Thermodynamics Project

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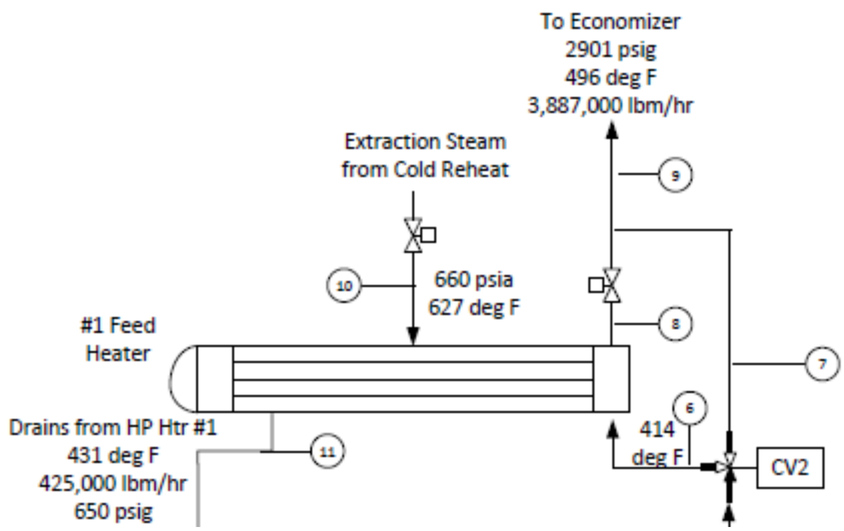
Problem Number One: Leakby of control valve from BFP Discharge



For #1 Feed Heater, the energy transfer should be same, which is Q.out = Q.in, but with "previous calculation"[see the attachment after this final edition work], we found there exits transfer efficiency issue, then we need to introduce η into equation

m(left)*(h10-h11) vs m(right)*(h8-h6)

$m_{left1} := 425000 \frac{lbm}{hr}$ $m_{right1} := 3887000 \frac{lbm}{hr}$

Point 10

It is superheated water, so I looked up the Table A-6E

$P_{10} := 660psi$

$T_{10} := 627\,°F$

T (F)	P=600psia	P=700psia
600	h=1289.9 Btu/lbm	h=1280.7 Btu/lbm
650	h=1321.3 Btu/lbm	h=1313.8 Btu/lbm

$$h_{10P600} := \left[\frac{1321.3 - 1289.9}{650 - 600}\cdot(627 - 600) + 1289.9\right]\cdot\frac{Btu}{lbm} = 1306.856\cdot\frac{Btu}{lbm}$$

$$h_{10P700} := \left[\frac{1313.8 - 1280.7}{650 - 600}\cdot(627 - 600) + 1280.7\right]\cdot\frac{Btu}{lbm} = 1298.574\cdot\frac{Btu}{lbm}$$

$$h_{10} := \frac{h_{10P700} - h_{10P600}}{700 - 600}\cdot(660 - 600) + h_{10P600} = 1301.887\cdot\frac{Btu}{lbm}$$

Point 11

$$P_{11} := (650 + 14.7)psi = 664.7\cdot psi$$

$$T_{11} := 431\ °F$$

Since at 430F, the sat pressure is 343.64 psi, so it is compressed liquid for point 11

T (F)	P (psia)	vf (ft^3/lbm)	hf (Btu/lbm)
430	343.64	0.0191	407.86
440	381.49	0.01926	418.97

Method 1: use the pressure correction estimate function

$$P_{11sat} := \left[\frac{381.49 - 343.64}{440 - 430}\cdot(431 - 430) + 343.64\right]\cdot psi = 347.425\cdot psi$$

$$v_{11} := \left[\frac{0.01926 - 0.0191}{440 - 430}\cdot(431 - 430) + 0.0191\right]\cdot\frac{ft^3}{lbm} = 0.019116\cdot\frac{ft^3}{lbm}$$

$$h_{11sat} := \left[\frac{418.97 - 407.86}{440 - 430}\cdot(431 - 430) + 407.86\right]\cdot\frac{Btu}{lbm} = 408.971\cdot\frac{Btu}{lbm}$$

