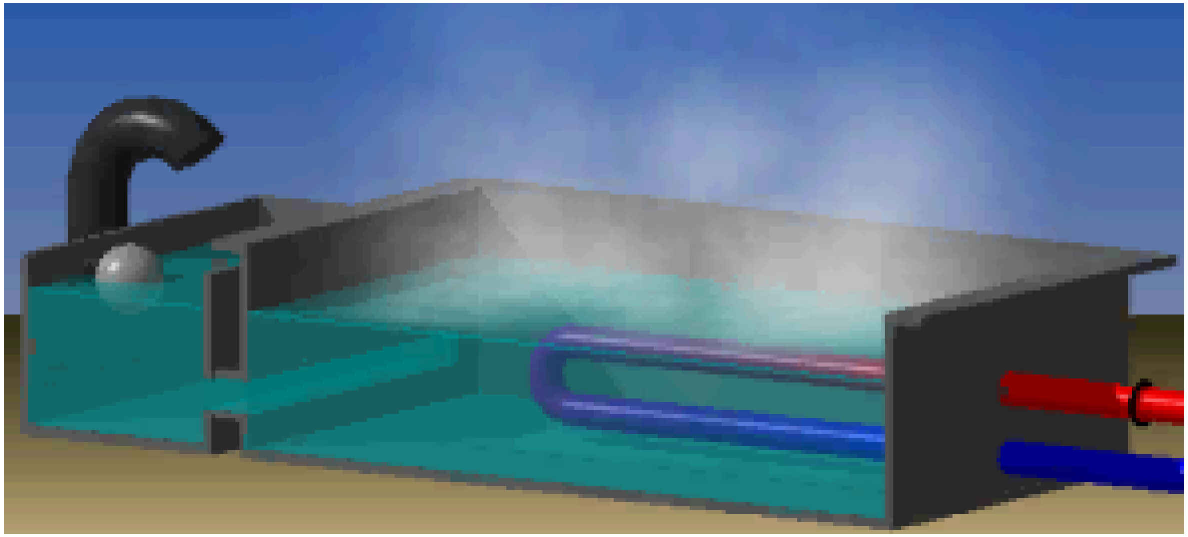
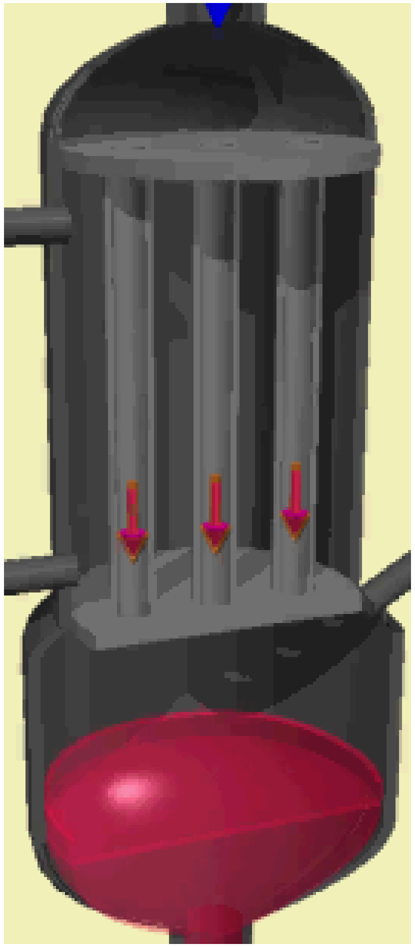
Mechanism of evaporation



- removing a liquid by boiling off some of the liquid
- thermal separation/concentration
- vapour removed as top product
- concentrated solution as bottom product
- desired products
  - ➢ concentrated solution eg. Milk
  - ➢ vapour usually water vapour
  - ➢ crystal eg. Salt crystal

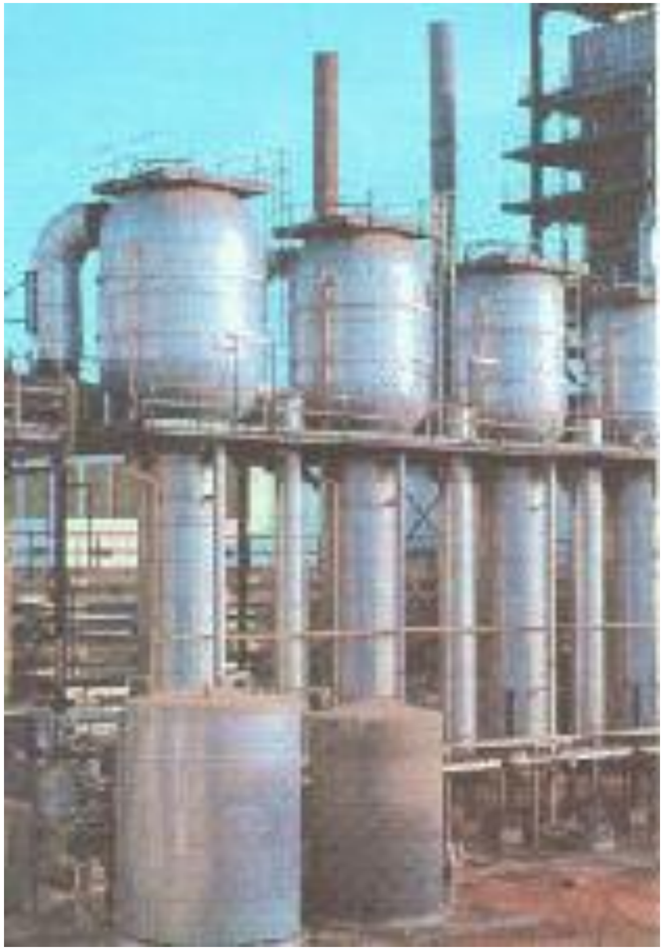
Types of evaporators

3 Vertical-tube natural circulation evaporator



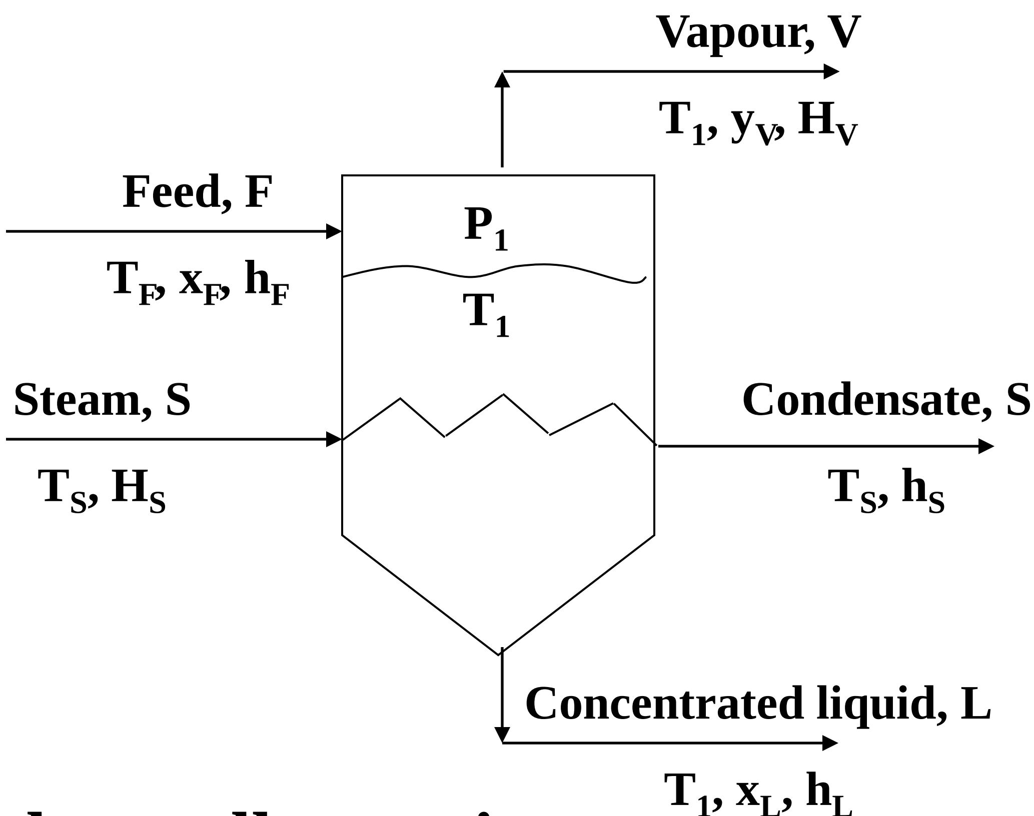
(a) Falling-film evaporator

(b) Climbing-film evaporator



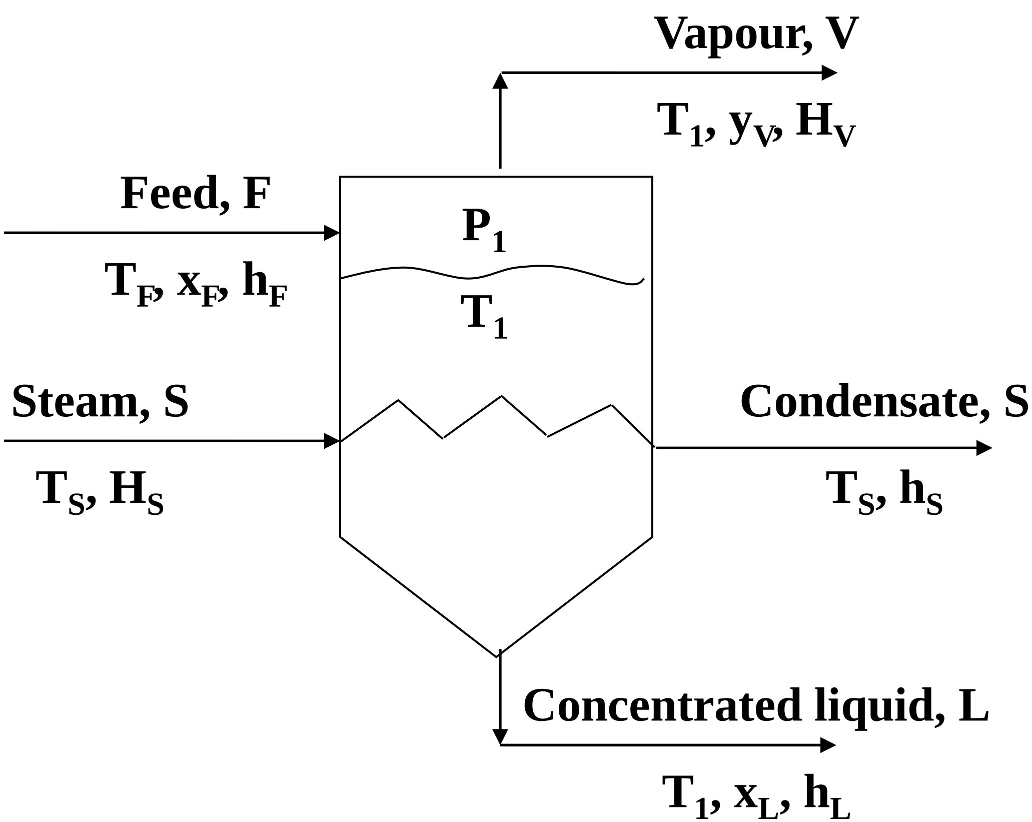
(a) Falling-film evaporator **(b) Climbing-film evaporator**

1. single-effect evaporator



- **relatively small capacity**
- **cost of steam relatively cheap**
- **wasteful as latent heat of vapour is discarded**
- **$T_F = T_{bp}$, dilute solution, 1 kg steam = 1 kg vapour**

Calculation methods for single-effect evaporator (dilute)

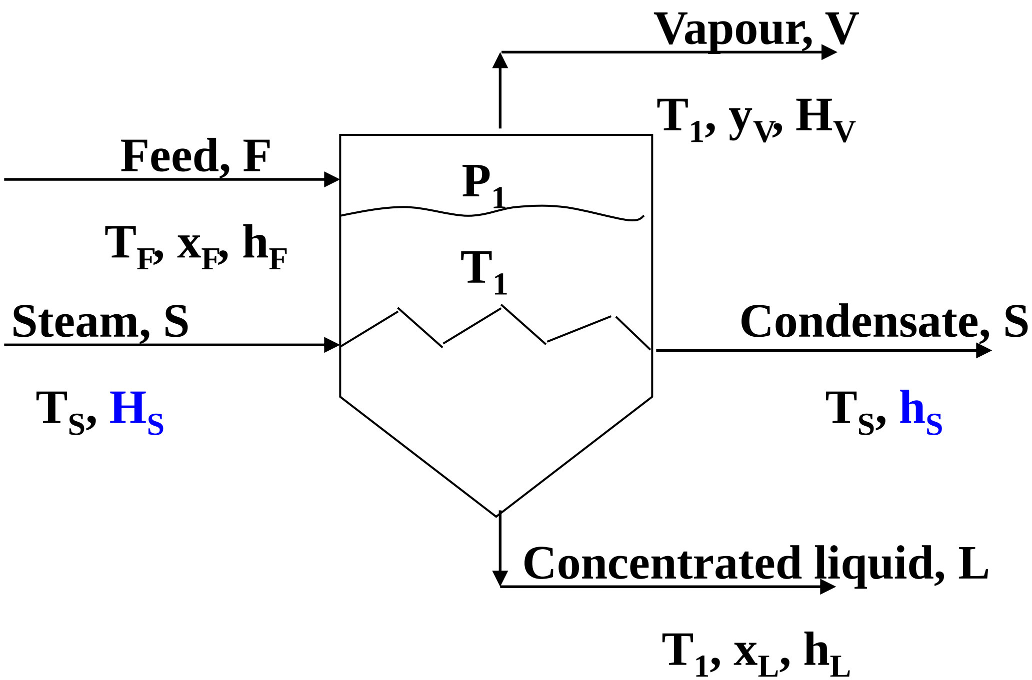


1. Vapour (V) & concentrated liquid (L) flowrates

Total material balance : $F = L + V$

Solute/solid balance: $F(x_F) = L(x_L)$ ($y_v = 0$ as vap has no salt)

Calculation methods for single-effect evaporator (dilute)



2. Heat-transfer surface area (A) & no boiling-point rise (BPR) :

Energy balance: $Fh_F + S(H_S - h_S) = Lh_L + VH_V$

Heat transfer equation: $q = S\lambda = UA\Delta T = UA(T_S - T_1)$

where $S(H_S - h_S) = S\lambda$

$h = c_P(T - T_{ref.})$

H_V = latent heat at T_1 ($T_{ref.} = T_1$)

c_P of inorganic salt in water $\cong$ c_P of water = 4.14 kJ/kg.K

Example 8.4-1 (Geankoplis textbook)

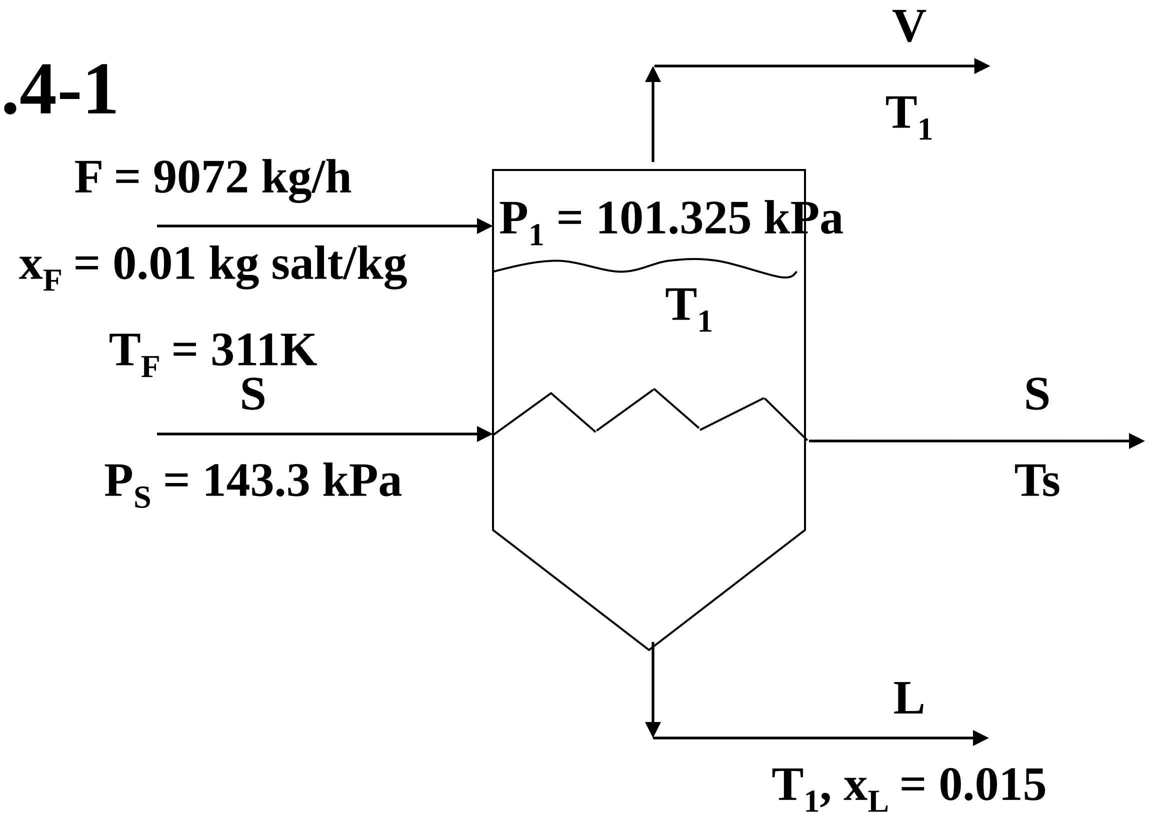
A continuous single-effect evaporator concentrates 9072 kg/h of a 1.0 wt% salt solution entering at 311.0K (37.8^{o}C) to a final concentration of 1.5 wt%. The vapor space of the evaporator is at 101.325 kPa (1.0 atm abs) and the steam supplied is saturated at 143.3 kPa. The overall coefficient U = 1704 W/m^2.K. Calculate

i) the amounts of vapor and liquid product

ii) the heat-transfer area required.

