from Steam table

①

3- effect Evaporator

For 13.4 kPa (1.44 psia), $t_{s\,out}$ = 51.67 °C

= 0.0134 MPa

(0.013, 51.034) (0.014, 52.547) (0.0134, x)

$$\frac{52.547 - 51.034}{0.014 - 0.013} = \frac{52.547 - x}{0.014 - 0.0134}$$

$x = 51.6392$ °C (from steam table)

Using the eqⁿ for BPR for evaporator no. 3 with $x = 0.5$

$$BPR_3 = 1.78x + 6.22x^2$$
$$= 2.45 \text{ °C}$$

$$T_3 = 51.64 + 2.45 = 54.09 \text{ °C}$$

$F = 8000$ kg/h $= L_3 + (V_1 + V_2 + V_3)$

$F x_F = 8000(0.1) = L_3(0.5) + (V_1 + V_2 + V_3)\,10$

$L_3 = 1600$ kg/hr

Total vaporised $= V_1 + V_2 + V_3 = 6400$ kg/hr

$V_1 = V_2 = V_3 = 2133.33$ kg/hr

Total Material balance on 1, 2 & 3

① $F = V_1 + L_1$

$8000 = 2133.33 + L_1$

$L_1 = 5866.67$ kg/hr

... from Steam table

$\Delta T_{available} = T_{S1} - T_{3(sat)} - (BPR_1 + BPR_2 + BPR_3)$

$= 121.1 - 51.64 - (0.36 + 0.66 + 2.41)$

② $L_1 = V_2 + L_2$

$5866.67 = 2133.33 + L_2$

$L_2 = 3733.34$ kg/hr

③ $L_2 = V_3 + L_3$

$3733.34 = 2133.33 + L_3$

$L_3 = 1600.01$ kg/hr

Solids balance on 1, 2 & 3

① $F x_F = L_1 x_1$

$8000 \times 0.1 = 5866.67\, x_1$

$x_1 = 0.136$

② $L_1 x_1 = L_2 x_2$

$5866.67 \times 0.136 = 3733.34\, x_2$

$x_2 = 0.213$

$L_2 x_2 = L_3 x_3$

$3733.34\,(0.213) = 1600.01\, x_3$

$x_3 = 0.496$

$BPR_1 = 1.78 x_1 + 6.22 x_1^2 = 0.36\,°C$

$BPR_2 = 1.78 x_2 + 6.22 x_2^2 = 0.66\,°C$

$BPR_3 = 2.41\,°C$

3

the values from Steam Table

$\Delta T_{available} = T_{S1} - T_3(sat) - (BPR_1 + BPR_2 + BPR_3)$

$= 121.1 - 51.64 - (0.36 + 0.66 + 2.41)$

(from interpolation ; steam table)

$= 66.03\,°C$

$$\Delta T_1 = \frac{66.03\left(\frac{1}{3123}\right)}{\frac{1}{3123} + \frac{1}{1987} + \frac{1}{1136}} = 12.40\,°C$$

$\Delta T_2 = 19.50\,°C$

$\Delta T_3 = 34.11\,°C$

1. $T_1 = T_{S1} - \Delta T_1$

$= 121.1 - 15.8\,°C$

$= 105.54\,°C$

$T_2 = T_1 - BPR_1 - \Delta T_2$

$= 105.54 - 0.36 - 18.34 = 86.84\,°C$

$T_{S2} = T_1 - BPR_1$

$= 105.54 - 0.36$

$= 105.18\,°C$

$T_3 = T_2 - BPR_2 - \Delta T_3$

$= 86.84 - 0.66 - 32.11$

$= 53.87\,°C$

... values from Steam table

$T_{S_3} = T_2 - BPR_2$
$= 86.84 - 0.66$
$= 85.98\ °C$

Effect 1	Effect 2	Effect 3	~~Effect 4~~ Condense
$T_{S_1} = 121.1°C$	$T_{S_2} = 105.18°C$	$T_{S_3} = 85.98°C$	$T_{S_4} = 51.6°C$
$T_1 = 105.54°C$	$T_2 = 86.84°C$	$T_3 = 53.87°C$	