For compressed liquid, assume the volume is constant so that we can use the estimation equation

$$h_{11} := h_{11sat} + v_{11}\cdot\left(P_{11} - P_{11sat}\right) = 410.093\cdot\frac{Btu}{lbm}$$

not for use

Method 2: use the compressed liquid table

T (F)	P=500psia	P=1000psia
400	h=375.33 Btu/lbm	h=375.91 Btu/lbm
450	h=430.24 Btu/lbm	h=430.51 Btu/lbm

$$h_{11P500} := \left[\frac{430.24 - 375.33}{450 - 400}\cdot(431 - 400) + 375.33\right]\cdot\frac{Btu}{lbm} = 409.374\cdot\frac{Btu}{lbm}$$

$$h_{11P1000} := \left[\frac{430.51 - 375.91}{450 - 400}\cdot(431 - 400) + 375.91\right]\cdot\frac{Btu}{lbm} = 409.762\cdot\frac{Btu}{lbm}$$

$$h_{11} := \frac{h_{11P1000} - h_{11P500}}{(1000 - 500)psi}\cdot\left(P_{11} - 500psi\right) + h_{11P500} = 409.502\cdot\frac{Btu}{lbm}$$

In order to have more accuracy, I will choose the second method for my h11 value. The equation in first method is an approximation, which has more standard deviation (error) than the second. For the following compressed liquid's h value calculation, if pressure is higher than 500 pisa and we can use both methods, then it is accurate to use table interpolation. But if the pressure is lower than 500 psia, such as 14 point, then we have to use approximation method by using h=hsat+v*dp equation.

So the better h vaule is

$$h_{11} = 409.502\,\frac{Btu}{lbm}$$

Therefore, energy transfer on the left side is

$$Q_{left1} := m_{left1}\cdot\left(h_{10} - h_{11}\right) = 105350.99\cdot\frac{Btu}{s}$$

Point 9

$$P_9 := (2901 + 14.7)psi = 2915.7\cdot psi$$

$$T_9 := 496\,°F$$

$$m_{dot9} := m_{right1} = 3887000\cdot\frac{lbm}{hr}$$

T (F)	P (psia)	vf (ft^3/lbm)	hf (Btu/lbm)
490	621.24	0.02022	476.09
500	680.56	0.02044	487.89

Since at 490F, the sat pressure is 621.24 psi, so it is compressed liquid for point 9

Method 1: use the pressure correction estimate function

$$P_{9sat} := \left[\frac{680.56 - 621.24}{500 - 490}\cdot(496 - 490) + 621.24\right]\cdot psi = 656.832\cdot psi$$

$$v_9 := \left[\frac{0.02044 - 0.02022}{500 - 490}\cdot(496 - 490) + 0.02022\right]\cdot\frac{ft^3}{lbm} = 0.020352\cdot\frac{ft^3}{lbm}$$

$$h_{9sat} := \left[\frac{487.89 - 476.09}{500 - 490}\cdot(496 - 490) + 476.09\right]\cdot\frac{Btu}{lbm} = 483.17\cdot\frac{Btu}{lbm}$$

For compressed liquid, assume the volume is constant so that we can use the estimation equation

$$h_9 := h_{9sat} + v_9\cdot\left(P_9 - P_{9sat}\right) = 491.677\cdot\frac{Btu}{lbm}$$

not for use

Method 2: use the compressed liquid table

T (F)	P=2000psia	P=3000psia
450	h=431.16 Btu/lbm	h=431.94 Btu/lbm
500	h=487.54 Btu/lbm	h=487.53 Btu/lbm

$$h_{9P2000} := \left[\frac{487.54 - 431.16}{500 - 450}\cdot(496 - 450) + 431.16\right]\cdot\frac{Btu}{lbm} = 483.03\cdot\frac{Btu}{lbm}$$

$$h_{9P3000} := \left[\frac{487.53 - 431.94}{500 - 450}\cdot(496 - 450) + 431.94\right]\cdot\frac{Btu}{lbm} = 483.083\cdot\frac{Btu}{lbm}$$

$$h_9 := \frac{h_{9P3000} - h_{9P2000}}{3000 - 2000}\cdot(2915.7 - 2000) + h_{9P2000} = 483.078\cdot\frac{Btu}{lbm}$$