Assume that, since it is dilute, the solution has the same boiling point as water.

Example 8.4-1



Vapour (V) & concentrated liquid (L) flowrates

Total material balance : $9072 = F = L + V$ (1)

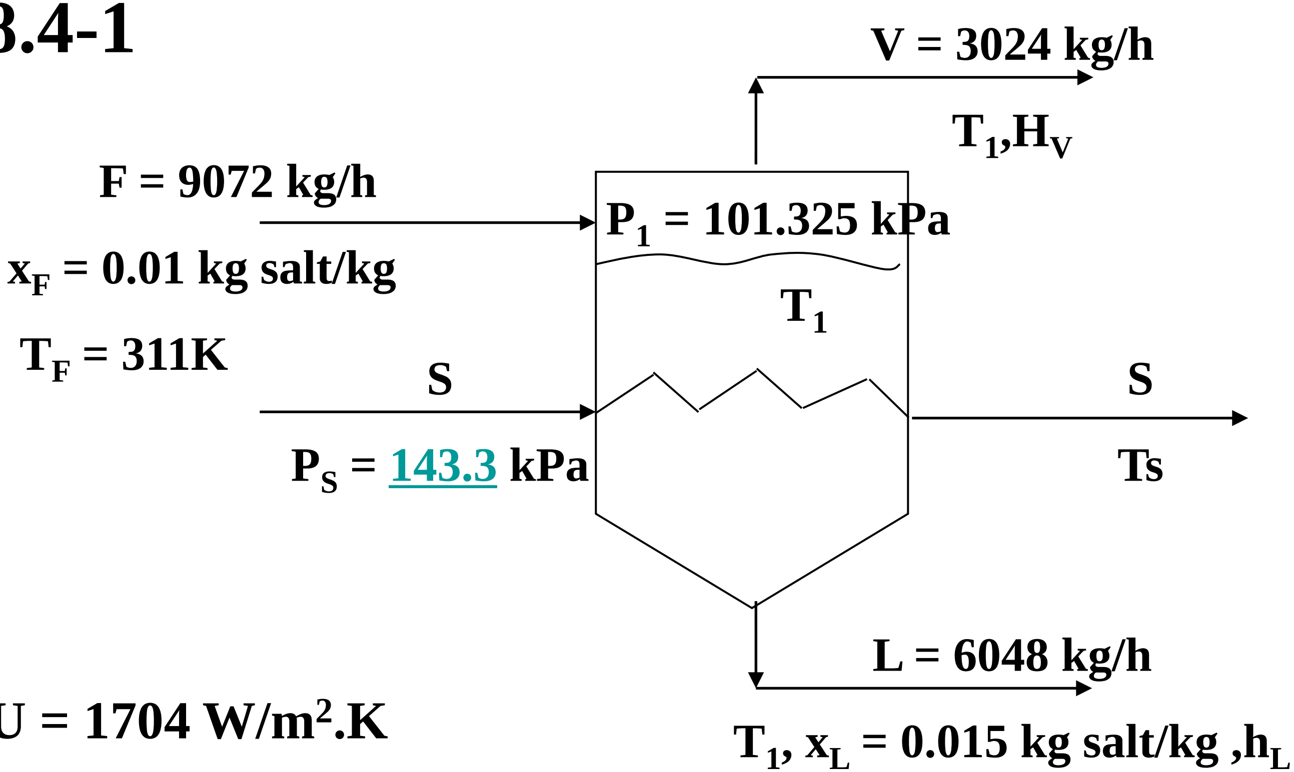
Salt balance: $F(x_F) = L(x_L)$

$$9072(0.01) = L(0.015)$$

$$L = \qquad \text{kg/h}$$

Substituting L = kg/h into eq. (1), V = kg/h

Example 8.4-1



U = 1704 W/m^2.K

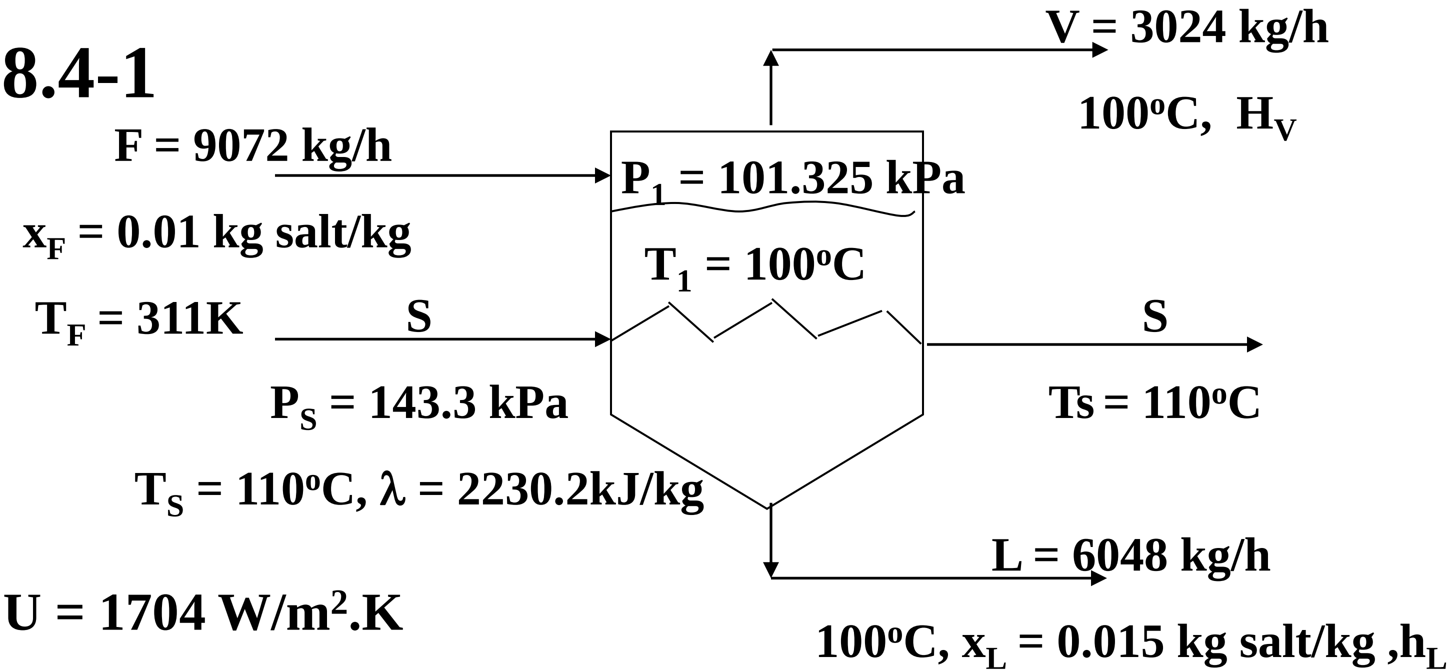
From the steam table (A.2-9) at P_S = 143.3 kPa, T_S = °C ,

H_S = kJ/kg, h_S = kJ/kg, $\therefore \lambda$ = ( ) = kJ/kg

From the steam table (A.2-9) at P_1 = 101.325 kPa, T_1 = °C ,

$H_{sat.\ vapour}$ = kJ/kg, h_{liquid} = kJ/kg

Example 8.4-1



From the steam table (A.2-9) at, $T_1 = 100^oC$,H = 2676.1 kJ/kg, h = 419.04 kJ/kg

$T_{ref} = 100^oC$ (same as T_1),

Energy balance: $Fh_F + S(H_S - h_S) = Lh_L + VH_V$

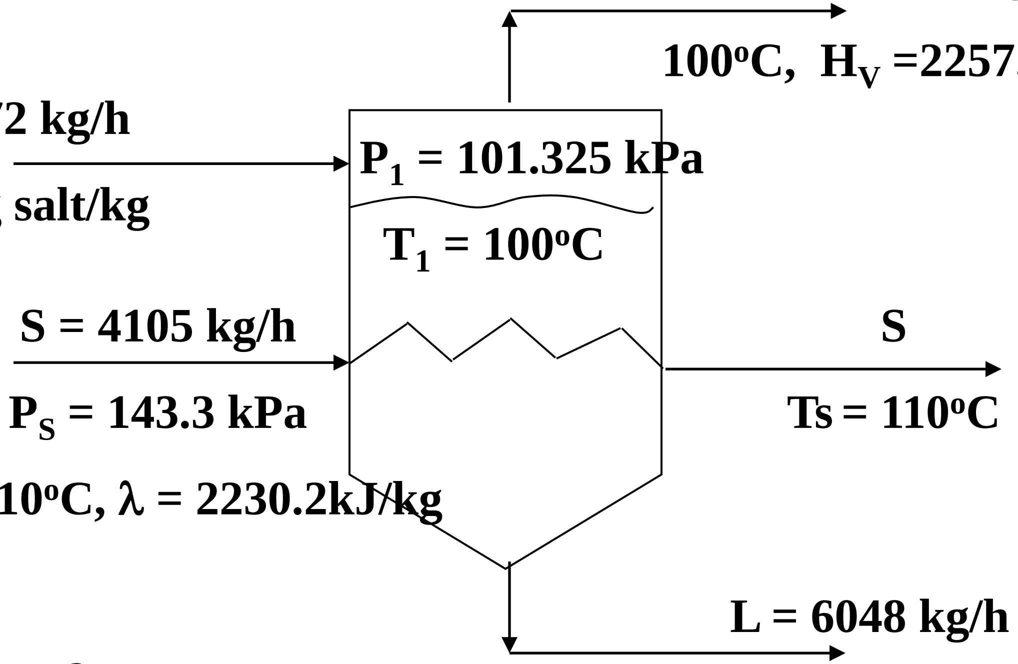
$9072h_F + S(2230.2) = 6048(h_L) + 3024(H_V)$

where $h_F = c_{PF}(T_F - T_{ref.}) =$ = kJ/kg

$h_L = c_{PL}(T_1 - T_{ref}) =$ =

$H_V = [(H_{sat.vapour}) - h_{liquid}] = ($ $) =$ kJ/kg

S = kg/h



$U = 1704\ W/m^2.K$

Heat transfer equation:

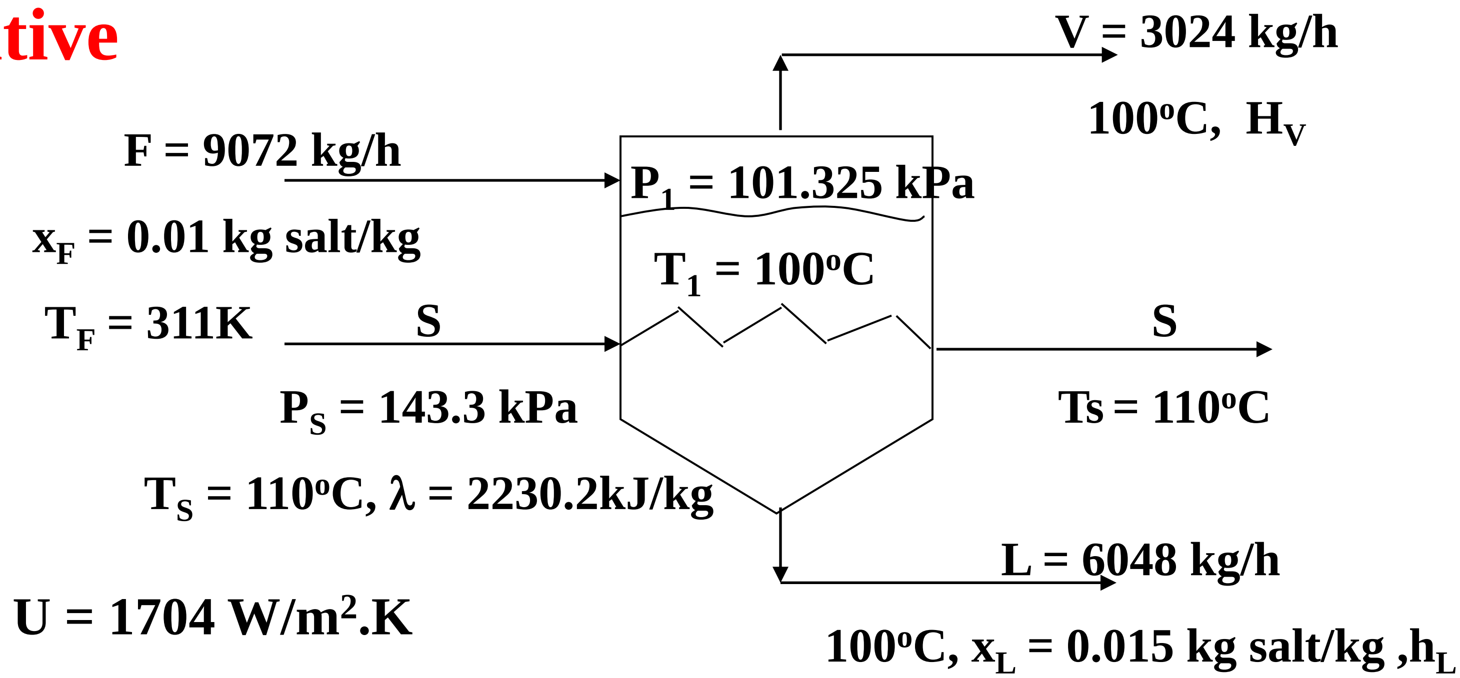
$$q = S\lambda = UA\Delta T = UA(T_S - T_1)$$

$$q = S\lambda = \frac{4105\ \cancel{kg}}{\cancel{h}} \left| \frac{2230.2\ kJ}{\cancel{kg}} \right| \frac{1\cancel{h}}{3600s} = 2543\ kJ/s$$

$$A = q/[U\ (T_S - T_1)]$$

$$A = \frac{2543.0 \times 10^3\ \cancel{W}}{(110-100)\ \cancel{K}} \left| \frac{m^2.\cancel{K}}{1704\ \cancel{W}} \right. = 149.3\ m^2$$

Alternative method



From the steam table (A.2-9) at, T_1 = 100°C ,H = 2676.1 kJ/kg, h = 419.04 kJ/kg

T_{ref} = 0°C (same as steam table),

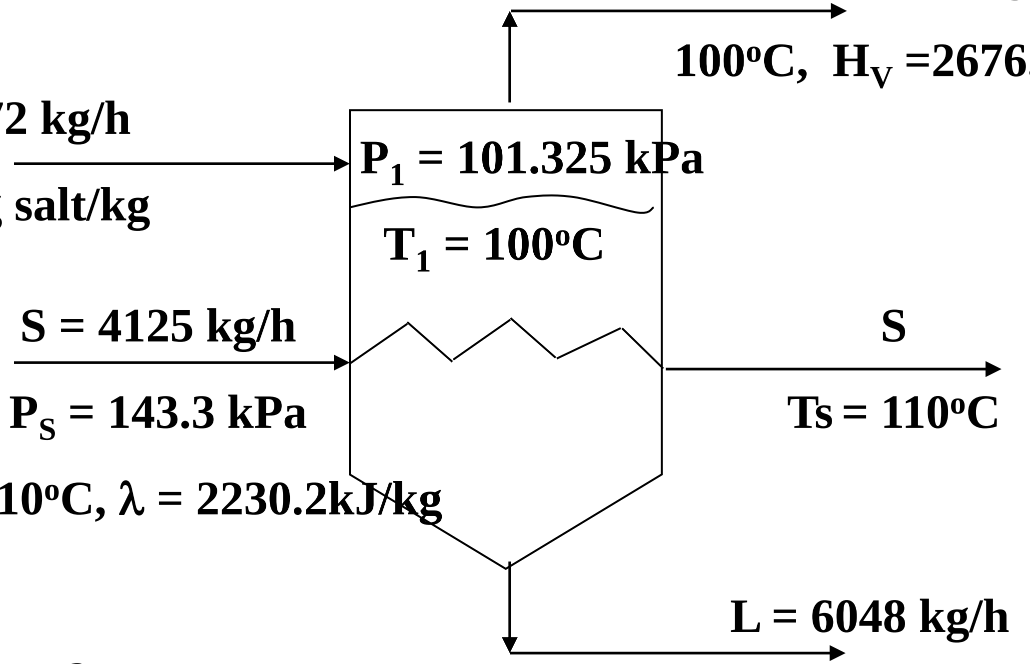
Energy balance: $$Fh_F + S(H_S - h_S) = Lh_L + VH_V$$

$$9072h_F + S(2230.2) = 6048(419.04) + 3024(2676.1)$$

where h_F = 159.22 kJ/kg (after interpolation) from steam table (A.2-9)

$$9072(157.32) + S(2230.2) = 6048(419.04) + 3024(2676.1)$$

S = 4125 kg/h (compare to 4108 kg/h)



