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HRT Pressurizer Heater Test

Summary

Tests have been made on a HRT pressurizer heater under simulated HRT operating conditions. As measured on the test facility, the power output from the heater is 5.5 Kw at 208 V. Of this about 1.0 Kw is loss through the built-in insulation, the clamps, and the heater ends when the heater is at operating temperature of 730°F. Subsequent tests confirm this value. (1)

Therefore, a net power transfer of 4.5 Kw from the heater to the pressurizer appears assured, and this power level can be maintained with heater temperatures under 750°F. This operating level is considered satisfactory for the HRT pressurizer.

The bolts on the clamps are somewhat weak and rust easily. Heavier bolts constructed of a noncorrosive material are recommended. Also further tests are recommended to determine the effect of the torque of the bolts on the heat transferred from the heater to the pressurizer.

Type of Test

A test facility shown in Figure 1 was used for testing the clamshell-type pressurizer heater under simulated HRT operating conditions. The heater was attached to the vertical section of the test loop and water was boiled in this section. Vapor generated in this loop was then condensed by the condenser shown in Figure 1. Air was used as the coolant for this condenser. A rupture disk was attached downstream from the condenser in order to prevent a buildup of overpressure within the loop.

The heater test was divided into three parts:

1. The loop was entirely insulated down to the ends of the heater.

(1) R. F. Hughes, Efficiency of HRT Pressurizer Heater Insulation, ORNL CF-56-11-90, Nov. 13, 1956.

In addition to the normal amount of insulation on the heater itself, seven layers of aluminum foil were wrapped around the heater assembly.

2. Same as above except the aluminum foil insulation was removed.

3. Same as above except the aluminum foil insulation and the magnesia insulation at each end of the heater were removed. About two inches of bare pipe was exposed at each end of the heater. This condition approximates that on the HRT.

Results

Results of the test runs are shown in Table I. The nomenclature and the relations used for the calculations are shown in Appendix A. It can be seen from this table that the heater to pipe overall coefficient is about $112 \text{ Btu}/(\text{hr})(\text{sq.ft})(^{\circ}\text{F})$ at a temperature of about 730°F . Heat losses from the bare heater under HRT conditions are about 1 Kw. This result has been confirmed by subsequent tests ⁽¹⁾. Insulating the loop clear down to the heater did not help to conserve the heat very much, but the addition of the aluminum foil insulation did help. Estimation of the heat losses from the aluminum insulation is found in Appendix B.

Part of the heat loss was through the clamps. Surface temperature measurements show that the clamps and the surrounding area are somewhat warmer than the rest of the heater unit's surface. This is due to the fact that these clamps are attached directly to the aluminum body of the heater. These losses are not excessive, however, and no changes for insulation purposes are recommended at this time.

The eight calrods used in the heater assembly are each rated at 1000 watts at 240 volts. With 209 volts applied, as in the HRT, the power output should be 750 watts per calrod or 6.0 Kw per heater assembly. As

3

Table I

Basic Data

Case	Heater Condition	$T_h, ^\circ\text{C}$	$T_s, ^\circ\text{C}$	P_h, Kw	t_h	F_a	P_a, psia	$W_a, \text{lb/hr}$	$\Delta T_a, ^\circ\text{C}$
1	With Insulated Ends plus Al Foil Blanket (28.4 hrs)	373.6	340.8	5.47	.775	.820	103.4	248.5	102.9
2	With Insulated Ends (53.6 hrs)	388.3	342.3	5.59	.855	.800	107.6	247.2	104.6
3	Bare Assembly (37.5 hrs)	385.3	341.6	5.50	.864	.762	103.4	230.9	106.0

Calculations

Case	Heater Condition	$3413 P_h t_h, \text{Btu/hr}$	$Q_{sc}, \text{Btu/hr}$	$Q_h + Q_{sc}, \text{Btu/hr}$	Est. $Q_h, \text{Btu/hr}$	Est. $Q_{sc}, \text{Btu/hr}$	Est. $U, \frac{\text{Btu}}{(\text{sqft})(\text{hr})}$
1	With Insulated Ends plus Al Foil Blanket (28.4 hrs)	14470	11050	3420	1070*	13400	155.7
2	With Insulated Ends (53.6 hrs)	16310	11170	5140	2790	13520	112.0
3	Bare Assembly	16200	10570	5630	3280	12920	112.7

* Appendix B

measured on the heater test facility, the power output is 5.5 Kw which is within manufacturing tolerance.

A net power transfer of 4.5 Kw from the heater to the pressurizer appears assured. Because of the good heat transfer characteristics of the heater, this power level can be maintained with heater temperatures under 750^o F. This operating level is considered satisfactory for the HRT pressurizers.

In order to obtain good heat transfer from the heater to the fluid in the loop, the heater must be fastened very tightly to the pipe. This meant that the heater clamps must be tightened when the heater is hot. Further tests may be desired in order to determine the torque required to get good heat transfer from the heater to pipe wall.

Also, it was noticed that bolts for the heater clamps were a little weak and that they rusted easily. 1/2 inch bolts made out of some non-rusting material would be desirable here. The present bolts tend to bend at the point where the eye of the bolts join the body of the bolt. Also, the bolts should be locked or staked so that they do not come all the way out when opening.