Step 4: F : $C_p = 3726$ J/kgK (copy)

L_1 : C_p $\Rightarrow (10, 3726)\ (20, 3559)\ (13.4, x)$

$$\frac{3559 - 3726}{20 - 10} = \frac{3559 - x}{20 - 13.4}$$

$x = 3669.22$

$C_p = 3669.22$ J/kg K

L_2 : C_p 0.213

(20, 3559) (30, 3349) (21.3, x)

$$\frac{3559 - 3349}{20 - 30} = \frac{3349 - x}{30 - 21.3}$$

$x = 3531.7$

L_3 : C_p $0.496 \approx 0.5$

$C_p = 2923.608$ J/kgK

Enthalpy values from Steam Table

Effect 1 : $T_1 = 105.54\ °C$

$T_{S_2} = 105.18\ °C$

$BPR_1 = 0.36\ °C$

$T_{S_1} = 121.1\ °C$

$H_1 = H_{S_2} + 1.884\,(BPR_1)$

$(105,\ 2683.4)\quad (106,\ 2684.9)\quad (105.18,\ x)$

$$\frac{2684.9 - 2683.4}{1} = \frac{2684.9 - x}{106 - 105.18}$$

$$\therefore x = 2683.67.$$

$$H_1 = 2683.67 + 1.884\,(0.36)$$

$$= 2684.34\ \text{kJ/kg}$$

$\lambda_{S_1} = H_{S_1} - h_{S_1}$

$H_{S_1} \rightarrow (121,\ 2707.4)\quad (122,\ 2708.8)\quad (121.1,\ x)$

$$\frac{2708.8 - 2707.4}{122 - 121} = \frac{2708.8 - x}{122 - 121.1}$$

$$x = 2704.84\ \text{kJ/kg}$$

$h_{S_1} \rightarrow (121,\ 508.06)\quad (122,\ 512.31)\quad (121.1,\ x)$

$$\frac{512.31 - 508.06}{122 - 121} = \frac{512.31 - x}{122 - 121.1}$$

$$x = 508.485\ \text{kJ/kg}$$

⑦
⑥

Effect 3 :

$T_3 = 52.0\ldots$

$\lambda_{S_1} = H_{S_1} - h_{S_1}$

$= 2196.355$ kJ/kg

(latent heat of condensation)

Effect 2 :

$T_2 = 86.84°C$ $T_{S_3} = 86.19°C$ $BPR_2 = 0.66$

$H_2 = H_{S_3} + 1.884\,(0.66)$

$H_{S_3} \rightarrow (86, 2653.0)$ $(87, 2654.6)$ $(86.19, x)$

$$\frac{2654.6 - 2653}{87 - 86} = \frac{x - 2653.0}{86.19 - 86}$$

$x = 2653.304$ kJ/kg

$\rightarrow$ $H_2 = 2653.304 + 1.884\,(0.66)$

$= 2654.547$ kJ/kg

$\lambda_{S_2} = H_1 - h_{S_2}$

$= 2684.34 - h_{S_2}$

Heat

8 $h_{S_2} \rightarrow$ ~~86~~ $(105, 440.27)$ $(106, 444.50)$ $(105.18, x)$

$$\frac{444.50 - 440.27}{106 - 105} = \frac{444.50 - x}{106 - 105.18}$$

$x = 441.0314$ kJ/kg

$\lambda_{S_2} = 2684.34 - 441.0314$

$= 2243.3086$ kJ/kg

745200 + 2196.355 x A = ...