$U = 1704\ W/m^2.K$

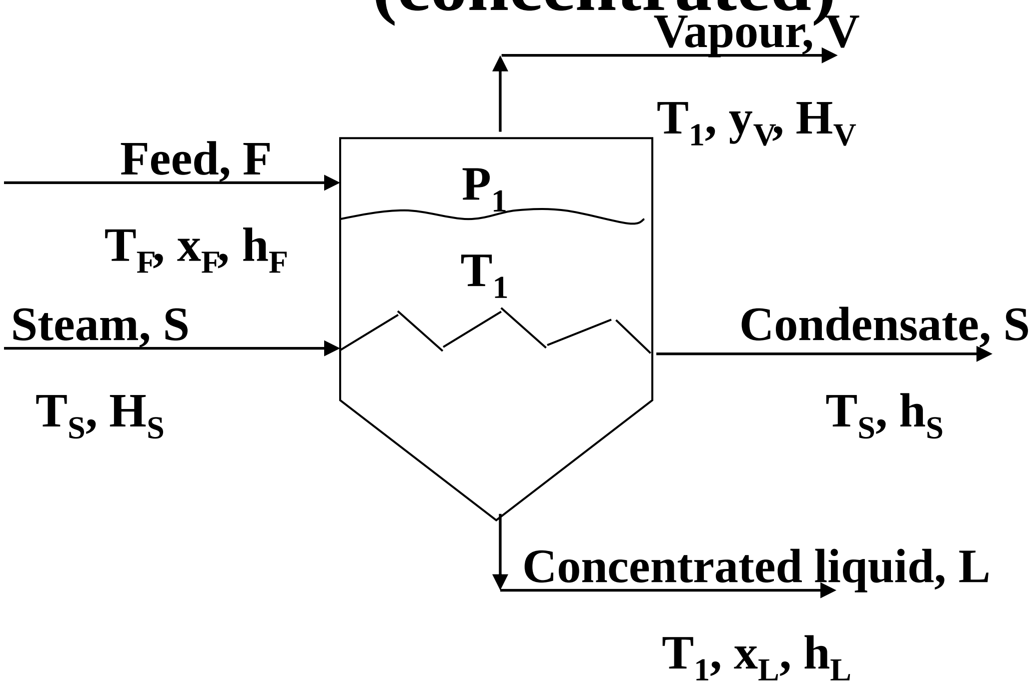
Heat transfer equation: $q = S\lambda = UA\Delta T = UA(T_S - T_1)$

$$q = S\lambda = \frac{4125\ \cancel{kg}}{\cancel{h}} \left| \frac{2230.2\ kJ}{\cancel{kg}} \right| \frac{1\cancel{h}}{3600 s} = 2555.4\ kJ/s$$

$$A = q/[U\ (T_S - T_1)]$$

$$A = \frac{2555.4 \times 10^3\ \cancel{W}}{(110\text{-}100)\ \cancel{K}} \left| \frac{m^2.\cancel{K}}{1704\ \cancel{W}} \right. = 150\ m^2\ \ (\text{compare to } 149.3\ m^2)$$

Calculation methods for single-effect evaporator (concentrated)



2. Heat-transfer surface area (A) & with boiling-point rise (BPR) :

Energy balance: $Fh_F + S(H_S - h_S) = Lh_L + VH_V$

Heat transfer equation: $q = S\lambda = UA\Delta T = UA(T_S - T_1)$

where $T_1 = T_{sat.\ at\ P1} + BPR$ or from fig. 8.4-2

h_F and h_L from fig. 8.4-3

$H_V = H_{sat.\ at\ P1} + 1.884(BPR)$

Boiling-point rise (BPR) of solution

Boiling-point elevation describes the phenomenon that the boiling point of a liquid (a solvent) will be higher when another compound is added, meaning that a solution has a higher boiling point than a pure solvent. This happens whenever a non-volatile solute, such as a salt, is added to a pure solvent, such as water.

Therefore, the boiling-point elevation means that when a solute is dissolved in a solvent, the boiling point of the resulting solution is higher than that of the pure solvent.

Boiling-point rise (BPR) of solution

Concentrated solution – thermal properties differ from water

Duhring line chart – estimate boiling-point rise for a solution

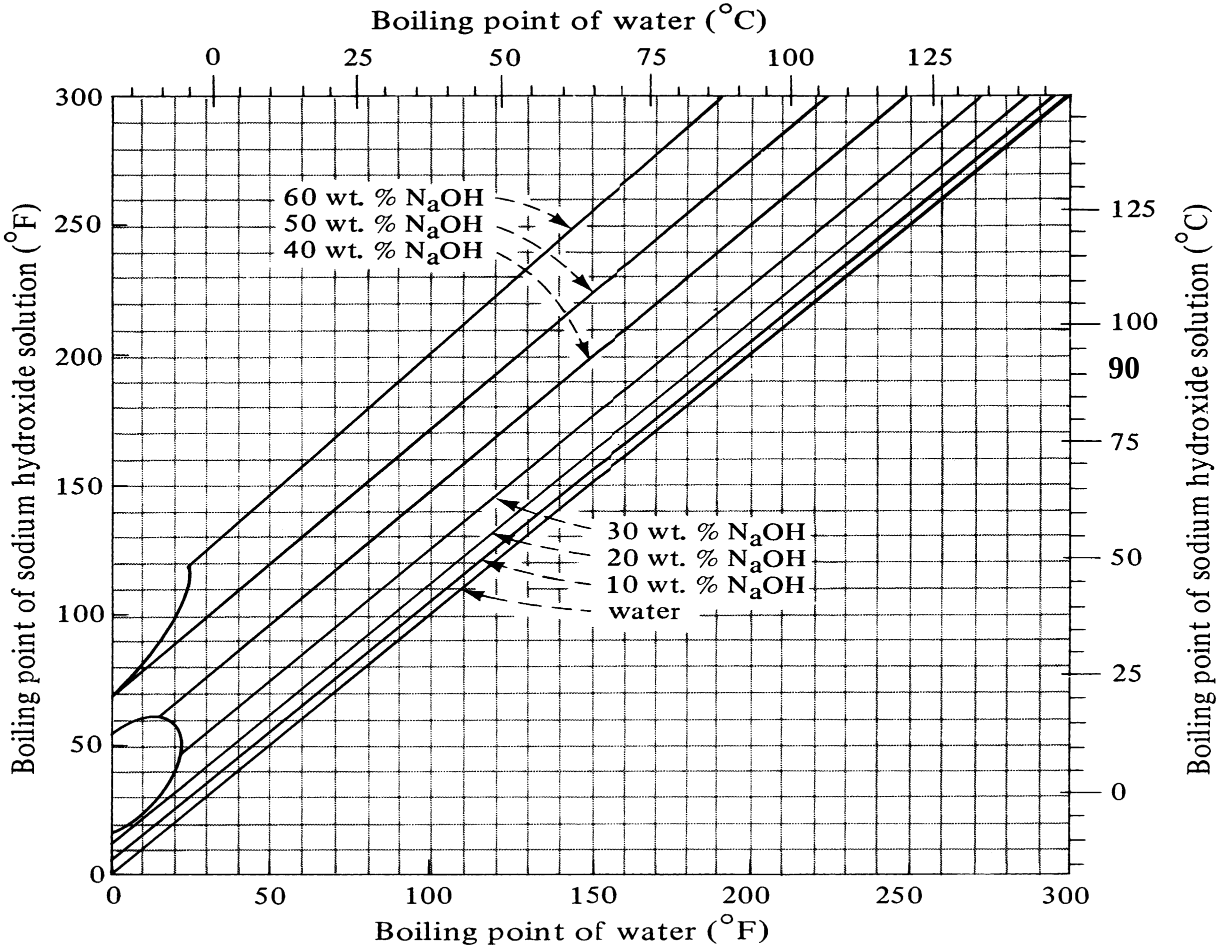


Figure 8.4-2. Duhring line chart for aqueous solutions of sodium hydroxide

Example 8.4-2 Use of Duhring Chart for BPR

As an example of the use of the chart, the pressure in an evaporator is given as 25.6 kPa (3.72 psia) and a solution of 30% NaOH is being boiled. Determined the boiling temperature of NaOH solution and the boiling point rise , BPR of the solution over that of water at the same pressure.

Steam table, bpt of water at 25.6 kPa = 65.5^oC (150^oF)

From Duhring chart, at 150^oF and 30% NaOH, bpt of NaOH solution is 79.5^oC (175^oF)

BPR = (79.5 – 65.6)^oC = 13.9^oC

Boiling-point rise (BPR) of solution

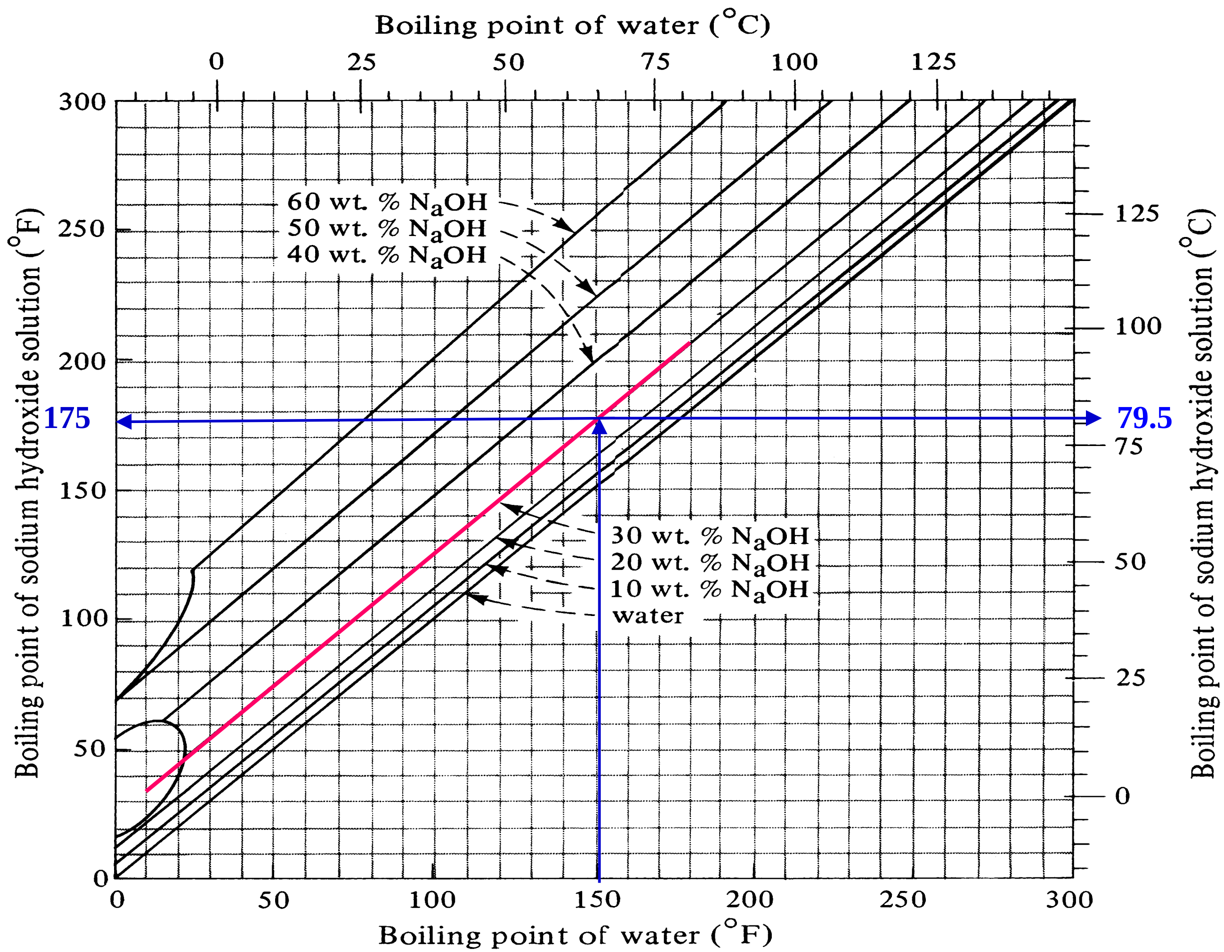


Figure 8.4-2. Duhring line chart for aqueous solutions of sodium hydroxide

Enthapy-concentration chart

enthapy chart – $T_{ref.}$ = liquid water at 0°C

- used together with steam tables

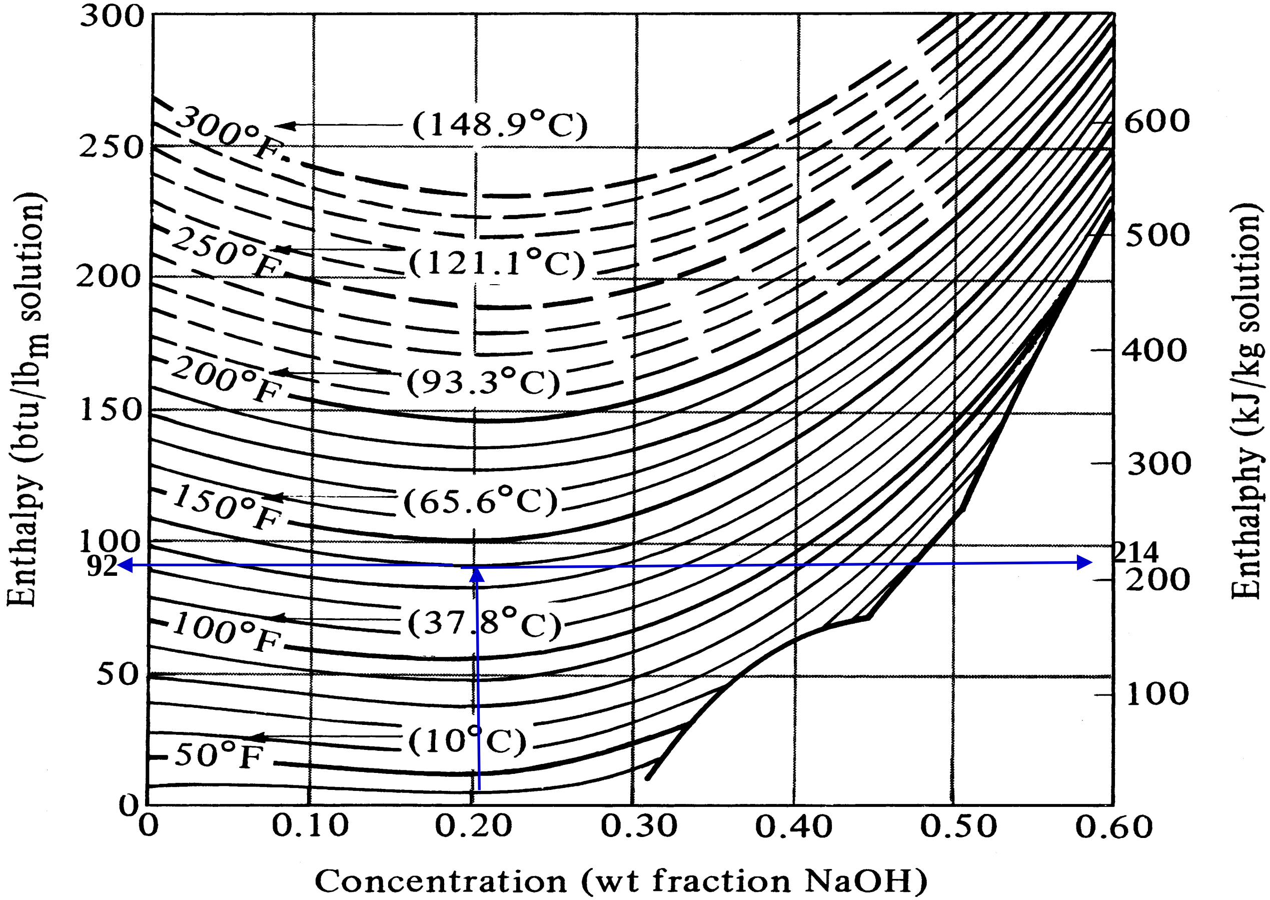


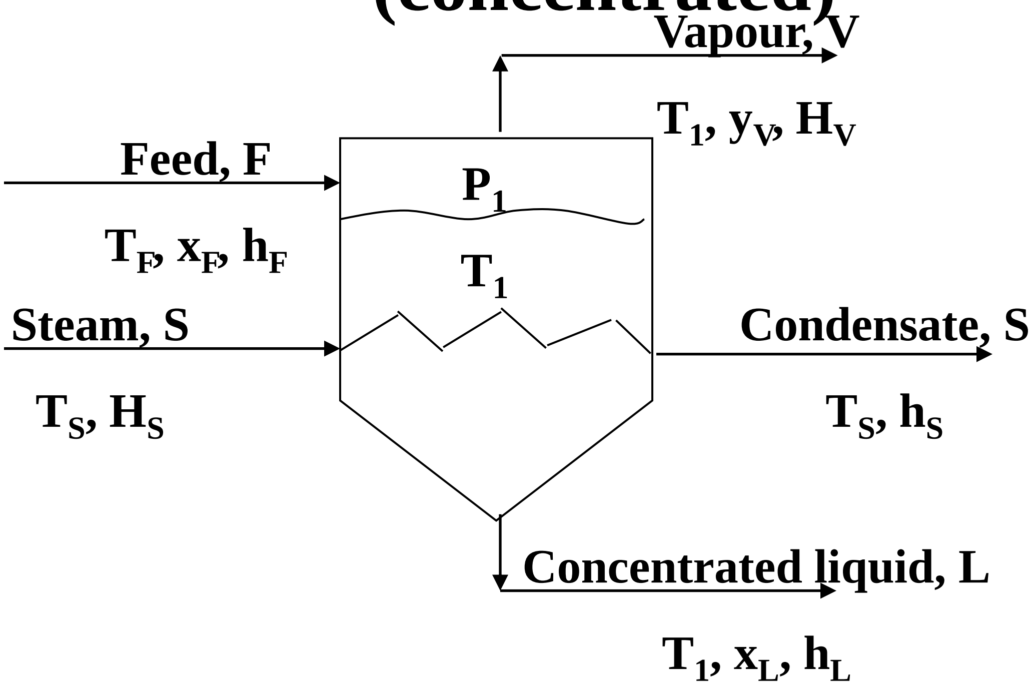
Figure 8.4-3. Enthapy-concentration chart for the system NaOH-water

Example 8.4-3

An evaporator is used to concentrate 4536 kg/h (10,000 Ib_m/h) of a 30% solution of NaOH in water entering at 60^{o}C (140^{o}F) to a product of 40% solids. The pressure of the saturated steam used is 172.4 kPa (25 psia) and the pressure in the vapor space of the evaporator is 11.7 kPa (1.7 psia). The overall heat-transfer coefficient is 1560 W/m^2.K (275 btu/h.ft^2.^{o}F).