Point 8

Since there is no record on the point 7 from sensors, I can assume nothing going through that brankch, which leads to h8 value = h9.

$$h_8 := h_9 = 483.078\cdot\frac{Btu}{lbm}$$

On the right side, in order to make this system work, the pressure should slightly decrease all the way from point 1 to point 9, like P6=2920psi, the P5=2925psi, but the difference in pressure doesn't affect h value a lot since the specific volume value is very small, and it only affect second decimal place (hundredth place) for the final answer. Also, there is not enough information to find pressure at each point, therefore, it is reasonable and accurate enough to assume all pressure on the left side are same as the value of P9, which is 2915.7 psi

Point 6

$$T_6 := 414\,°F$$

$$P_6 := P_9 = 2915.7\,psi$$

T (F)	P (psia)	vf (ft^3/lbm)	hf (Btu/lbm)
410	276.69	0.01878	385.9
420	308.76	0.01894	396.84

Method 1: use the pressure correction estimate function

$$P_{6sat} := \left[\frac{308.76 - 276.69}{420 - 410}\cdot(414 - 410) + 276.69\right]\cdot psi = 289.518\cdot psi$$

$$v_6 := \left[\frac{0.01894 - 0.01878}{420 - 410}\cdot(414 - 410) + 0.01878\right]\cdot\frac{ft^3}{lbm} = 0.018844\cdot\frac{ft^3}{lbm}$$

$$h_{6sat} := \left[\frac{396.84 - 385.90}{420 - 410}\cdot(414 - 410) + 385.90\right]\cdot\frac{Btu}{lbm} = 390.276\cdot\frac{Btu}{lbm}$$

For compressed liquid, assume the volume is constant so that we can use the estimation equation

$$h_6 := h_{6sat} + v_6\cdot\left(P_6 - P_{6sat}\right) = 399.434\cdot\frac{Btu}{lbm}$$

not for use

Method 2: use the compressed liquid table

T (F)	P=2000psia	P=3000psia
400	h=377.12 Btu/lbm	h=378.41 Btu/lbm
450	h=431.16 Btu/lbm	h=431.94 Btu/lbm

$$h_{6P2000} := \left[\frac{431.16 - 377.12}{450 - 400}\cdot(414 - 400) + 377.12\right]\cdot\frac{Btu}{lbm} = 392.251\cdot\frac{Btu}{lbm}$$

$$h_{6P3000} := \left[\frac{431.94 - 378.41}{450 - 400}\cdot(414 - 400) + 378.41\right]\cdot\frac{Btu}{lbm} = 393.398\cdot\frac{Btu}{lbm}$$

$$h_6 := \frac{h_{6P3000} - h_{6P2000}}{(3000 - 2000)\cdot psi}\cdot\left(P_6 - 2000psi\right) + h_{6P2000} = 393.302\,\frac{Btu}{lbm}$$

Therefore, energy transfer on the right side is

$$Q_{right1} := m_{right1}\cdot\left(h_8 - h_6\right) = 96933.816\cdot\frac{Btu}{s}$$

$Q_{left1} = 1.112 \times 10^{8}\,W$ vs $Q_{right1} = 1.023 \times 10^{8}\,W$

So we can find the efficiency of #1 Feed Heat

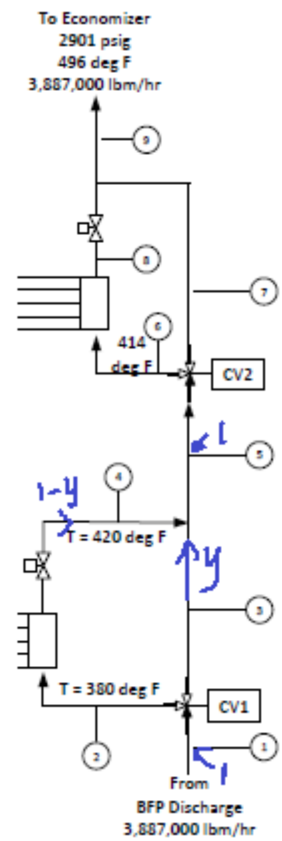
$$\eta_{FH} := \frac{Q_{right1}}{Q_{left1}} = 92.01\,\%$$