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Effect 3 :

$T_3 = 53.87°C$ $T_{S4} = 51.6°C$ $BPR_3 = 2.45$

$H_3 = H_{S4} + 1.884(2.45)$

$= 2594 + 1.884(2.45) = 2598.6158$

$\lambda s_3 = H_2 - h s_3 = 2654.547 - h s_3$

$S_3 \rightarrow$ (86, 360.22) (87, 364.42) (86.19, x)

$$\frac{364.42 - 360.22}{87 - 86} = \frac{364.42 - x}{87 - 86.19}$$

$x = 361.018$

$\cancel{\lambda s_3 = 2654.547 - 361.018}$

$\lambda s_3 = 2654.547 - 361.018$

$= 2293.529$ kJ/kg

$\rightarrow V_1 = 8000 - L_1$ $V_2 = L_1 - L_2$

$V_3 = L_2 - L_3$

<u>Heat balance</u> :

$F C_p (T_F) + S \lambda s_1 = L_1 C_p (T_1 - 0) + V_1 H_1$

① $8000 \times 3.726 \times 25 + 8(2196.355) =$

$L_1 \times 3.669(105.54 - 0) + (8000 - L_1)(2684.34)$

(2) $L_1 C_p (T_1 - 0) + V_1 \lambda_{S_2} = L_2 C_p (T_2 - 0) + V_2 H_2$

$$L_1 (3.669)(105.54 - 0) + (18000 - L_1)(2243.3086)$$

$$= L_2 (3.531)(86.84 - 0) + (L_1 - L_2)(2654.547)$$

(3) $L_2 C_p (T_2 - 0) + V_2 \lambda S_3 = L_3 C_p (T_3 - 0) + V_3 H_3$

$$L_2 (3.631)(86.84 - 0) + (L_1 - L_2)(2293.529)$$

$$= 1600.01 (2.923)(54.09 - 0) + (12 - 1600.01)(2598.61)$$

$$\Rightarrow 387.22 L_1 + 17946468.8 - 2243.31 L_1$$

$$= 306.63 L_2 + 2654.547 L_1 - 2654.547 L_2$$

$$\Rightarrow -4510.637 L_1 + 17946468.8 = -2347.917 L_2$$

$$\Rightarrow 4510.637 L_1 - 2347.917 L_2 = 17946468.8 \quad \text{(1)}$$

3 $Eq^n \Rightarrow$ $306.63 L_2 + 2293.529 L_1 - 2293.529 L_2$

$$= 252969.69 + 2598.61 L_2 - 4157801.98$$

$$-4585.509 L_2 + 2293.529 L_1 = -3904832.3$$

$$2293.529 L_1 - 4585.509 L_2 = -3904832.29$$

$L_1 = 5978.469$ kg/hr

$L_2 = 3841.8036$ kg/hr

$L_3 = 1600.01$ kg/hr

$745200 + 2196.355 \times 8 = 2315020.191 + 5426476.525$

$S = 3185.412$

$V_1 = 2021.531$ kg/hr

$V_2 = 2136.66$ kg/hr

$V_3 = 2241.79$ kg/hr

Step 5: $q_1 = S\lambda_{S_1}$

$$= \frac{3185.412}{3600} \times 2196.355 \times 1000$$

$$= 1.943 \times 10^6 \text{ W}$$

$$q_2 = V_1 \lambda_{S_2} = \frac{2021.531}{3600} \times 2243.3086 \times 10^3$$

$$= 1.26 \times 10^6 \text{ W}$$

$$q_3 = V_2 \lambda_{S_3} = \frac{2136.66}{3600} \times 2293.529 \times 10^3$$

$$= 1.36 \times 10^6 \text{ W}$$

$$A_1 = \frac{q_1}{U_1 \Delta T_1} = \frac{1.943 \times 10^6}{3123 (15.56)} = 39.98 \text{ m}^2$$

$$A_2 = \frac{1.26 \times 10^6}{1987 (18.34)} = 34.57 \text{ m}^2$$

$$A_3 = \frac{1.36 \times 10^6}{1136 (32.11)} = 37.28 \text{ m}^2$$

$A_{avg} = 37.27 \ m^2$

$$\text{Steam economy} = \frac{V_1 + V_2 + V_3}{S}$$

$$= 2.009.$$