Calculate the steam used, the steam economy in kg vaporized/kg steam used, and the heating surface area in m^2.

Calculation methods for single-effect evaporator (concentrated)



2. Heat-transfer surface area (A) & with boiling-point rise (BPR) :

Energy balance: $Fh_F + S(H_S - h_S) = Lh_L + VH_V$

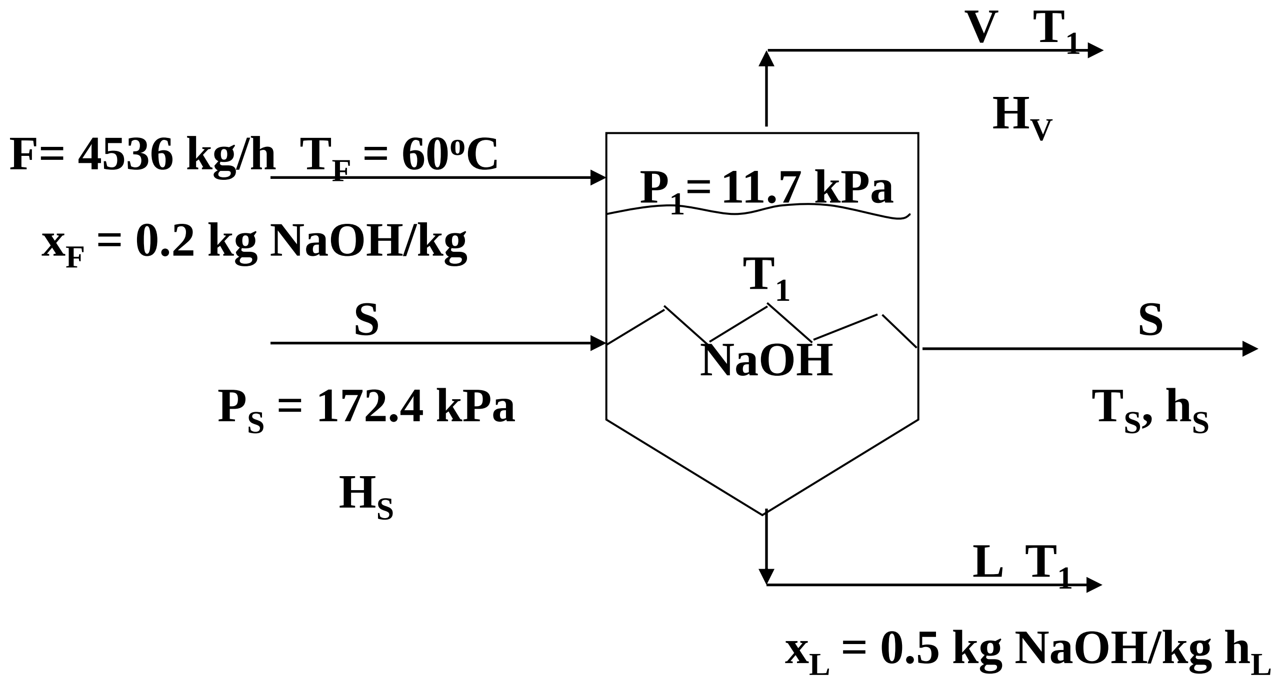
Heat transfer equation: $q = S\lambda = UA\Delta T = UA(T_S - T_1)$

where $T_1 = T_{sat.\ at\ P1} + BPR$ or from fig. 8.4-2

h_F and h_L from fig. 8.4-3

$H_V = H_{sat.\ at\ P1} + 1.884\ (BPR)$

Example 8.4-3



Given : U = 1560 W/m^2.K

Total material balance : $$4536 = F = L + V \qquad (1)$$

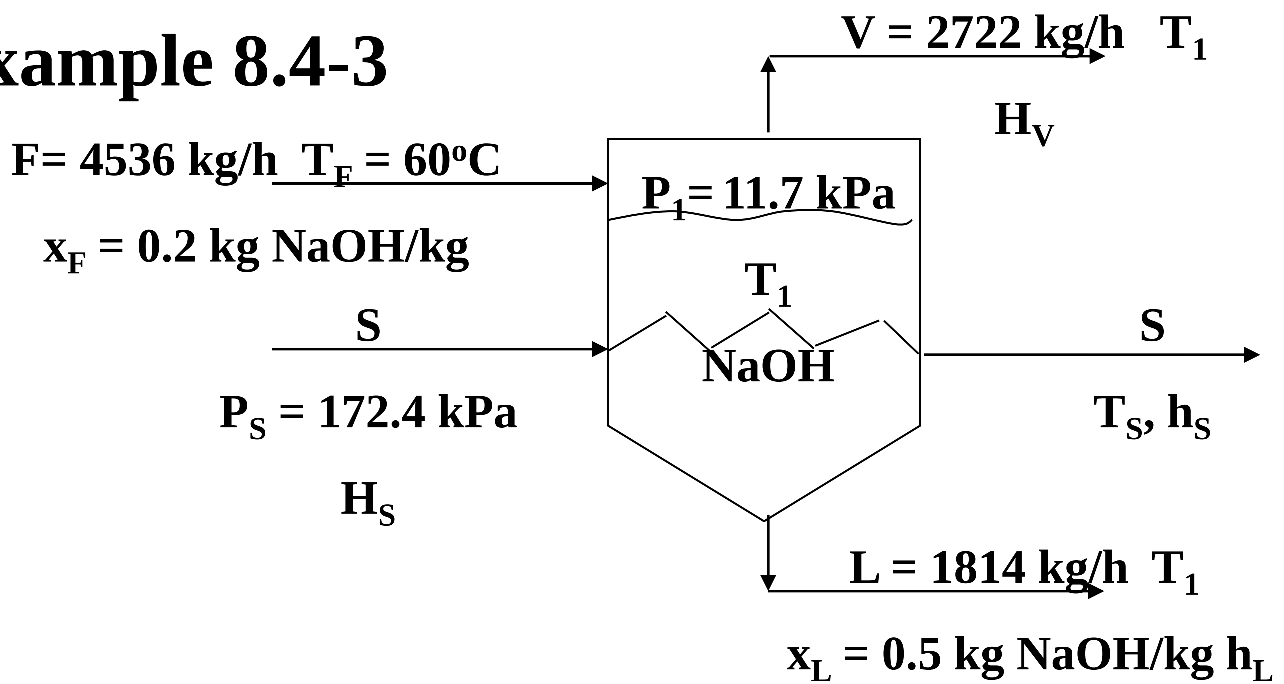
Solute/solid balance: $$F(x_F) = L(x_L)$$

$$4536(0.2) = L(0.5)$$

$$L = 1814 \text{ kg/h}$$

Substituting L = 1814 kg/h into eq. (1), V = 2722 kg/h

Example 8.4-3



Given : $U = 1560\ W/m^2.K$

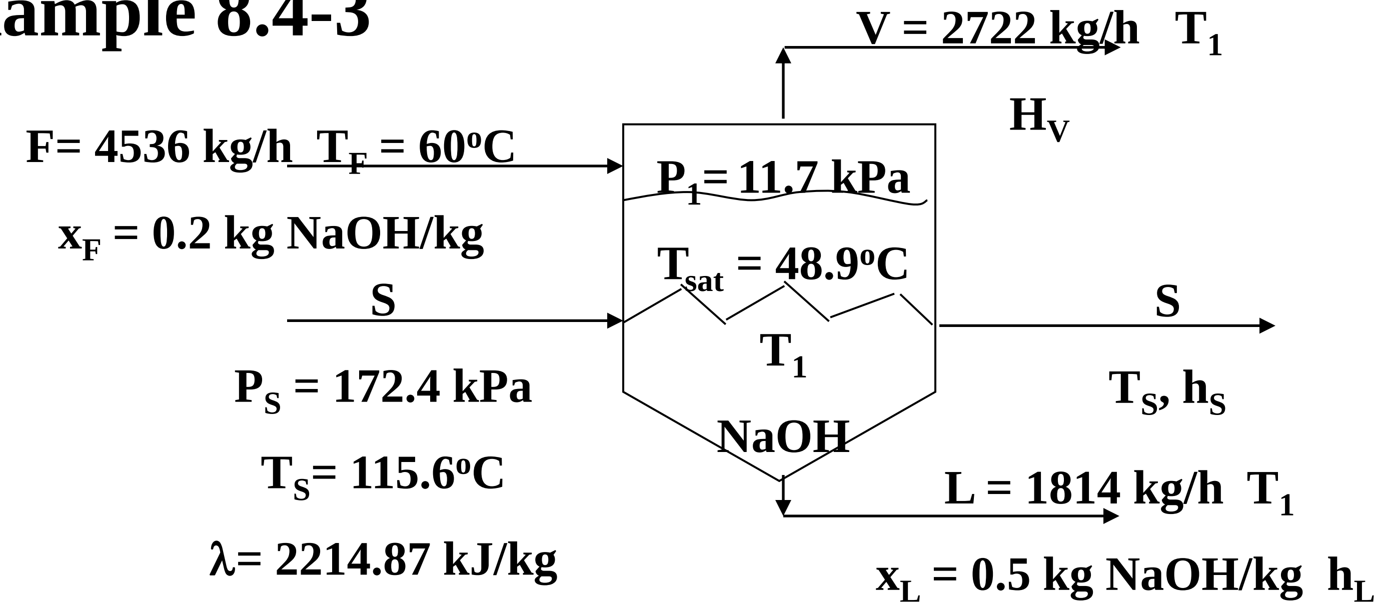
From the steam table (A.2-9) at P_S = 172.4 kPa, after interpolation, $T_S = 115.6^oC$,

H_S = 2699.9 kJ/kg, h_S = 485.03 kJ/kg, $\therefore \lambda = (2699.9 - 485.03) = 2214.87$ kJ/kg

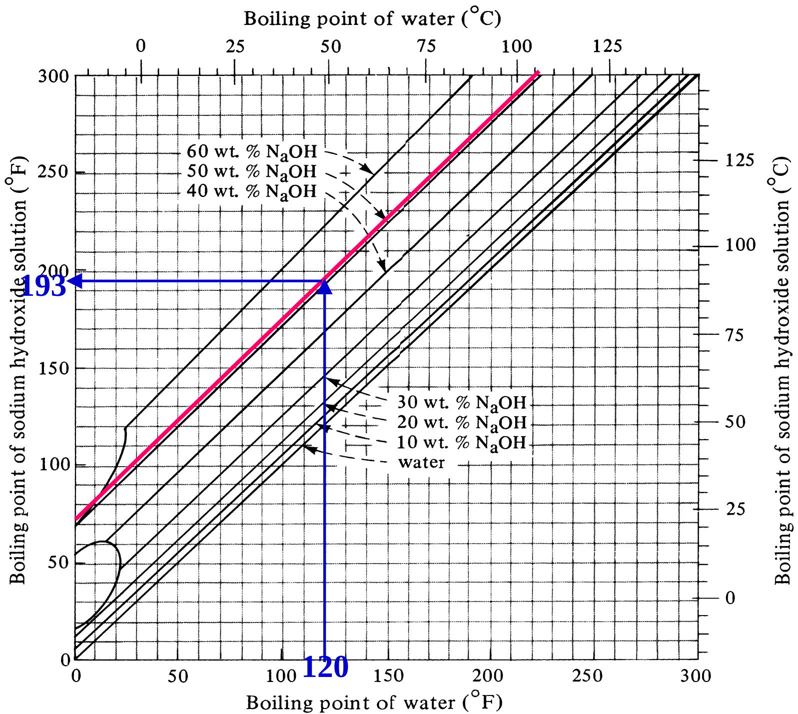
From the steam table (A.2-9) at P_1 = 11.7 kPa, after interpolation,

$T_{sat.} = T_{boiling\ point\ of\ water} = 48.9^oC$, $H_{sat.\ vapour}$ = 2590 kJ/kg

Example 8.4-3

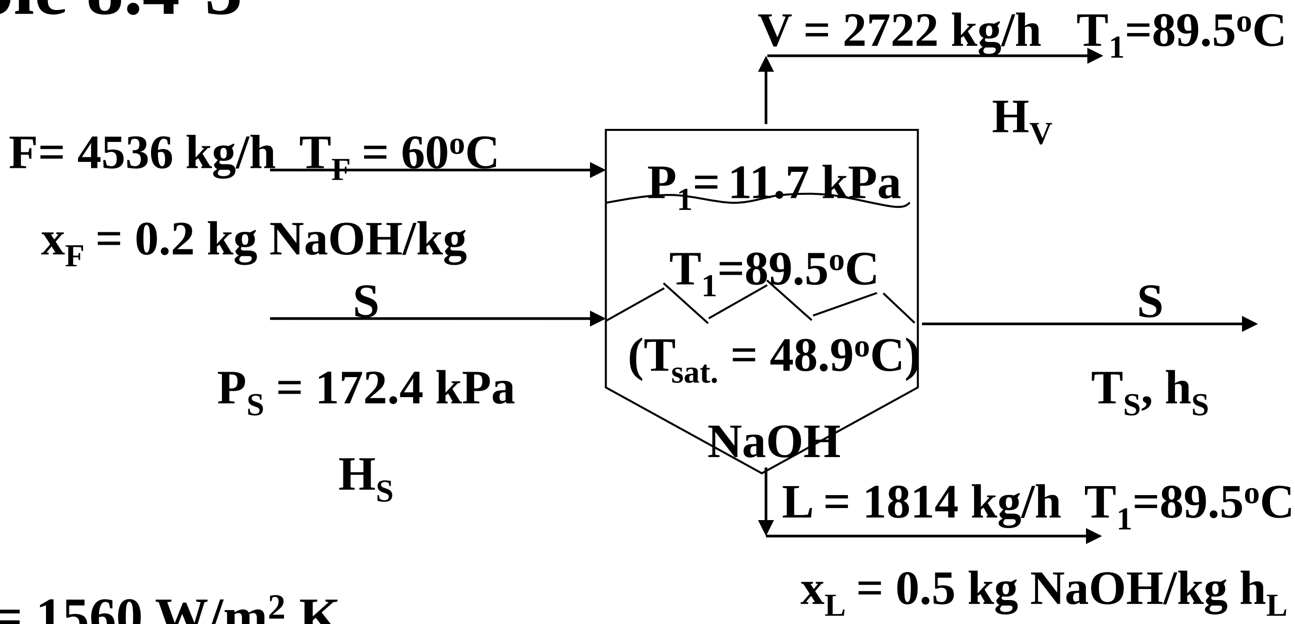


T_1 is obtained from Figure 8.4-2, at 50% NaOH and $T_{bp\ water}$ = 48.9ºC(120ºF)



$\therefore T_1$ = 193ºF (89.5ºC)

