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SUBJECT: Continuation of HRT Fuel Solution Evaporator Study

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DISCLAIMER

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In ORNL CF-54-5-2, two preliminary design studies of an evaporator for use with the HRT were presented. A third possible arrangement is shown by Figure 1 of this memorandum, in which the evaporation is presumed to occur in two inclined 4-inch - schedule 40 stainless steel steam-jacketed pipes supported below the inner dump tanks. In addition to the primary functions of supplying diluent steam for the recombiner gases and a means of fuel solution concentration, this arrangement should also tend to keep the fuel solution in the dump tanks agitated, and as the fuel solution becomes concentrated an "eversafe" storage volume of $\sim$80 liters is automatically provided.

It was shown in ORNL CF-54-5-2, that for an evaporation rate of 1/2 gpm a calculated surface area of 8.5 ft^2 is required, based on the evaporation occurring from the surfaces of vertical steam-jacketed stainless steel pipes. The inner pipe of the arrangement shown by Figure 1 of CF-54-5-2 is a 4" - schedule 40 pipe, hence, this analysis for the surface area requirements is also applicable to the arrangement of Figure 1 herein. Actually, the proposal of an inclined pipe with the vaporizing fluid flowing at relatively high velocity thru the pipe should be more favorable to heat transfer than the arrangement shown in CF-54-5-2.

The general specifications for the evaporator schematically shown by Figure 1 herein are as follows:

Evaporation rate, gpm	0.500	1.00
*Pressure in evaporator, psia	14.7	14.7
*Evaporation temperature, ^{o}F	$\sim$212	$\sim$212
Heat balance:		
Rate, lb/hr	264	528
Heat transferred, Btu/hr	2.76×10^5	5.52×10^5

* Elevation in boiling point was not considered and the properties were assumed those of H_2O for this study. A factor of safety of $\sim$1.3 was applied to the final results.

Heat transfer coefficients		
Steam side coefficient, Btu/hr-ft^2-^{o}F	1500	1500
Wall coefficient, Btu/hr-ft^2-^{o}F	520	520
Boiling coefficient, Btu/hr-ft^2-^{o}F	2.3 ΔT_B^2	2.3 ΔT_B^2
Jacket steam pressure, psig	75	75
Jacket steam temperature, ^{o}F	320	320
Apparent temperature difference, ^{o}F	108	108
Calculated heat transfer area, ft^2	8.5	17
Actual heat transfer area, ft^2	12.5	25
Factor of safety	1.47	1.47
Apparent overall heat transfer coeff, Btu/hr-ft^2-^{o}F	204	204
Calculated overall heat transfer coeff., Btu/hr-ft^2-^{o}F	300	300
Heat flux, Btu/ft^2-hr	22,000	22,000

Recirculation rate and outlet velocity from vaporizer pipe. In order to keep the solution in the inner dump tanks well mixed, it is desirable that the solution should be agitated during storage by recirculation at a relatively high rate. The following calculations indicate that for every pound of vapor released in the vaporizer pipe there will be recirculated 176 pounds of solution. If it is assumed that the dump tanks are fabricated from 14-inch schedule 40 stainless steel pipe and that following a dump the tanks will run approximately half full, the rate of recirculated solution will be 85 gpm per tank.

The velocity of vapor-solution mixture leaving the evaporator pipe and entering the dump tanks is shown to be 22.9 ft/sec. This mixture contains 176 times as much solution as it does vapor, hence an entrainment separator must be provided in the system to remove this moisture before the vapor-gas mixture enters the recombiner. Much of this moisture may be removed by settling out

in the dump tank vapor volume if the vapor-gas outlet is located at the opposite end of the tank from the evaporator outlet connection.