As I explained on the previous page, all the pressure are reasonable to be assumed constant

Point 5

$T_5 := T_6 = 414\cdot°F$ $P_5 := P_6 = 2915.7\cdot psi$

$$h_5 := h_6 = 393.302\cdot\frac{Btu}{lbm}$$



Point 4

$T_4 := 420\,°F$ $P_4 := P_6 = 2915.7\cdot psi$

T (F)	P (psia)	vf (ft^3/lbm)	hf (Btu/lbm)
420	308.76	0.01894	396.84

Method 1: use the pressure correction estimate function

$P_{4sat} := 308.76psi$ $v_4 := 0.01894\,\frac{ft^3}{lbm}$ $h_{4sat} := 396.84\cdot\frac{Btu}{lbm}$

$$h_4 := h_{4sat} + v_4\cdot(P_4 - P_{4sat}) = 405.977\cdot\frac{Btu}{lbm}$$ not for use

Method 2: use the compressed liquid table

T (F)	P=2000psia	P=3000psia
400	h=377.12 Btu/lbm	h=378.41 Btu/lbm
450	h=431.16 Btu/lbm	h=431.94 Btu/lbm

$$h_{4P2000} := \left[\frac{431.16 - 377.12}{450 - 400}\cdot(420 - 400) + 377.12\right]\cdot\frac{Btu}{lbm} = 398.736\cdot\frac{Btu}{lbm}$$

$$h_{4P3000} := \left[\frac{431.94 - 378.41}{450 - 400}\cdot(420 - 400) + 378.41\right]\cdot\frac{Btu}{lbm} = 399.822\cdot\frac{Btu}{lbm}$$

$$h_4 := \frac{h_{4P3000} - h_{4P2000}}{(3000 - 2000)\cdot psi}\cdot(P_4 - 2000psi) + h_{4P2000} = 399.73\,\frac{Btu}{lbm}$$

Point 1

$T_1 := 380\ °F$ $\qquad P_1 := P_6 = 2915.7 \cdot psi$

Point 2

$T_2 := T_1 = 380 \cdot °F$ $\qquad P_2 := P_1 = 2915.7 \cdot psi$

Point 3

$T_3 := T_1 = 380 \cdot °F$ $\qquad P_3 := P_1 = 2915.7 \cdot psi$

T (F)	P (psia)	vf (ft^3/lbm)	hf (Btu/lbm)
380	195.74	0.01836	353.53

Method 1: use the pressure correction estimate function

$P_{3sat} := 195.74 psi \qquad v_3 := 0.01836 \frac{ft^3}{lbm} \qquad h_{3sat} := 353.53 \cdot \frac{Btu}{lbm}$

$$h_3 := h_{3sat} + v_3 \cdot (P_3 - P_{3sat}) = 362.771 \cdot \frac{Btu}{lbm}$$

Method 2: use the compressed liquid table

T (F)	P=2000psia	P=3000psia
300	h=273.33 Btu/lbm	h=275.22 Btu/lbm
400	h=377.12 Btu/lbm	h=378.41 Btu/lbm

$$h_{3P2000} := \left[\frac{377.12 - 273.33}{400 - 300} \cdot (380 - 300) + 273.33\right] \cdot \frac{Btu}{lbm} = 356.362 \cdot \frac{Btu}{lbm}$$

$$h_{3P3000} := \left[\frac{378.41 - 275.22}{400 - 300} \cdot (380 - 300) + 275.22\right] \cdot \frac{Btu}{lbm} = 357.772 \cdot \frac{Btu}{lbm}$$

$$h_3 := \frac{h_{3P3000} - h_{3P2000}}{(3000 - 2000) \cdot psi} \cdot (P_3 - 2000psi) + h_{3P2000} = 357.653 \frac{Btu}{lbm}$$

By assume the y percentage of flow rate is leak-by from CV-1, then we can get the equation as shown below and use Mathcad solve function to find the y value

$$(1 - y) \cdot h_4 + y \cdot h_3 = 1 \cdot h_5 \text{ solve } \rightarrow 0.15278445012501416084$$