Example 8.4-3



Given : $U = 1560\ W/m^2.K$

$BPR = T_1 - T_{sat} = (89.5 – 48.9)^oC = 40.6^oC$

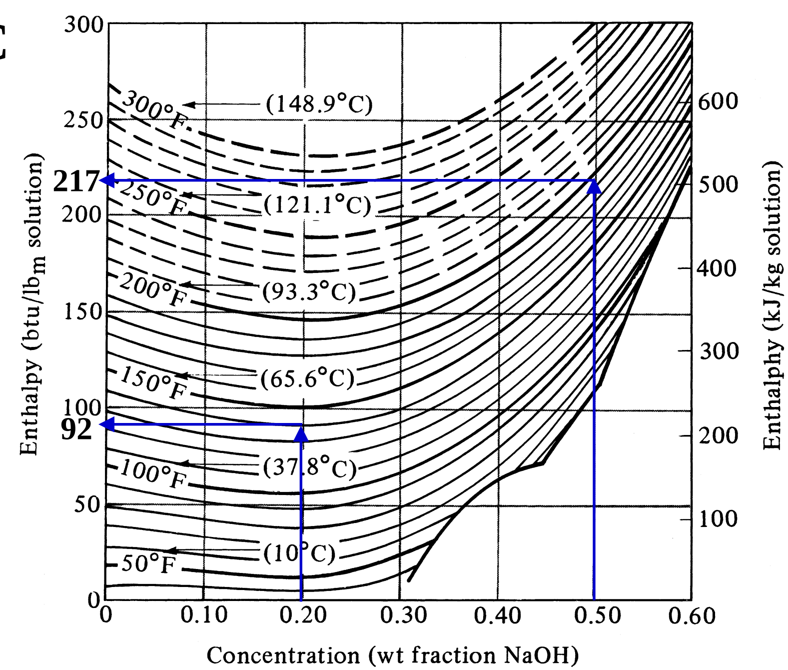
$T_{ref.} = 0^oC$ (same figure 8.4-3),

h_F at $60^oC(140^oF)$ & 20% NaOH from figure 8.4-3,

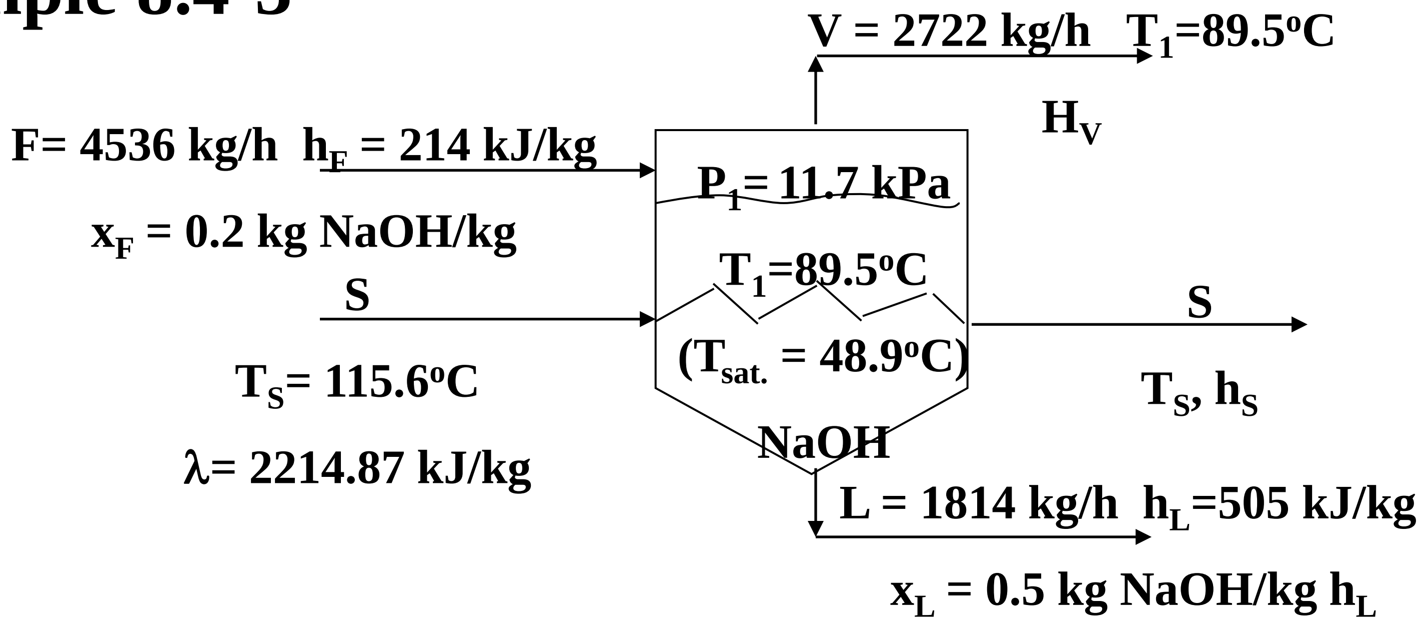
$\therefore h_F = 92\ btu/Ib_m\ (214\ kJ/kg)$

h_L at $89.5^oC\ (193^oF)$ & 50% NaOH from figure 8.4-3,

$\therefore h_L = 217\ btu/Ib_m\ (505\ kJ/kg)$



Example 8.4-3



Given : $U = 1560\ W/m^2.K$

$BPR = T_1 - T_{sat} = (89.5 – 48.9)^oC = 40.6^oC$

$T_{sat.} = 48.9^oC$, $H_{sat.\ vapour} = 2590\ kJ/kg$

Energy balance:

$$Fh_F + S(H_S – h_S) = Lh_L + VH_V$$

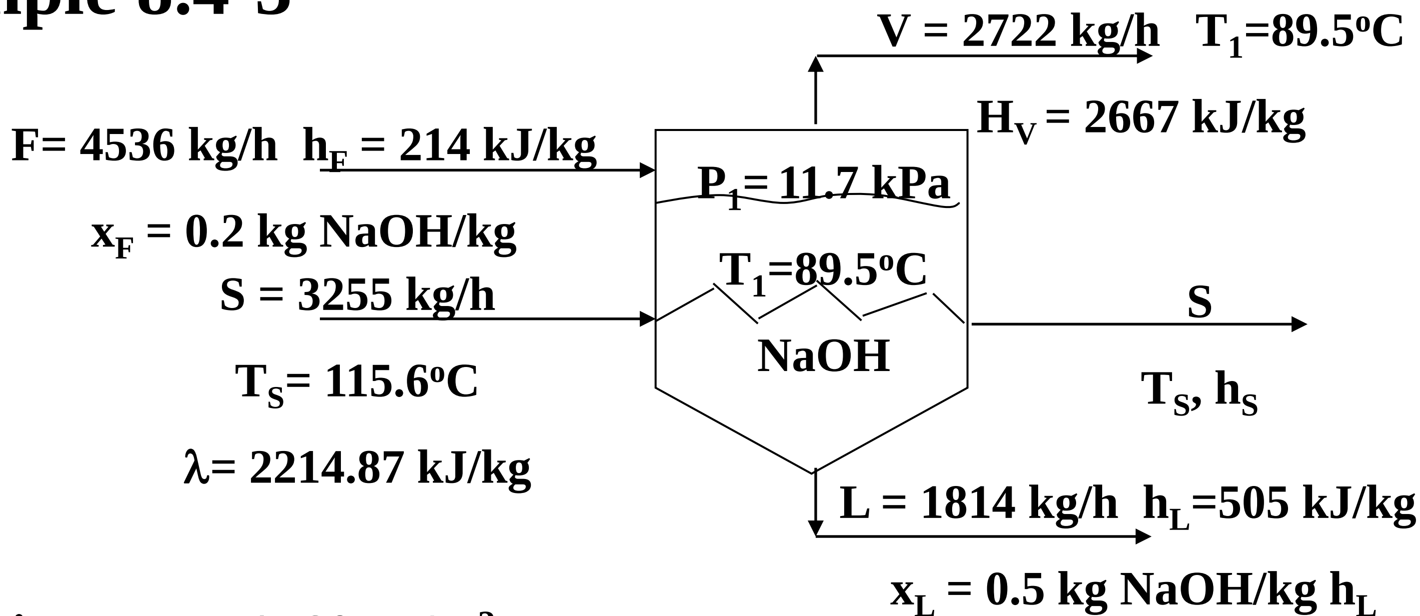
$$4536(214) + S(2214.87) = 1814(505) + 2722H_V$$

$$H_V = 2590 + 1.884(40.6) = 2667\ kJ/kg$$

$$4536(214) + S(2214.87) = 1814(505) + 2722(2667)$$

$$S = 3255\ kg/h$$

Example 8.4-3



Given : $U = 1560\ \text{W/m}^2\text{.K}$

Heat transfer equation:

$$q = S\lambda = UA\Delta T = UA(T_S - T_1)$$

$$q = S\lambda = \frac{3255\ \text{kg}}{\text{h}} \left| \frac{2214.87\ \text{kJ}}{\text{kg}} \right| \frac{1\text{h}}{3600\text{s}} = 2002\ \text{kJ/s}$$

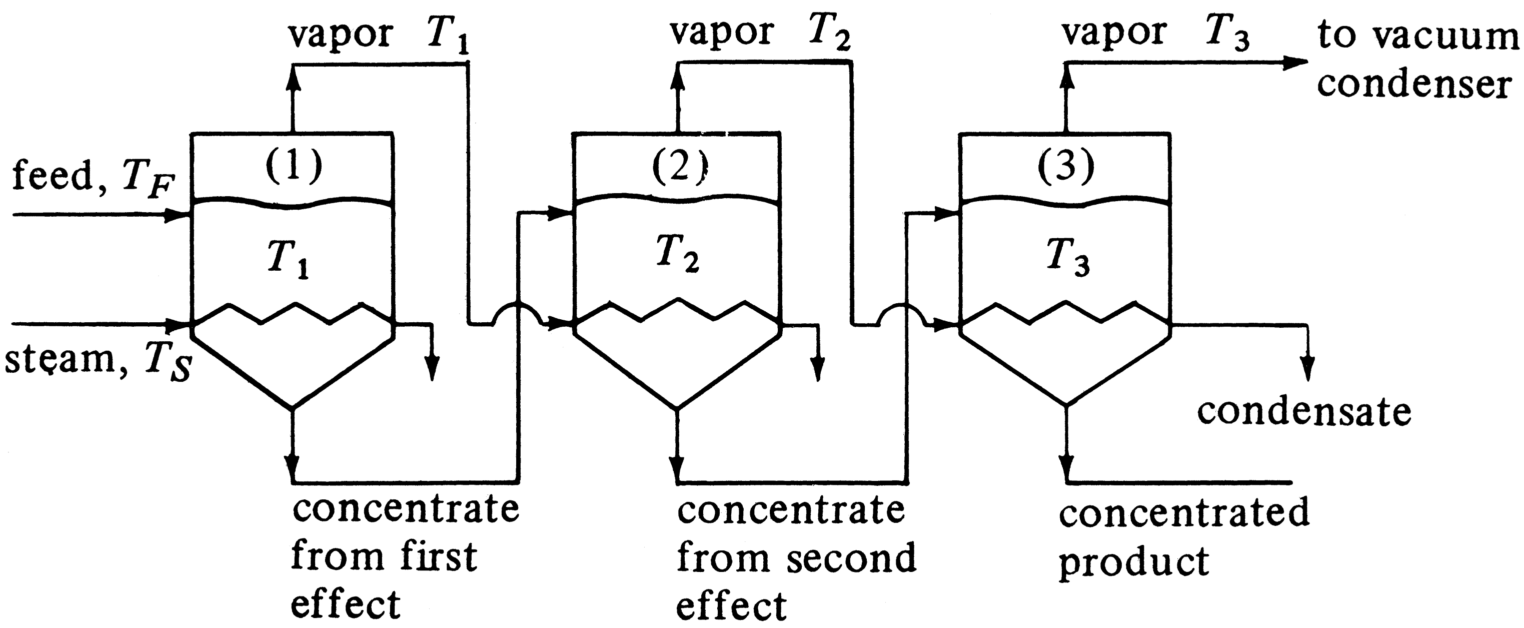
$$A = \frac{2002 \times 10^3\ \text{W}}{(115.6-89.5)\ \text{K}} \left| \frac{\text{m}^2\text{.K}}{1560\ \text{W}} \right. = \boxed{49.2\ \text{m}^2}$$

Steam economy = V/S = 2722/3255 = 0.836 →

<1: not economical

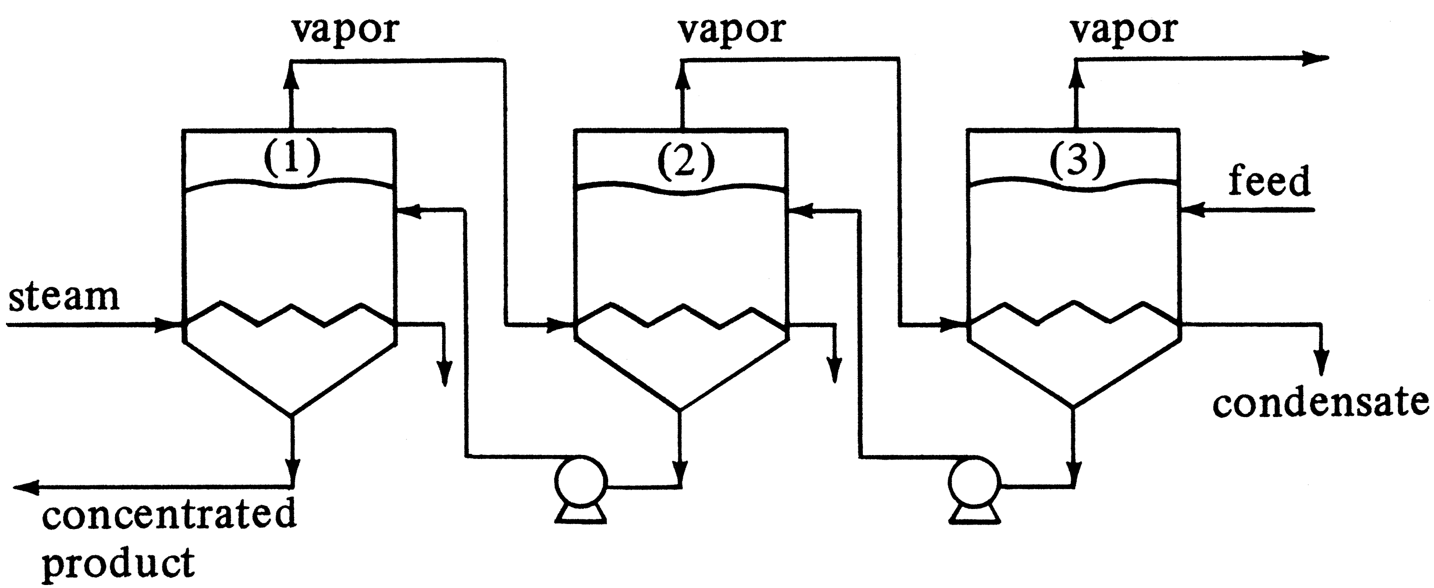
>1: more economical

1. forward-feed multiple-effect evaporator



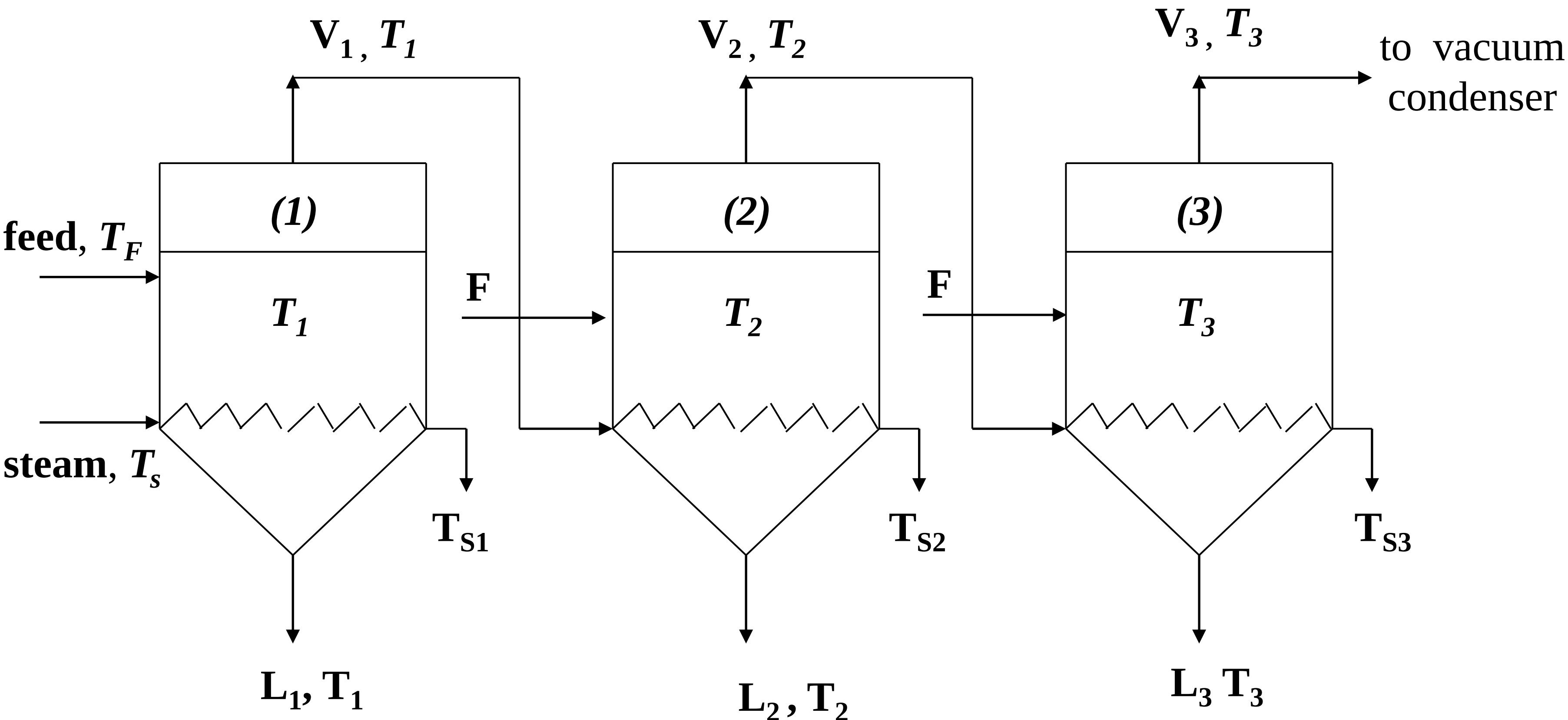
- **fresh feed to 1st stage/effect**
- **conc. prod. from 1st effect to 2nd effect**
- **vapour from 1st effect as heating medium for 2nd effect**
- **co-current flow**
- **$T_F = T_{bp}$, dilute solution, 1 kg steam = 3 kg vapour**
- **feed is hot**
- **heat-sensitive final product**