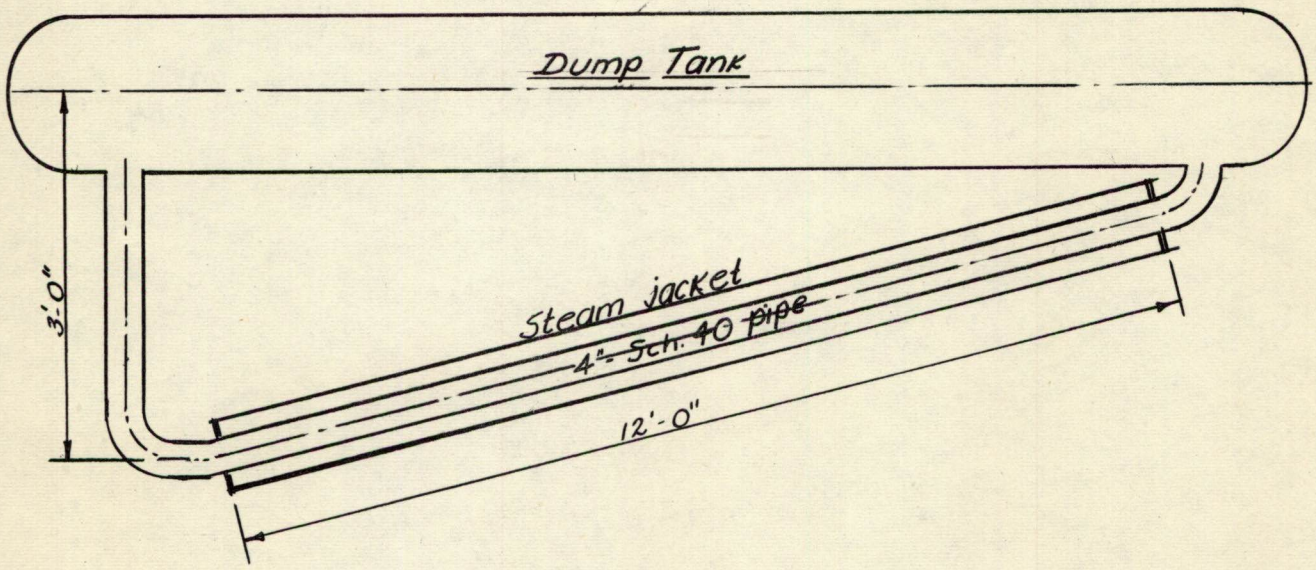

Figure 1
Schematic Diagram of HRT Fuel Solution Evaporator

A. Properties of Fuel Solution (16.3 g U/kg D_2O)

At 212°F

$$\text{Inlet} \begin{cases} \rho_i = 68 \text{ lb/ft}^3 \\ \mu_i = 0.823 \text{ lb/hr-ft} \end{cases}$$

The specific volume of vapor out of the vaporizing section may be estimated from steam tables, taking into account the density difference between H_2O and D_2O.

$$v_{steam} = \frac{26.8}{1.07} = 25 \text{ ft}^3/\text{lb}$$

$$\therefore \quad \rho_{steam} = \frac{1}{25} = 0.04 \text{ lb/ft}^3$$

B. Recirculation Ratios

Attained when the sum of the resistances in the vaporization circuit is equal to the hydrostatic driving force on the vaporizing fluid.

Principal resistances.

(1) Pressure drop thru inlet piping.

(2) Pressure drop thru vaporizer pipe.

(3) Expansion loss due to vaporization.

(4) Static pressure leg of vapor and solution in vaporizer pipe.

(5) Pressure drop thru outlet piping.

Assumptions:

(1) Expansion loss due to vaporization. Taken as two velocity heads based on the mean of the inlet and outlet densities.

$$\Delta p = \frac{G^2}{144\, g\, \rho_{av}} \quad \text{psi}$$

(2) Average density in vaporizing pipe. At the start of the vaporizing zone the density is that of liquid, whereas, at the outlet it is considerably less, even if the percentage converted to vapor is not very high. Likewise, with constant-flow area the velocity increases toward the outlet owing to the large volume of the exit fluid, although the mass velocity is constant. On the other hand, the viscosity effective upon the pressure drop probably does not vary much over the vaporizing zone, being that of the liquid throughout. The pressure drop can be computed using the mass velocity, the Reynolds number based on liquid properties at inlet conditions and the mean density between inlet and outlet.

$$\text{Approximate density} = \frac{v_1 + v_2}{2}$$

It is stated in Process Heat Transfer by Kern, that since the pressure drop is inversely proportional to the density, the approximate method is safe.

(3) Recirculation ratio = $\frac{\text{lbs/hr of solution leaving}}{\text{lbs/hr of vapor alone}}$

Evaporation rate - 1 gpm total or 1/2 gpm per section.

1/2 gpm = 4.4 lb/min at atm.

or (4.4)(60) = 264 lb/hr of vapor at 14.7 psia.

