedwater heating rather than for steam generation. The study summarizes the influencing factors as they appear at this time; the effect on the thermal efficiency of the heat-power cycle is presented in some detail.

Discussion and Conclusions:

Because of the many factors involved, most of which have not yet been fully explored, it is premature to make a recommendation regarding the function of the blanket heat exchanger. On the basis of this study, it is concluded that, (a), there is sufficient merit in using it as a feedwater heater to warrant continued study of the concept, and (b), the effect of using it as a feedwater heater on the thermal efficiency of the heat power cycle results in only 3 to 4% loss of the gross electrical output, so that this factor is probably not a deciding influence.

Using the blanket heat exchanger for water heating rather than for steam generation would have the advantages of:

- a. Elimination of at least one closed feedwater heater and associated extraction opening on the turbine.
- b. Elimination of one section of 12" steam main and possibly one steam holdup drum.
- c. Elimination of one water level controller (although a flow control valve would still be required).
- d. Reduction of the head room requirements for a vertical shell-and-tube heat exchanger—the type currently considered as best for handling slurry. It is estimated that as a steam generator the blanket heat exchanger would be 22 to 24 ft high, but as a feedwater heater without need for the steam separating space, would be only 12 to 14 ft high⁽¹⁾. If space is allowed for tipping the unit on its side for removal through the containment vessel wall, the shorter unit is very desirable.
- e. Elimination to a large extent of the blowdown problem of removal of solids accumulation on the horizontal tube sheet.

Disadvantages to using the blanket exchanger for feedwater heating are:

- a. The thermal efficiency of the heat-power cycle would be reduced due to the loss in availability by not taking full advantage of the blanket temperature. This loss would result in a 3 to 4% reduction of the gross electrical output, or about 500-kw when the reactor is at 60-mw power level.

(1) Vroom, D. W., Private Communication, 5/1/58.

- b. Radiolytic oxygen formed in the blanket exchanger may increase the oxygen concentration in the core heat exchanger steam space. Since oxygen scavenging chemicals may be required in any event, this may not be of great importance.
- c. The heat transfer coefficient in the blanket exchanger would not be as good as for boiling heat transfer, but since the slurry-side film is the major resistance to heat flow, this is probably not of great consequence.
- d. Detection of sources of leaks causing radioactivity in the steam from the reactor system may be more difficult, although it appears feasible to monitor the feedwater line between the blanket and core heat exchangers.
- e. There may be some loss in flexibility in varying the core and blanket exit fuel stream temperatures from the heat exchangers independently of each other. It may be noted in Figure 2 that a bypass line with a control valve has been shown around the blanket heat exchanger in order to adjust the heat removal rate and the average blanket temperature. The temperature of the feedwater to both heat exchangers must be high enough to prevent thermal shocking. Until the reactor has operated long enough for the blanket to develop appreciable power for heating the feedwater, a supplemental heater will probably be required, as indicated in Figure 2.

Effect on Generated Electrical Output

The system assumed for the blanket heat exchanger as a steam generator is shown in Figure 1, and for the exchanger as a feedwater heater is shown in Figure 2. In both cases moisture separation has been assumed external to the turbine, in one step, rather than in the eight or nine steps internal to the turbine assumed by Black and Veatch⁽²⁾. A deaerating feedwater heater is shown; the drain from the first low-pressure heater is pumped forward rather than flashed back; and air ejector steam consumption has not been included. These small differences, together with slightly different assumed turbine efficiency and steam to throttle conditions, will result in gross generated electrical outputs about 6% higher than reported by Black and Veatch. Since the systems shown in Figure 1 and Figure 2 are compared on the same basis, however, this difference from the Black and Veatch report has little bearing on the conclusions to be drawn from this study.

(2) "Report on Site Selection and Steam Power Plant HRE-3", Black and Veatch, Consulting Engineers, Kansas City, Missouri, December 1957.

The following assumptions have been made as applying to both systems:

Steam to throttle	450 psia, dry and saturated
Reactor heat	50-mw core, 10-mw blanket
Condensing steam conditions	1.5" Hg abs, 90°F hotwell
External moisture separator	Located 10% throttle pressure; can dry to 1% moisture
Pressure losses	5% between extraction points and heaters and in moisture separator
Turbine efficiencies	84.8% h-p element 87.2% l-p element 96.5% mech. + elec. eff.
Feedpump work	20 Btu/lb exhaust loss Neglected

Calculations

Case I — Blanket Heat Exchanger as a Steam Generator

A. Assumptions

(in addition to those previously listed)

1. Flow system as shown in Figure 1.
2. Three stages of feedwater heating, 90°F to 180°F; 180°F to 270°F; 270°F to 360°F. First heater drain pumped forward, second heater as deaerator, third heater drain flashed back.
3. Extraction steam pressures: 171 psia, 45 psia, and 8.8 psia.
4. Terminal temperature differences first and last heaters of 50°F.
5. State points in the cycle as tabulated in Table I. Steam conditions in the turbine as taken from the assumed expansion lines, Figure 3.