2. backward-feed multiple-effect evaporator



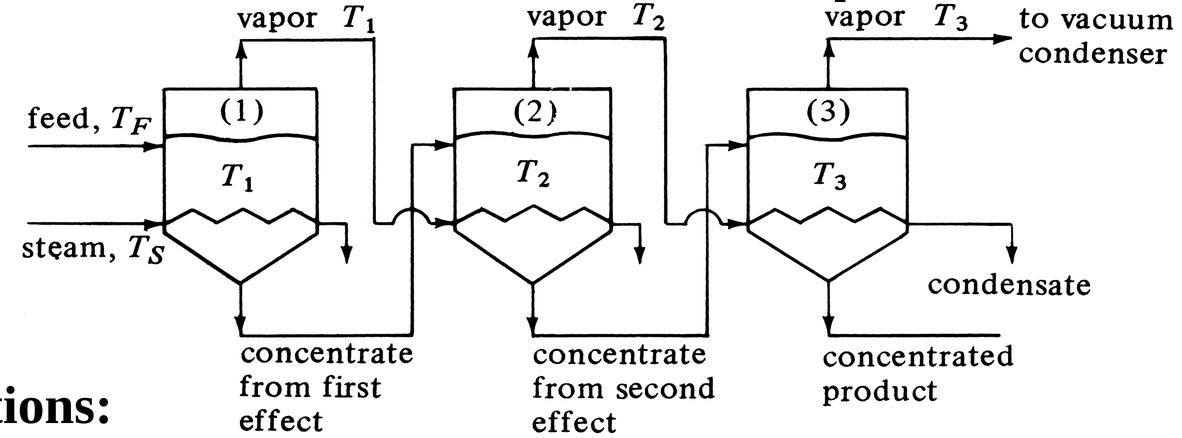
- fresh feed enter last stage/effect
- conc. prod. from3st effect to 2nd effect
- vapour from 1st effect as heating medium for 2nd effect
- counter-current flow
- liquid pumps in each effect ($P_1 › P_2 › P_3$)
- cold feed as less liquid needs to be heated
- highly viscous conc. prod. as higher temp. reduce viscosity

3. parallel-feed multiple-effect evaporator



- **fresh feed and withdrawal conc. prod. at each effect**
- **vapour from 1st effect as heating medium for 2nd effect**
- **almost saturated feed**
- **solid crystals as product**

Triple-effect forward feed evaporators

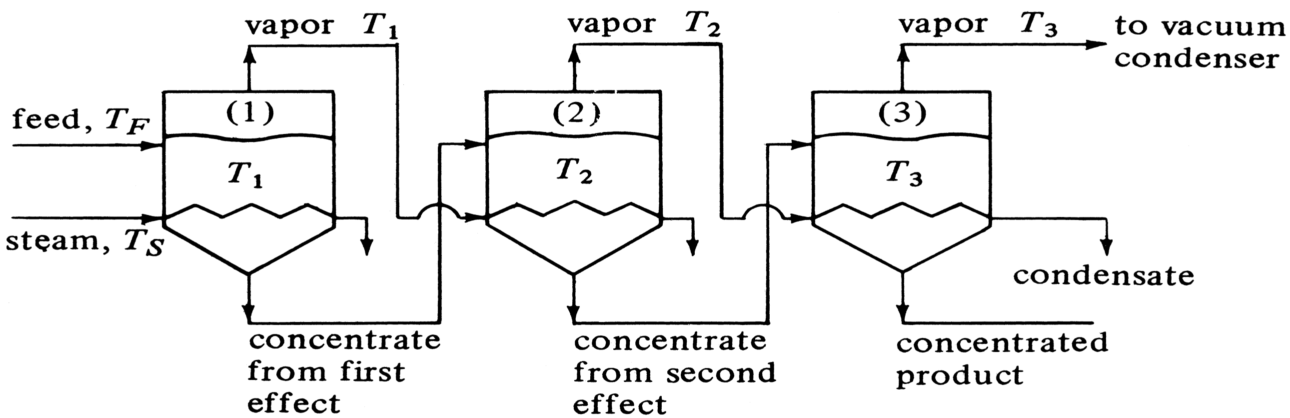


Assumptions:

- **latent heat of condensing steam = latent heat of vapour**
- **areas in all effects are equal (A_1=A_2=A_3)**
- $q_1 = U_1 A_1 \Delta T_1$
- $q_1 = S\lambda_{S\ 1}$
- $\Delta T_1 = T_{S1} - T_1$
- $\Delta T_1 = \sum \Delta T \dfrac{1/U_1}{1/U1 + 1/U2 + 1/U3}$
- $\Delta T_2 = T_{S2} - T_2$

- **No BPR:** $\Delta T_2 = T_1 - T_2$
- **No BPR:** $\sum \Delta T = T_{S1} - T_{S4}$
- **BPR:** $\Delta T_2 = T_1 - BPR_1 - T_2$
- **BPR:** $\sum \Delta T = T_{S1} - T_{S4} - (BPR_1 + BPR_2 + BPR_3)$

Procedure for Triple-effect forward feed evaporators

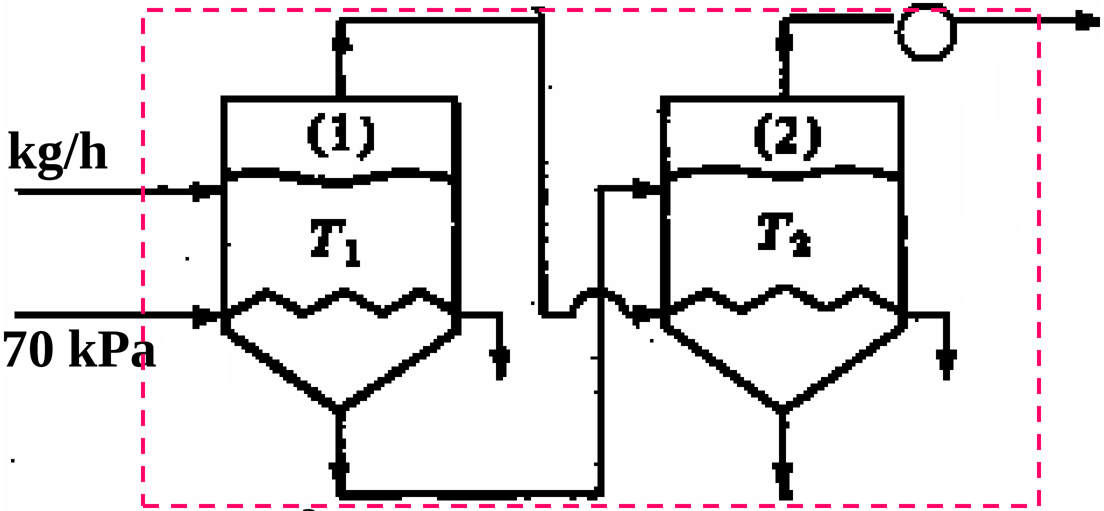


Determine:

1. T_3 & BPR_3
2. L_3 & $V_1+V_2+V_3$. Assume $V_1=V_2=V_3$
3. L_1, L_2, x_1 & x_2
4. BPR_1 & BPR_2
5. $\sum\Delta T$, ΔT_1, ΔT_2 & ΔT_3. Readjust if necessary
6. T_1, T_{S1}, T_2, T_{S2}, T_3 & T_{S3}
7. c_P, enthalpies, L_1, L_2, V_1, V_2, V_3 & S
8. Compare ans. from step7 with ans. from steps 2 & 3. If errors $\rangle$ 10%, redo step 3.
9. If errors $\langle$ 10%, calculate q_1, q_2, q_3, A_1, A_2, A_3 & $A_{ave.}$ If errors $\rangle$10%, revise ΔTs.

Example

$F = 22680$ kg/h
$x_F = 0.12$
$T_F = 93^oC$
$P_{s1} = 170$ kPa



$P_{s3} = 9$ kPa

$x_2 = 0.6$

Given: $BPR^oC = 0.63 - 3.62x + 15x^2$

c_p kJ/kg.K = $4.19 - 2.93x$

$U_1 = 2271$ W/m^2.K, $U_2 = 1420$ W/m^2.K

At 9 kPa, $T_{sat3.} = 43.66^oC$ (from A.2-9 after interpolation)

$BPR_2 = 0.63 - 3.62(0.6) + 15(0.6)^2 = 3.858^oC$

$\therefore T_2 = T_{sat.3} + BPR_2 = 43.66 + 3.858 = 47.52^oC$

Total balance: $F = (V_1+V_2) + L_2 = 22680$ kg/h

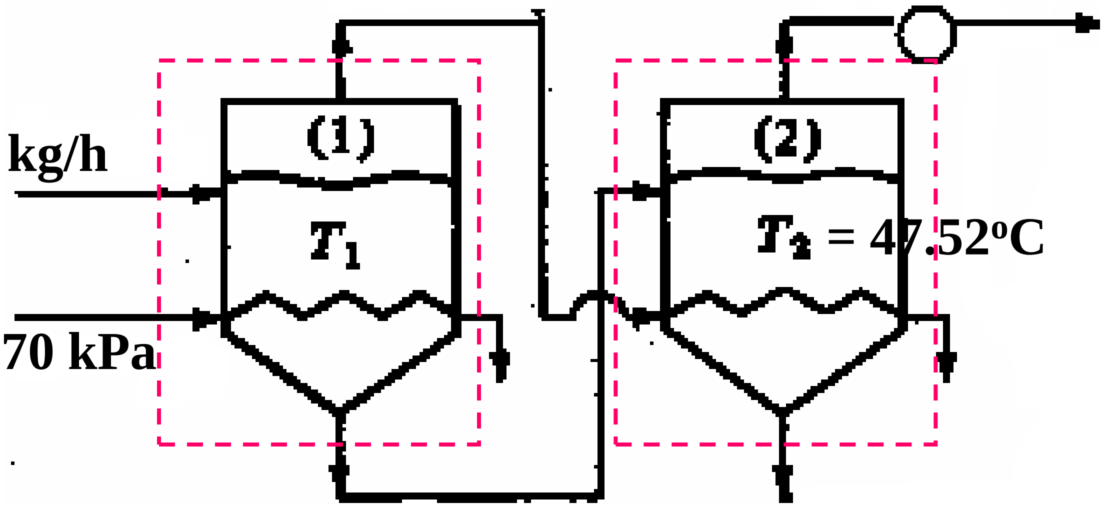
Solid balance: $Fx_F = L_2x_2$ $\quad 22680(0.12) = L_2(0.6) \quad \therefore L_2 = 4536$ kg/h

$F = 22680$ kg/h

$x_F = 0.12$

$T_F = 93^oC$

$P_{s1} = 170$ kPa



$L_2 = 4536$ kg/h

$x_2 = 0.6$

Total balance: $22680 = (V_1+V_2) + 4536$

$(V_1+V_2) = 18\,144$ kg/h

Assume $V_1=V_2$ $V_1=V_2 = 18\,144/2 = 9072$ kg/h

Effect 1: **Total balance:** $F = 22680 = V_1 + L_1$

$22680 = 9072 + L_1$

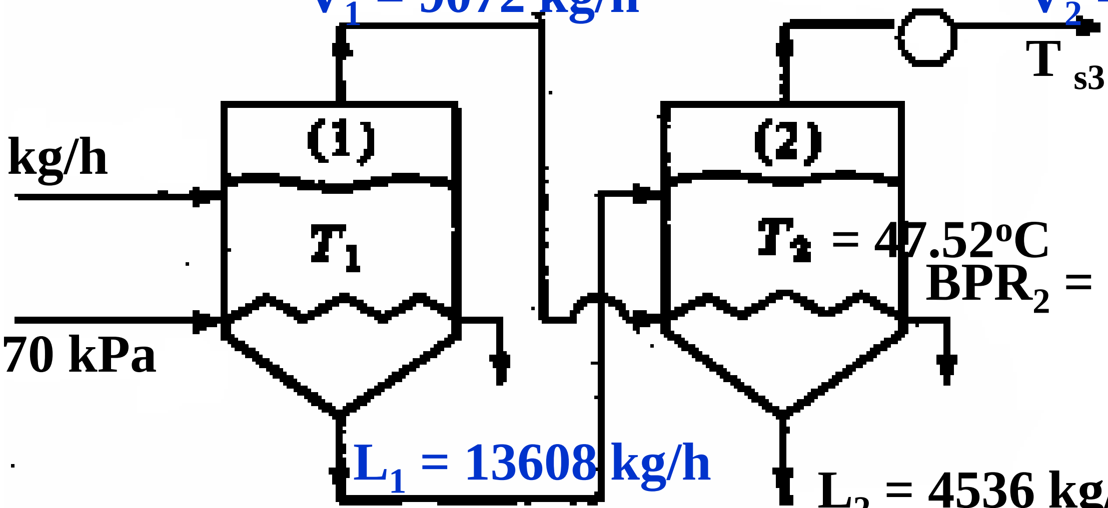
$L_1 = 13\,608$ kg/h

Solid balance: $Fx_F = L_1x_1$

$22680(0.12) = 13\,608x_1$

$x_1 = 0.2$

Effect 2: **Total balance:** $L_1 = V_2 + L_2$ $13608 = 9072 + 4536$ √



$U_1 = 2271\ W/m^2.K$

$U_2 = 1420\ W/m^2.K$

$$BPR = 0.63 - 3.62x + 15x^2$$

$$BPR_1 = 0.63 - 3.62(0.2) + 15(0.2)^2 = 0.506^oC$$

At 170 kPa, $T_s = 115^oC$

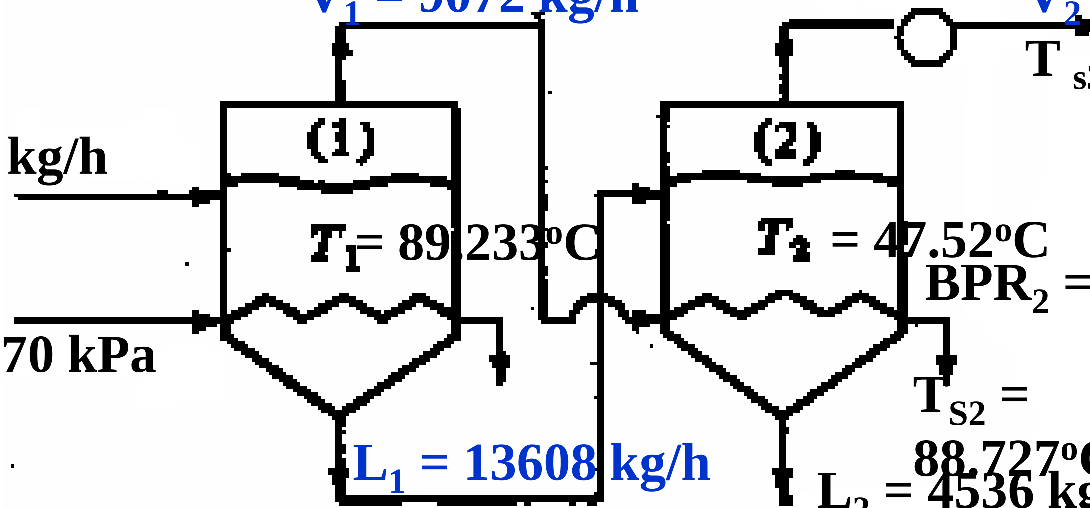
$$\sum\Delta T = T_{S1} - T_{S3} - (BPR_1 + BPR_2) = 115 - 43.66 - (3.858 + 0.506) = 66.976^oC$$

$$\Delta T_1 = \sum\Delta T \frac{1/U_1}{1/U_1 + 1/U_2} = 66.976 \frac{1/2271}{1/2271 + 1/1420} = 25.767^oC$$

$$\Delta T_1 = T_{S1} - T_1 \qquad 25.767 = 115 - T_1 \qquad \therefore T_1 = 89.233^oC$$

$$\Delta T_2 = \Sigma\Delta T - \Delta T_1 = 66.976 - 25.767 = 41.209^oC$$

$$\Delta T_2 = T_{S2} - T_2 \qquad 41.209 = T_{S2} - 47.52 \qquad \therefore T_{S2} = 88.727^oC$$