	Recirculation Ratio			
	1	10	100	176
Weight flow of vapor, lb/hr	264	264	264	264
Weight flow of recirculated soln., lb/hr	264	2640	26,400	46,500
Liquid volume out of vaporizer pipe, ft^3/hr	3.89	38.9	389	683.0
Vapor volume out of vaporizer pipe ft^3/hr	6600	6600	6600	6600
Total liquid and vapor volume out of vaporizer pipe, ft^3/hr	6604	6639	6989	7283
Total liquid and vapor weight out of vaporizer pipe, lb/hr	528	2904	26,664	46,764
Specific volume of outlet mixture ft^3/lb	12.5	2.29	0.262	0.156
Average specific volume of mixture in vaporizer pipe ft^3/lb	6.26	1.15	0.138	0.0855
Average density of mixture in vaporizer pipe lb/ft^3	0.160	0.870	7.25	11.70
Mass flow velocity in vaporizer pipe $lb/hr\text{-}ft^2$	5970	32,800	302,000	529,000
Reynold's number based on inlet conditions DG/μ	2440	13,400	123,000	216,000

		Recirculation Ratio			
		1	10	100	176
(A) Pressure drop thru inlet section (Based on equivalent length of 6.25' of 4"-sch. 40 S.S. pipe)					
Liquid velocity in inlet pipe	ft/hr	87.8	482	4430	7780
	ft/sec	0.0244	0.134	1.230	2.16
Velocity head	ft	9.25×10^{-6}	2.78×10^{-4}	0.0236	0.0725
Pressure drop at inlet of approach pipe based on $0.5 \frac{V^2}{2g}$	ft	4.62×10^{-6}	1.39×10^{-4}	0.0118	0.0362
	psi	2.18×10^{-6}	6.56×10^{-5}	0.00557	0.0171
Reynold's number		2440	13,400	123,000	216,000
Friction factor		0.014	0.0085	0.0055	0.0050
Pressure drop thru approach pipe	ft	9.68×10^{-6}	1.77×10^{-4}	9.63×10^{-3}	2.70×10^{-2}
	psi	4.57×10^{-6}	8.35×10^{-5}	4.54×10^{-3}	0.0127
(B) Pressure drop thru vaporizer pipe (Based on 12'-0" of 4" sch. 40 pipe)					
Mixture velocity thru vaporizer pipe	ft/hr	37,300	37,800	41,700	45,200
	ft/sec	10.4	10.46	11.60	12.55
Velocity head	ft	1.67	1.68	2.08	2.45
Pressure drop	ft	3.37	2.04	1.64	1.75
	psi	0.00375	0.0123	0.0825	0.142
(C) Expansion loss due to vaporization					
Pressure drop	ft	3.36	3.37	4.16	4.90
	psi	0.00374	0.0203	0.210	0.398

		Recirculation Ratio			
		1	10	100	176
(D) Static pressure leg of vapor and solution in vaporizer pipe based on 2.5 ft downcomer					
Pressure drop	ft				
	psi	0.00278	0.0151	0.126	0.204
(E) Pressure drop thru outlet section (Based on loss thru one 4"-sch. 40 El. and Expansion)					
Velocity in outlet piping	ft/hr	74,700	75,000	79,200	82,600
	ft/sec	20.8	20.8	22.0	22.9
Velocity head	ft	6.70	6.70	7.52	8.16
Reynold's number		64,000	351,000	3,230,000	5,670,000
Friction factor		0.006	0.0049	0.0040	0.004
Pressure drop thru elbow	psi	0.00107	0.00477	0.0381	0.0695
Pressure drop - outlet	psi	0.00372	0.0204	0.178	0.362
Total resistance to flow	psi	0.01507	0.07296	0.64471	1.205
Head available for circulation	psi	1.18	1.18	1.18	1.180

Recommendations

The proposed arrangement of evaporator and dump-tank combination shown herein apparently satisfies the requirements of the system enumerated as follows;

1) Normal evaporation 1/2 gpm
2) Maximum evaporation 1 gpm
3) Eversafe storage 80 liters (50 liters is the minimum)
4) Solution agitation 85 gpm/tank

However, it is recommended that a full scale mockup of one section of the dump tank and evaporator system shall be fabricated for performance tests. The test set-up may be expanded to include the following;

1) Evaporation rate at various jacket steam pressures up to 100 psig.
2) Heat balance and overall heat transfer coefficient.
3) Recirculation rate through evaporator and dump tank.
4) Outlet vapor-liquid velocity.
5) Moisture content from dump tank gas vapor outlet.
6) Differential thermal stresses in steam jacket and evaporator pipe.
7) Dump tank contents by weigh cell.
8) Efficiency of proposed centrifugal mesh type entrainment separator.
9) Effect of concentration on evaporation rates and heat transfer coefficients.