B. Third (high-pressure) Heater (For $w_1 = 1.0$ lb/hr)

$$w_3(h_3 - h_{16}) = h_{17} - h_{15} \quad \text{Eq. (1)}$$

$$w_3 = 0.1163 \text{ lb/hr} \quad \text{Eq. (2)}$$

Figure 1

Blanket Heat Exchanger as Steam Generator

Figure 2

Blanket Heat Exchanger as Feedwater Heater

Figure 3
Turbine Expansion Curves
h - s Plane

TABLE I

State Points in Cycle Using Blanket Heat Exchanger
as a Steam Generator

<u>Point</u>	<u>psia</u>	<u>°F</u>	<u>Btu/lb</u>	<u>Quality</u>
1	450.0	456	1204	x = 1.0
2	170.6		1137	
3	162.5		1137	
4	45.0		1056	x = 0.123
5	42.5		1056	
6	45.0		1056	
7	42.5		239	
8	42.5		1162	x = 0.01
9	8.8		1062	
10	8.4		1062	
11	1.5" Hg	91.7	965	
12	1.5" Hg	90.0	58	sub-cooled
13	42.5	180	148	
14	42.5	185	153	
15	42.0	270	239	
16	162.5	365	337	
17	450.0	360	332	

TABLE II

State Points in Cycle Using Blanket Heat Exchanger
as Feedwater Heater

<u>Point</u>	<u>psia</u>	<u>°F</u>	<u>Btu/lb</u>	<u>Quality</u>
1	450.0	456	1204	x = 1.0
2	45		1056	
3	45		1056	x = 0.123
4	42.5		239	
5	42.5		1162	x = 0.01
6	1.5" Hg	91.7	965	
7	1.5" Hg	90.0	58	
8	42	270	239	
9	450	424	400*	

* = calculated

C. Second (deaerating) Heater (For $w_1 = 1.0$ lb/hr)

$$h_{15} = h_5 w_5 + h_7 w_7 + h_{13} (1 - w_3 - w_5 - w_7 - w_{10}) + h_{14} w_{10} + h_{16} w_3 \quad \text{eq. (3)}$$

$$w_7 = (1 - w_3 - w_5)(0.123 - 0.01) \quad \text{eq. (4)}$$

Substituting eq. (2) and (4) and values from Table I into eq. (3):

$$60 = 897.7 w_5 + 5 w_{10} \quad \text{eq. (5)}$$

D. First (low-pressure) Heater (For $w_1 = 1.0$ lb/hr)

$$(h_{13} - h_{12})(1 - w_3 - w_5 - w_7 - w_{10}) = w_{10}(h_{10} - h_{14}) \quad \text{eq. (6)}$$

Substituting eq. (2), (4) and values from Table I into eq. (6):

$$70.5 - 79.8 w_5 = 999 w_{10}$$

Solving eq. (5) and (7) simultaneously:

$$w_{10} = 0.0652 \text{ lbs/hr}$$

$$w_5 = 0.0665 \text{ lbs/hr}$$

$$w_7 = 0.0925 \text{ lbs/hr}$$

E. Generated Power Output

$$P = \frac{\eta_m w_1}{3413} \left[(h_1 - h_2) + (1 - w_3)(h_2 - h_4) + (1 - w_3 - w_5 - w_7)(h_8 - h_9) + (1 - w_3 - w_5 - w_7 - w_{10})(h_9 - h_{11}) \right] \quad \text{eq. (7)}$$

where:

$$w_1 = \frac{60 \times 3413 \times 10^3}{h_1 - h_{17}} = 0.235 \times 10^6 \text{ lbs/hr}$$

$$P = 18,250 \text{ kw (gross)}$$

Case II - Blanket Heat Exchanger as Feedwater Heater

A. Assumptions

(In addition to those previously listed)

1. Blanket at 10-mw power level.
2. Flow system as shown in Figure 2.
3. One stage of feedwater heating, 90°F to 270°F.
4. Extraction steam pressure: 45 psia
5. State points in the cycle as tabulated in Table II.
Steam conditions in the turbine as taken from Fig. 3.

B. Deaerating Feedwater Heater (For $w_1 = 1.0$ lb/hr)

$$w_2 h_2 + w_4 h_4 + (1 - w_2 - w_4) h_7 = h_8 \quad \text{eq. (8)}$$

$$w_4 = 0.113 (1 - w_2) \quad \text{eq. (9)}$$

$$h_4 = h_8$$

Combining eq. (1) and (2) and substituting values from Table II:

$$w_2 = \frac{0.887 (h_4 - h_7)}{h_2 - 0.887 h_7 - 0.113 h_4}$$

$$w_2 = 0.1642 \text{ lbs/hr}$$

$$w_4 = 0.0944 \text{ lbs/hr}$$

C. Main Heat Exchangers

$$w_1 = \frac{50 \times 3413 \times 1000}{h_1 - h_9} \quad (\text{core}) \quad \text{eq. (10)}$$

$$w_1 = \frac{10 \times 3413 \times 1000}{h_9 - h_8} \quad (\text{blanket}) \quad \text{eq. (11)}$$

Solving eq. (10) and (11) simultaneously:

$$h_9 = 400 \text{ Btu/lb (approx. 424°F)}$$

$$w_1 = 213,500 \text{ lbs/hr}$$

D. Generated Power Output

$$P = \eta_m w_1 [(h_1 - h_2) + (1 - w_2 - w_4)(h_5 - h_6)] \quad \text{eq. (12)}$$

$$P = 17,750 \text{ kw (gross)}$$

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