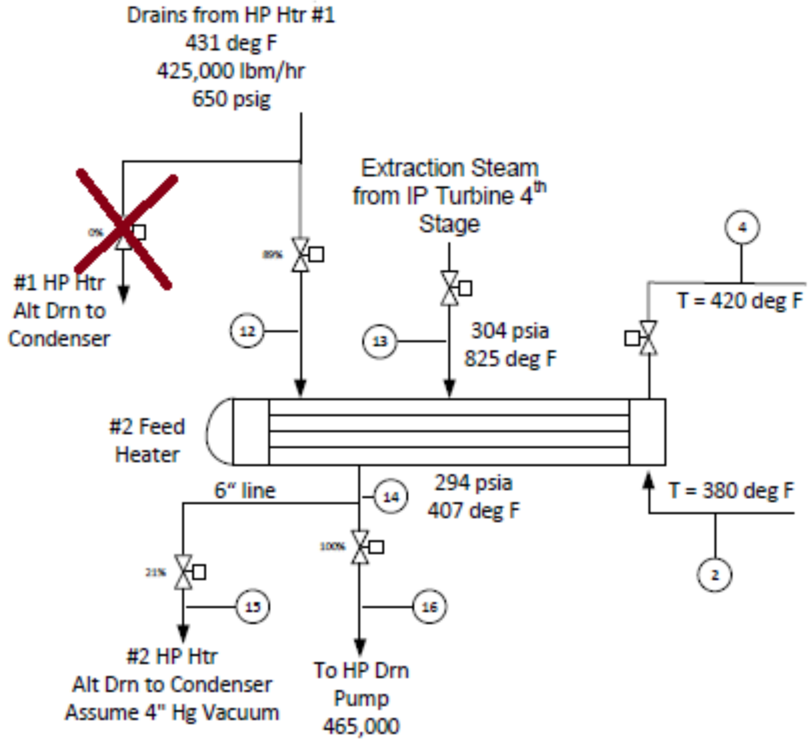
$y := 0.15278445012501416084 \qquad y = 15.278 \cdot \%$

$$m_{leakby} := y \cdot m_{right1} = 593873.158 \cdot \frac{lbm}{hr}$$

Therefore:

the amount of leak-by from CV-1 is <u>15.278%, (593873.158 lbm/hr)</u>

Problem Number Two: The amount of energy dumped to the conderser through #2 Alt HP drains (#2 alternate high pressure drains)



Point 12

$$h_{12} := h_{11} = 409.502 \cdot \frac{Btu}{lbm} \qquad m_{11} := 425000 \frac{lbm}{hr} \qquad m_{12} := m_{11}$$

Point 13

It is superheated water, so I looked up the Table A-6E

$$P_{13} := 304psi$$

$$T_{13} := 825\,°F$$

T (F)	P=300psia	P=350psia
800	h=1421.3 Btu/lbm	h=1419.1 Btu/lbm
900	h=1473.9 Btu/lbm	h=1472.2 Btu/lbm

$$h_{13P300} := \left[\frac{1473.9 - 1421.3}{900 - 800} \cdot (825 - 800) + 1421.3\right] \cdot \frac{Btu}{lbm} = 1434.45 \cdot \frac{Btu}{lbm}$$

$$h_{13P350} := \left[\frac{1472.2 - 1419.1}{900 - 800} \cdot (825 - 800) + 1419.1\right] \cdot \frac{Btu}{lbm} = 1432.375 \cdot \frac{Btu}{lbm}$$

$$h_{13} := \frac{h_{13P350} - h_{13P300}}{350 - 300} \cdot (304 - 300) + h_{13P300} = 1434.284 \cdot \frac{Btu}{lbm}$$

Point 14

$P_{14} := 294psi$ $T_{14} := 407\ °F$

T (F)	P (psia)	vf (ft^3/lbm)	hf (Btu/lbm)
400	247.26	0.01864	375.04
410	276.69	0.01878	385.9

Since at T=410, the sat pressure is still less than the P14, so it is compressed liquid

Only method: use the pressure correction estimate function

$$P_{14sat} := \left[\frac{276.69 - 247.26}{410 - 400}\cdot(407 - 400) + 247.26\right]\cdot psi = 267.861\cdot psi$$