Given: c_p (kJ/kg.K) = 4.19 – 2.93x

$c_{pF} = 4.19 - 2.93x_F = 4.19 - 2.93(0.12) = 3.838$ kJ/kg.K

$c_{p1} = 4.19 - 2.93x_1 = 4.19 - 2.93(0.2) = 3.604$ kJ/kg.K

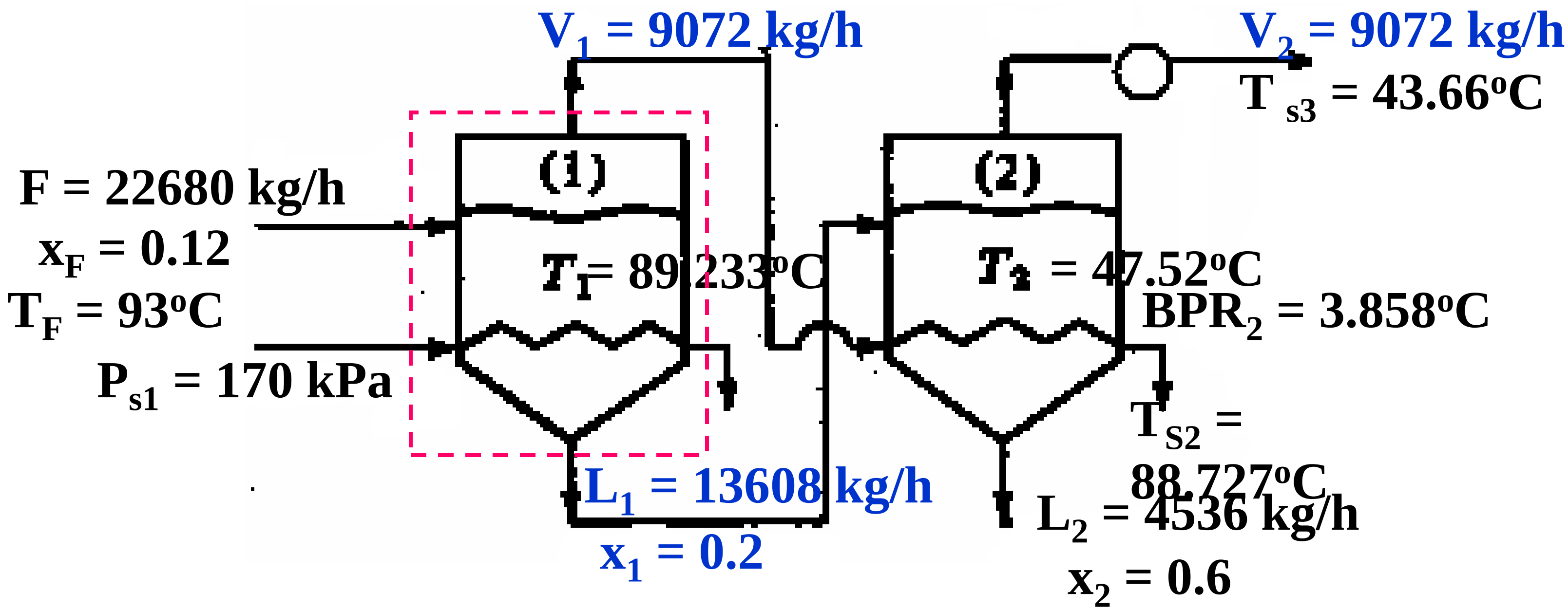
$c_{p2} = 4.19 - 2.93x_2 = 4.19 - 2.93(0.6) = 2.432$ kJ/kg.K

$T_{ref.} = 0^oC$ (liquid solution),

$h_F = c_{PF}(T_F - T_{ref.}) = 3.838(93 - 0) = 356.97$ kJ/kg

$h_1 = c_{P1}(T_1 - T_{ref.}) = 3.604(89.233 - 0) = 321.6$ kJ/kg

$h_2 = c_{P2}(T_2 - T_{ref.}) = 2.432(47.52 - 0) = 115.56$ kJ/kg



h_F = 356.97 kJ/kg h_1= 321.6kJ/kg h_2= 115.56 kJ/kg

Tref. = 0ºC , liquid solution (same as steam table),

Effect 1: Energy balance: $Fh_F + S(H_{S1} - h_{S1}) = L_1h_1 + V_1H_1$

$$22680h_F + S\lambda_{S1} = L_1h_1 + V_1H_1$$

Material balance: $22680 = V_1 + L_1$

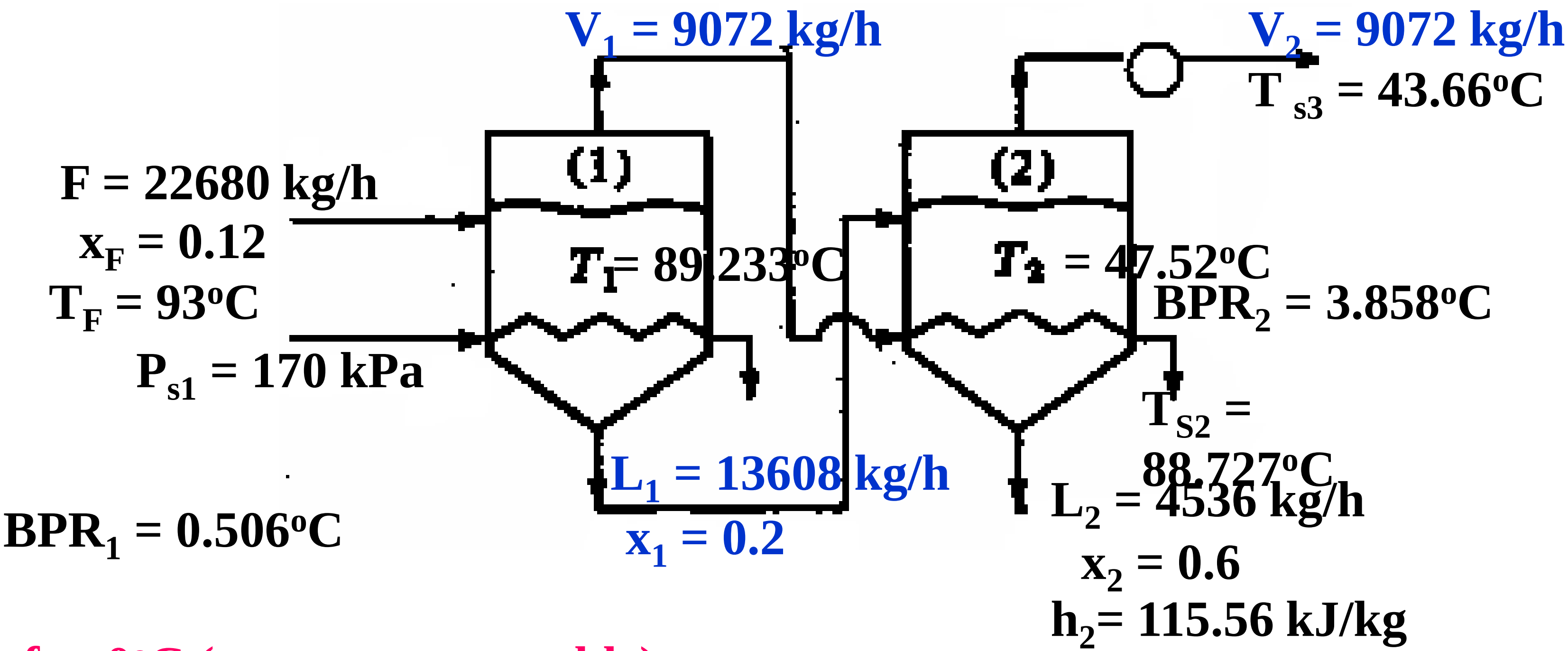
$$V_1 = 22680 - L_1$$

$$22680h_F + S\lambda_{S1} = L_1h_1 + (22680-L_1)H_1$$

$$22680(356.97) + S\lambda_{S1} = L_1(321.6) + (22680-L_1)H_1$$

T_{S1}=115ºC ,H_{S1} = 2699 kJ/kg & h_{S1} = 482.48 kJ/kg.

$$\therefore \lambda_{S1} = (2699-482.48) = 2216.52 \text{ kJ/kg}$$



Tref. = 0°C (same as steam table),

Effect 1: $22680(356.97) + S(2216.52) = L_1(321.6) + (22680-L_1)H_1$

$$H_1 = H_{S2} + 1.884(BPR_1)$$

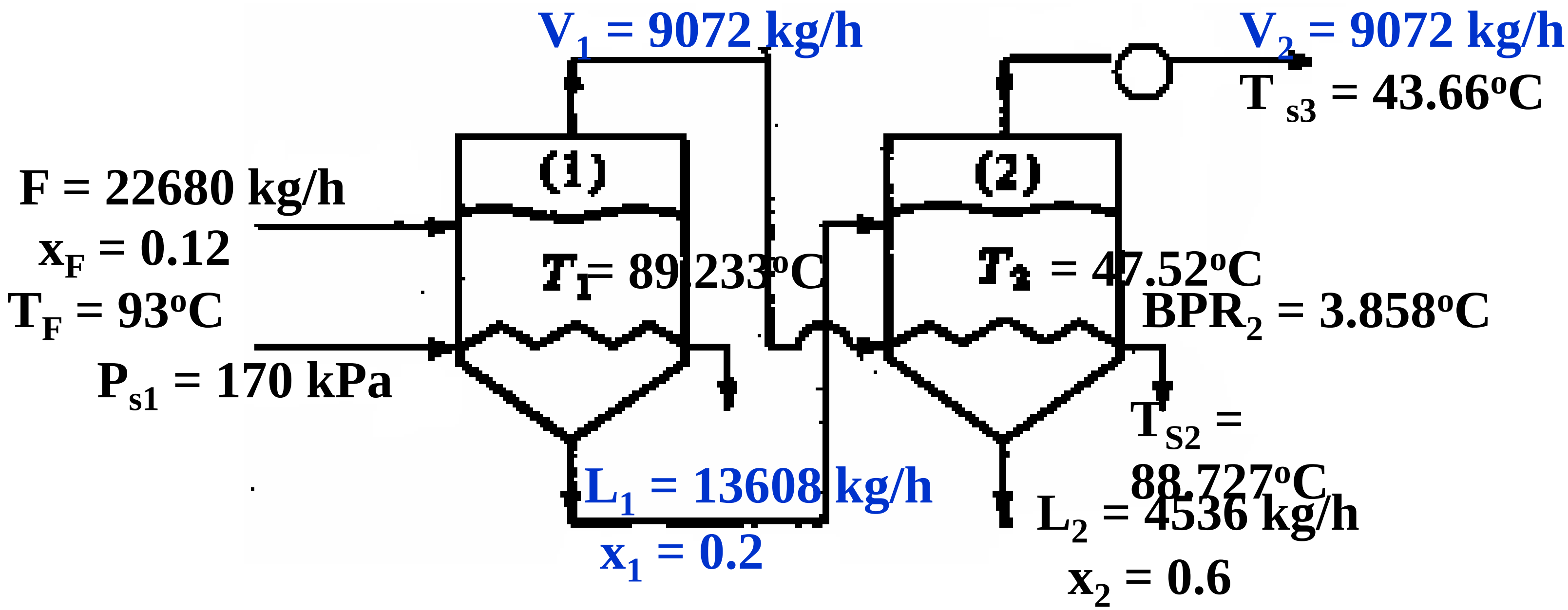
T_{S2}=88.727°C, H_{S2} = 2658.01 kJ/kg and h_{S2} = 371.57 kJ/kg

$$H_1 = 2658.01 + 1.884(0.506) = 2658.97 \text{ kJ/kg}$$

$$22680(356.97) + S(2216.52) = L_1(321.6) + (22680-L_1)(2658.97) \quad (1)$$

Effect 2: $L_1h_1 + V_1(H_1 - h_{S2}) = L_2h_2 + V_2H_2$

$$L_1(321.6) + (22680-L_1)(2658.97 - 371.57) = 4536(115.56) + (L_1-L_2)H_2$$



$H_2 = H_{S3} + 1.884(BPR_2)$

At 9 kPa, $T_{s3} = 43.66^oC$, $H_{S3} = 2580.81$ kJ/kg

$H_2 = 2580.81 + 1.884(3.858) = 2588.08$ kJ/kg

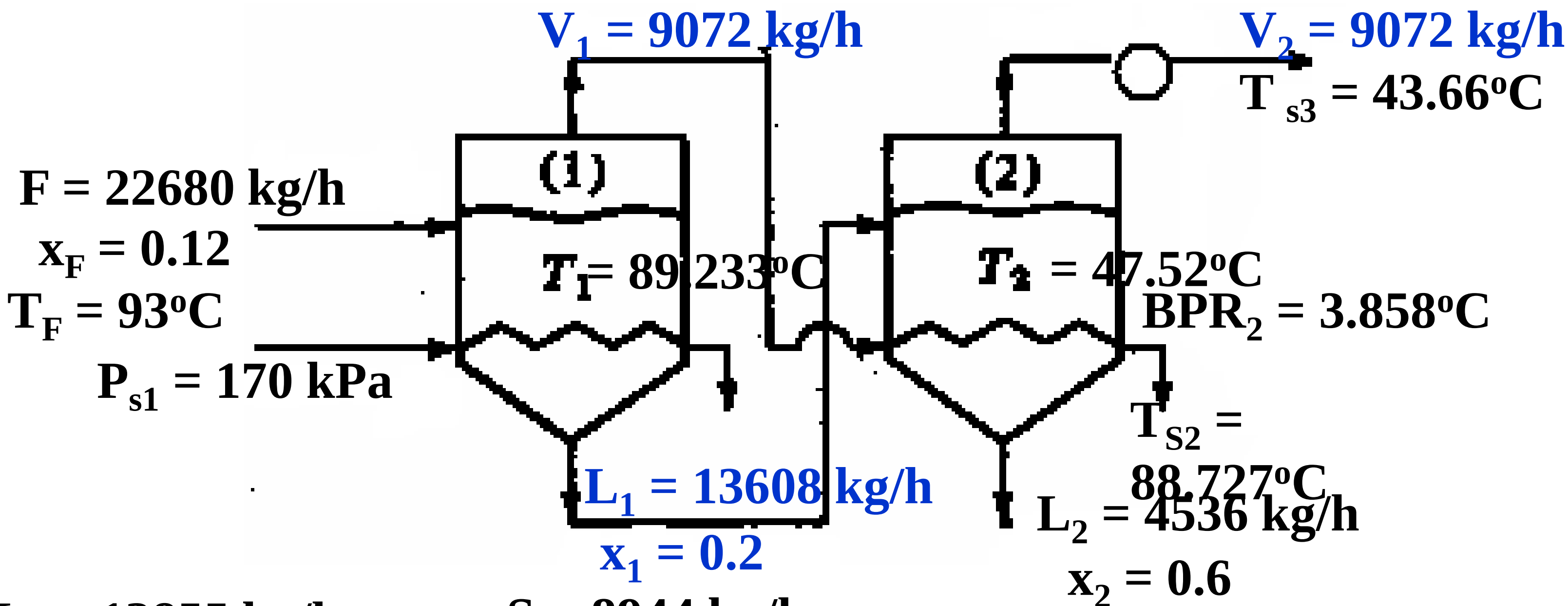
$$L_1(321.6) + (22680-L_1)(2658.97 - 371.57) = 4536(115.56) + (L_1-L_2)H_2$$

$$L_1(321.6) + (22680-L_1)(2658.97 - 371.57) = 4536(115.56) + (L_1-4536)(2588.08)$$

$$\therefore L_1 = 13855 \text{ kg/h}$$

$$22680(356.97) + S(2216.52) = L_1(321.6) + (22680-L_1)(2658.97) \qquad (1)$$

$$S = 8944 \text{ kg/h}$$



$L_1 = 13855$ kg/h S = 8944 kg/h

Substituting L_1 into the material balances of each effect:

$$V_1 = 22680 - L_1 = 22680 - 13855 = 8825 \text{ kg/h}$$

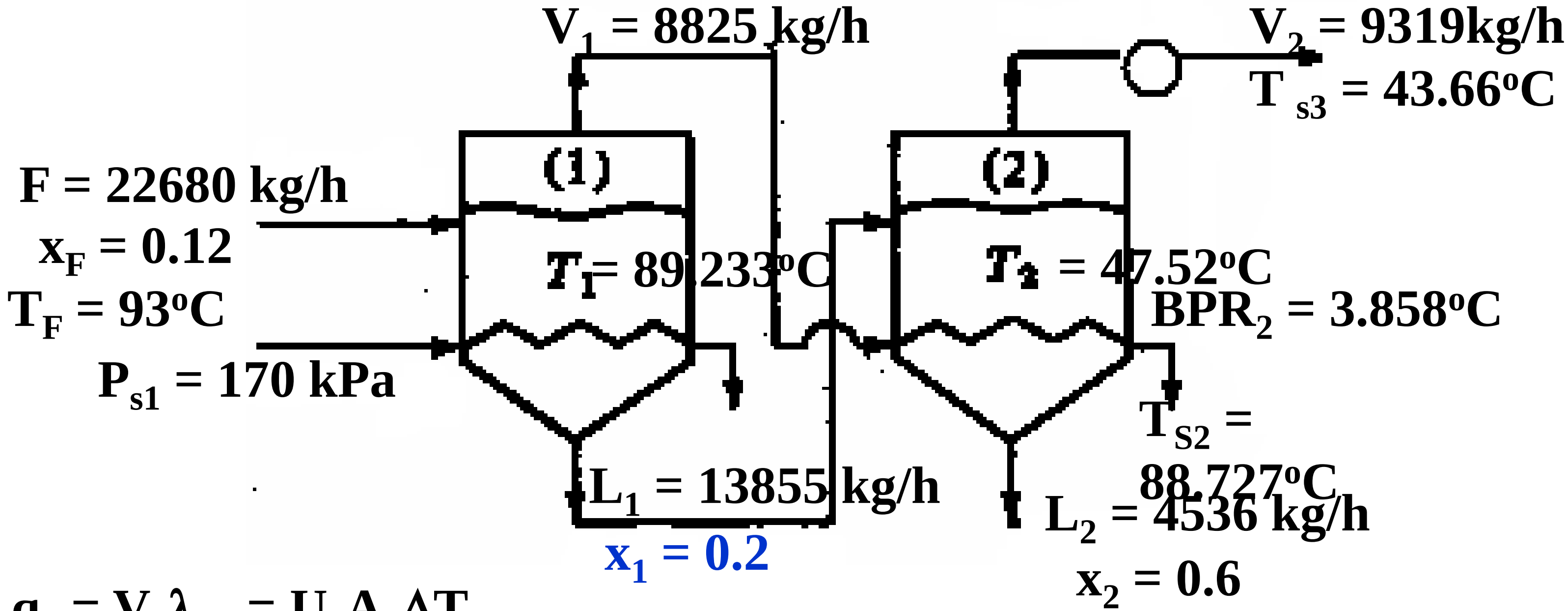
$$V_2 = L_1 - L_2 = 13855 - 4536 = 9319 \text{ kg/h}$$