H A. Mc Lain

Appendix A

Equations and Nomenclature Used in the Heater Calculation

The following nomenclature is used for Table 1 and the heater test calculation:

T_s	=	loop temperature, °C
T_h	=	heater temperature, °C
ΔT_a	=	air temperature rise through condenser, °C
C_p	=	specific heat of air, Btu/lb °F
F_a	=	fraction of rotameter full scale flow
P_a	=	air inlet pressure, psia
W_a	=	condenser air flow, lbs/hr
P_h	=	electric input to heater, Kw
t_h	=	fraction of heater time on
Q_h	=	direct heater loss, Btu/hr
Q_{hs}	=	heat transferred to loop, Btu/hr
Q_s	=	heat loss from loop, Btu/hr
Q_{sc}	=	heat transferred to condenser, Btu/hr
A_h	=	inside area of heater, ft ²
U_h	=	heater overall heat transfer coefficient, Btu/hr sq.ft °F

The following heat balances are used to calculate the heat quantities in Table 1:

Heat transferred to loop:

$$Q_{hs} = 3413 P_h t_h - Q_h$$

Heat removed by condenser:

$$Q_{sc} = 1.8 W_a C_p (\Delta T_a)$$

Heat removed from loop:

$$Q_{hs} = Q_{sc} + Q_s$$

Heat lost from the system:

$$Q_h + Q_s = 3413 P_h t_h - Q_{sc}$$

The overall heat transfer can then be determined by the following relation:

$$U_h = \frac{Q_{hs}}{1.8 A_h (T_h - T_s)}$$

The rate of air flow is determined by the following relation

$$W_a = 2.00 F_a \sqrt{\frac{P_a}{45}}$$

Appendix B

Heat Losses from the Aluminum Insulation

The aluminum insulation around the heater is considered as a cylinder 2-1/2 feet long and 3/4 inches in circumference. Heat is transferred from the outside surface of this cylinder to the surrounding air by radiation and convection.

The radiation heat loss may be estimated by the expression⁽²⁾

$$Q = 0.171 A \sigma \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right]$$

where A = surface area, sq. ft
 Q = heat transferred, Btu/hr
 T_1 = surface temperature, °F
 T_2 = air temperature, °F
 σ = surface emissivity

The emissivity of the aluminum insulation is about 0.10,⁽²⁾ the surface temperature is 225°F, and the air temperature is 90°F. Substituting into the above equation, the radiation heat loss from the aluminum insulation is

$$\begin{aligned} Q &= 0.171 \frac{3/4}{12} (2.5)(0.10) \left[\left(\frac{225 + 460}{100} \right)^4 - \left(\frac{90 + 460}{100} \right)^4 \right] \\ &= 134 \text{ Btu/hr} = 0.0392 \text{ Kw} \end{aligned}$$

Convection heat losses from the aluminum insulation are estimated by the relation

$$Q = h_c A \Delta T$$

where h_c = convective heat transfer coefficient, Btu/(hr)(°F)(sq.ft)
 ΔT = temperature difference between the outside surface and the air, °F

McAdams⁽²⁾ recommends the following relation for determining h_c of air when $\frac{L^3 \rho_f^2 g \beta \Delta T}{\mu_f^2} \left(\frac{C_p \mu}{k} \right)_f$ is greater than 10^9 and less than 10^{12}

$$h_c = 0.19 \Delta T^{1/3}$$

where L = length of heater, ft
 ρ_f = air density, lb/cu.ft
 g = acceration due to gravity
 β = coefficient of volumetric expansion, $(^\circ F)^{-1}$
 μ = viscosity, lb/hr ft
 C_p = specific heat, Btu/lb $^\circ F$
 k = thermal conductivity, Btu/(hr)($^\circ F$)(sq.ft/ft)

For air at the film temperature, McAdams gives the value

$$\frac{\rho_f^2 g \beta_f}{\mu_f^2} \left(\frac{C_p \mu}{k} \right)_f = 7.5 \times 10^5$$

For this case

$$\begin{aligned} \frac{L^3 \rho_f^2 g \beta_f \Delta T}{\mu_f^2} \left(\frac{C_p \mu}{k} \right)_f &= 7.5 \times 10^5 (L^3) (\Delta T) \\ &= 7.5 \times 10^5 (2.5)^3 (135) = 1.58 \times 10^{19} \end{aligned}$$

Therefore

$$h_c = 0.19 (135)^{1/3} = 0.974 \frac{\text{Btu}}{(\text{hr})(^\circ F)(\text{sq.ft})}$$

and

$$\begin{aligned} Q &= 0.974 \times (34/12)(2.5)(135) \\ &= 932 \text{ Btu/hr} = 0.273 \text{ kw} \end{aligned}$$

The total heat loss from the aluminum insulation is then 1066 Btu/hr or 0.312 kw.

(2) W. H. McAdams, Heat Transmission, 3rd Ed., McGraw-Hill Book Co., New York, (1954).

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H.R.T. PRESSURIZER HEATER — TEST LOOP

FIG.-1

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