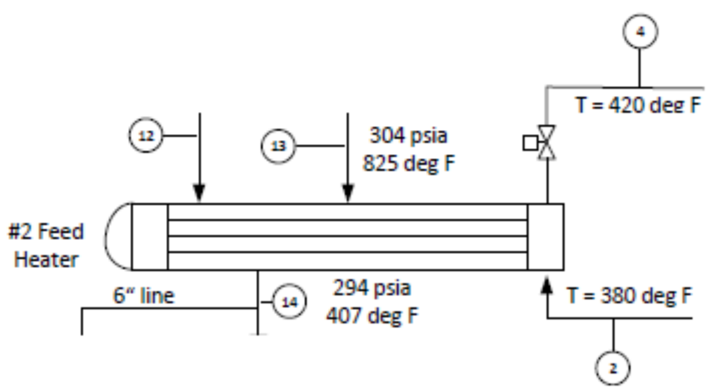
$$v_{14} := \left[\frac{0.01878 - 0.01864}{410 - 400}\cdot(407 - 400) + 0.01864\right]\cdot\frac{ft^3}{lbm} = 0.018738\cdot\frac{ft^3}{lbm}$$

$$h_{14sat} := \left[\frac{385.9 - 375.04}{410 - 400}\cdot(407 - 400) + 375.04\right]\cdot\frac{Btu}{lbm} = 382.642\cdot\frac{Btu}{lbm}$$

For compressed liquid, assume the volume is constant so that we can use the estimation equation

$$h_{14} := h_{14sat} + v_{14}\cdot\left(P_{14} - P_{14sat}\right) = 382.733\cdot\frac{Btu}{lbm}$$

Since we bought the two Feed Heaters from the same company and they are in same type, same size, therefore, they have the same energy transfer efficiency.
For the 32 Feed Heater, the Qleft2 = Qright2 / η, which means
m(12)*h12 + m(13)*h13 - m(14)*h14 = m(right2) * (h4-h2)
Also: m(12) + m(13) = m(14)



$m_{right2} := 3887000\frac{lbm}{hr}$ $h_2 := h_3 = 357.653\cdot\frac{Btu}{lbm}$

$$Q_{right2} := m_{right2}\cdot\left(h_4 - h_2\right) = 45431.81\cdot\frac{Btu}{s}$$

$$Q_{left2} := \frac{Q_{right2}}{\eta_{FH}} = 49376.847\frac{Btu}{s}$$

$$m_{12} = 425000 \cdot \frac{lbm}{hr}$$

By two relationships (mass conservation, and energy conservation with efficiency), two equations can be generated and then use Mathcad guess, given and solve functions to find the mass flow rate at point 13 and point 14

Guess value:

$$m_{13} := 1 \cdot \frac{lbm}{hr} \qquad m_{14} := 1 \cdot \frac{lbm}{hr}$$

Given

$$m_{13} \cdot h_{13} - m_{14} \cdot h_{14} = Q_{left2} - m_{12} \cdot h_{12}$$

$$m_{14} = m_{12} + m_{13}$$

$$\text{Find}(m_{13}, m_{14}) = \begin{pmatrix} 158223.078 \\ 583223.078 \end{pmatrix} \cdot \frac{lbm}{hr}$$

Therefore

$$m_{13} := 158223.078 \cdot \frac{lbm}{hr} \qquad m_{14} := 583223.078 \cdot \frac{lbm}{hr}$$

Also, there is another mass flow rate relationship which is m(15) + m(16) = m(14)

$$m_{16} := 465000 \frac{lbm}{hr}$$

The percentage of control valve only affects the velocity of flow material, but doesn't matter with mass flow rate, and enthalph (h) value.

Point 15

$$m_{15} := m_{14} - m_{16} = 118223.078 \cdot \frac{lbm}{hr}$$

$$h_{15} := h_{14} = 382.733 \cdot \frac{Btu}{lbm}$$

$$Q_{energy} := m_{15} \cdot h_{15} = 13.261 \cdot MW$$

Therefore:

the amount of energy dumped to condenser through #2 Alt HP drains is <u>13.261 MW</u>