Previous calculations: L_1 =13608 kg/h (% error = 1.78) , V_1 = 9072kg/h (% error = 2.8), V_2 = 9072 kg/h (% error = 2.65)

$$q_1 = S\lambda_{S1} = U_1 A_1 \Delta T_1$$

$$q_1 = S\lambda_{S1} = \frac{8944 \text{ kg}}{\text{h}} \Big| \frac{2216.52 \text{ kJ}}{\text{kg}} \Big| \frac{1\text{h}}{3600\text{s}} = 5507 \text{ kJ/s}$$

$$A_1 = \frac{5507 \times 10^3 \text{ W}}{25.767 \text{ K}} \Big| \frac{\text{m}^2 \text{ K}}{2271 \text{ W}} = 94.11 \text{ m}^2$$



$$q_2 = V_1\lambda_{S2} = U_2A_2\Delta T_2$$

$$q_2 = V_1\lambda_{S2} = \frac{8825\ \text{kg}}{\text{h}}\left|\frac{2287.4\ \text{kJ}}{\text{kg}}\right|\frac{1\text{h}}{3600\text{s}} = 5607\ \text{kJ/s}$$

$$A_2 = \frac{5607 \times 10^3\ \text{W}}{41.209\ \text{K}}\left|\frac{\text{m}^2\ \text{K}}{1420\ \text{W}}\right. = 95.82\ \text{m}^2$$

$$A_{ave.} = A_m = 94.97\ \text{m}^2$$

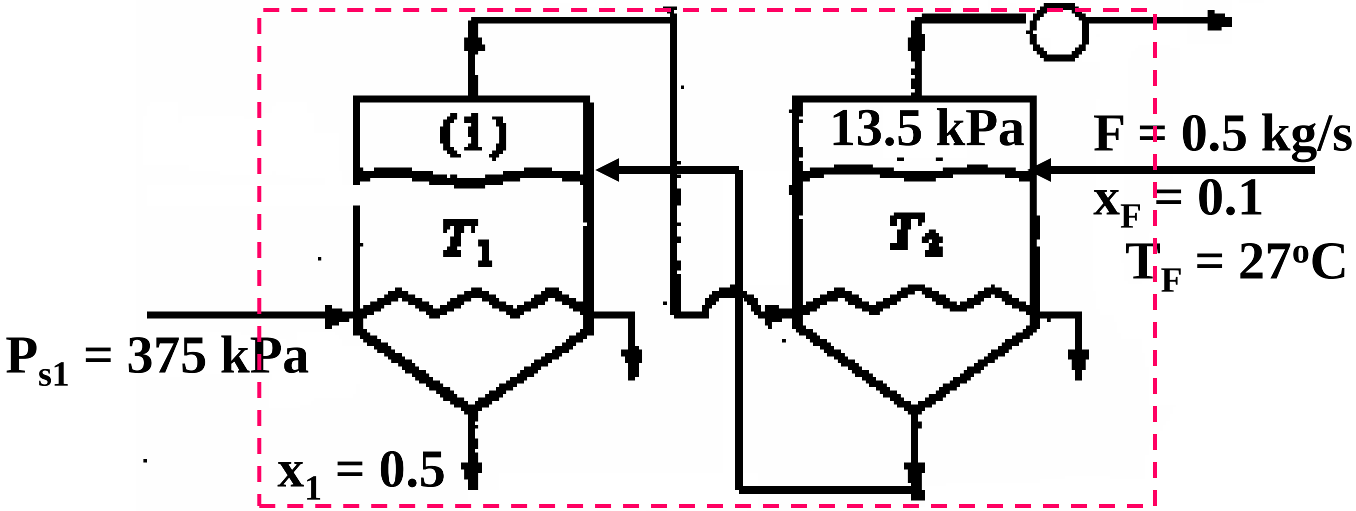
$A_1 = 94.11\ \text{m}^2$ (% error =0.9)

$A_2 = 95.82\ \text{m}^2$ (% error =0.9)

$$\therefore A = 94.97\ \text{m}^2$$

Steam economy = (8825 + 9319)/8944 = 2.03

Example



Given: No BPR

c_p kJ/kg.K = 4.18

$U_1 = 2.0$ kW/m^2.K, $U_2 = 1.7$ kW/m^2.K

At 13.5 kPa, $T_{sat3.} = 51.69$°C (from A.2-9 after interpolation) = T_2

Total balance: $F = (V_1+V_2) + L_1 = 0.5$

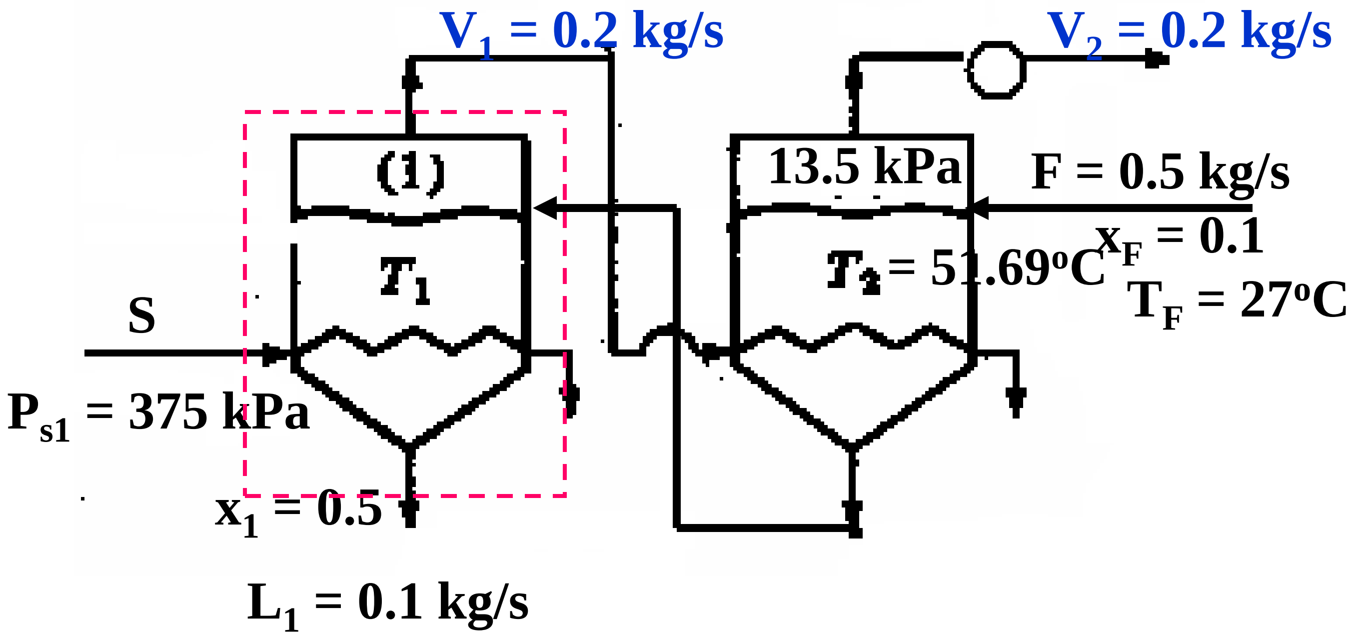
Solid balance: $Fx_F = L_1x_1$

$0.5(0.1) = L_1(0.5)$ $\therefore L_1 = 0.1$ kg/s

Total balance: $0.5 = (V_1+V_2) + 0.1$

$(V_1+V_2) = 0.4$ kg/s

Assume $V_1=V_2$ $V_1=V_2 = 0.4/2 = 0.2$ kg/s



Effect 1: **Total balance:** $L_2 = V_1 + L_1$

$= 0.2 + 0.1 = 0.3$ kg/s

Solid balance: $L_2x_2 = L_1x_1$

$0.3x_2 = 0.1(0.5)$ $\quad x_2 = 0.1667$

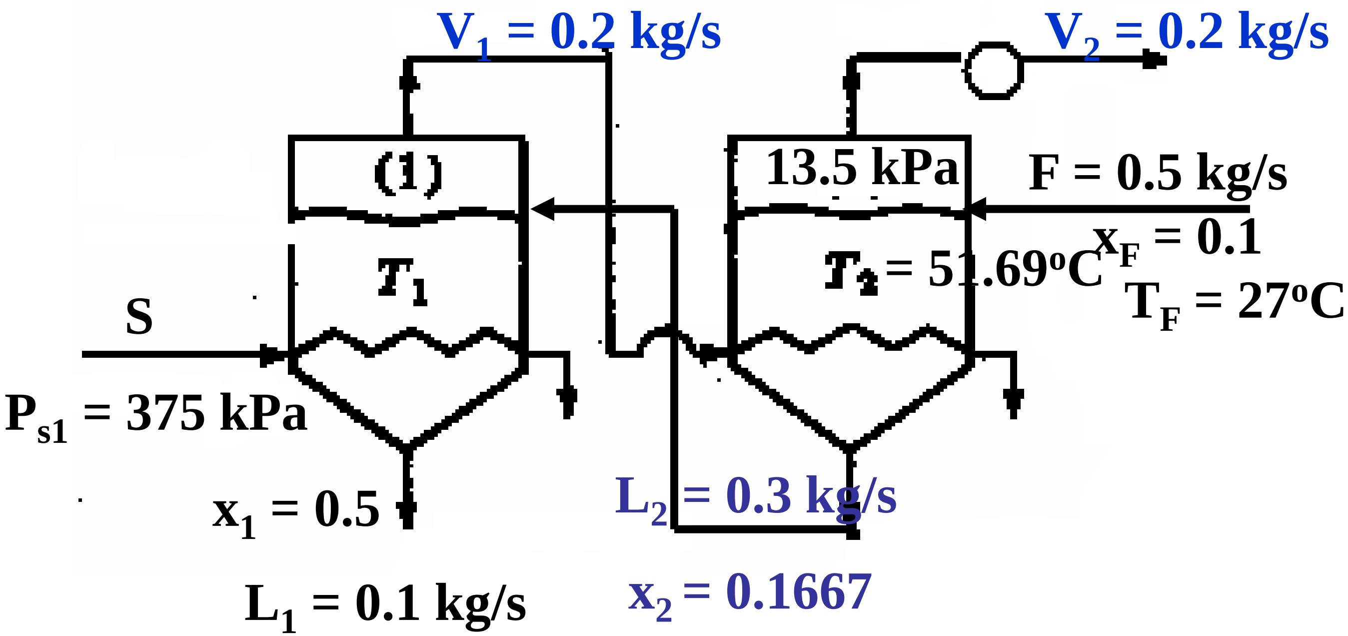
At 375 kPa, $T_{s1} = 142.96^oC$

$$\sum\Delta T = T_{S1} - T_{S3} = 142.96 - 51.69 = 91.27^oC$$

$$\Delta T_1 = \sum\Delta T \frac{1/U_1}{1/U_1 + 1/U_2} = 91.27 \frac{1/2}{1/2 + 1/1.7} = 41.93^oC$$

$$\Delta T_2 = \Sigma\Delta T - \Delta T_1 = 91.27 - 41.93 = 49.34^oC$$

Since cold feed, ΔT_2 will be readjusted to 51^oC and $\Delta T_1 = 40.27\ ^oC$



Since cold feed, ΔT_2 will be readjusted to 51^oC and $\Delta T_1 = 40.27\ ^oC$

$$\Delta T_2 = T_{S2} - T_2$$

$$51 = T_{S2} - 51.69$$

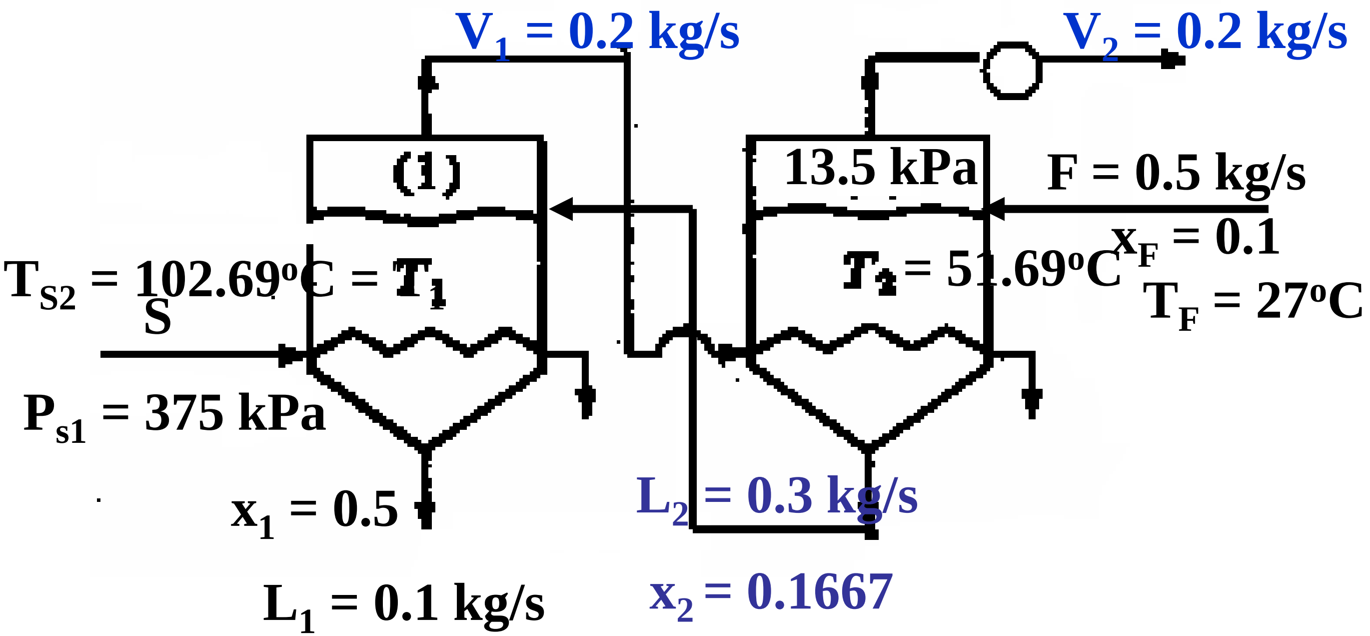
$$\therefore T_{S2} = 102.69^oC = T_1$$

$T_{ref.} = 0^oC$ (liquid solution),

$$h_F = c_{PF}(T_F - T_{ref.}) = 4.18(27 - 0) = 112.86 \text{ kJ/kg}$$

$$h_1 = c_{P1}(T_1 - T_{ref.}) = 4.18(102.69 - 0) = 429.244 \text{ kJ/kg}$$

$$h_2 = c_{P2}(T_2 - T_{ref.}) = 4.18(51.69 - 0) = 216.06 \text{ kJ/kg}$$



$T_{ref.} = 0^oC$ (liquid solution),

$h_F = 112.86$ kJ/kg $h_1 = 429.244$ kJ/kg $h_2 = 216.06$ kJ/kg

$T_{S1} = 142.96\ ^oC$, $H_{S1} = 2737.69$ kJ/kg & $h_{S1} = 601.87$ kJ/kg.

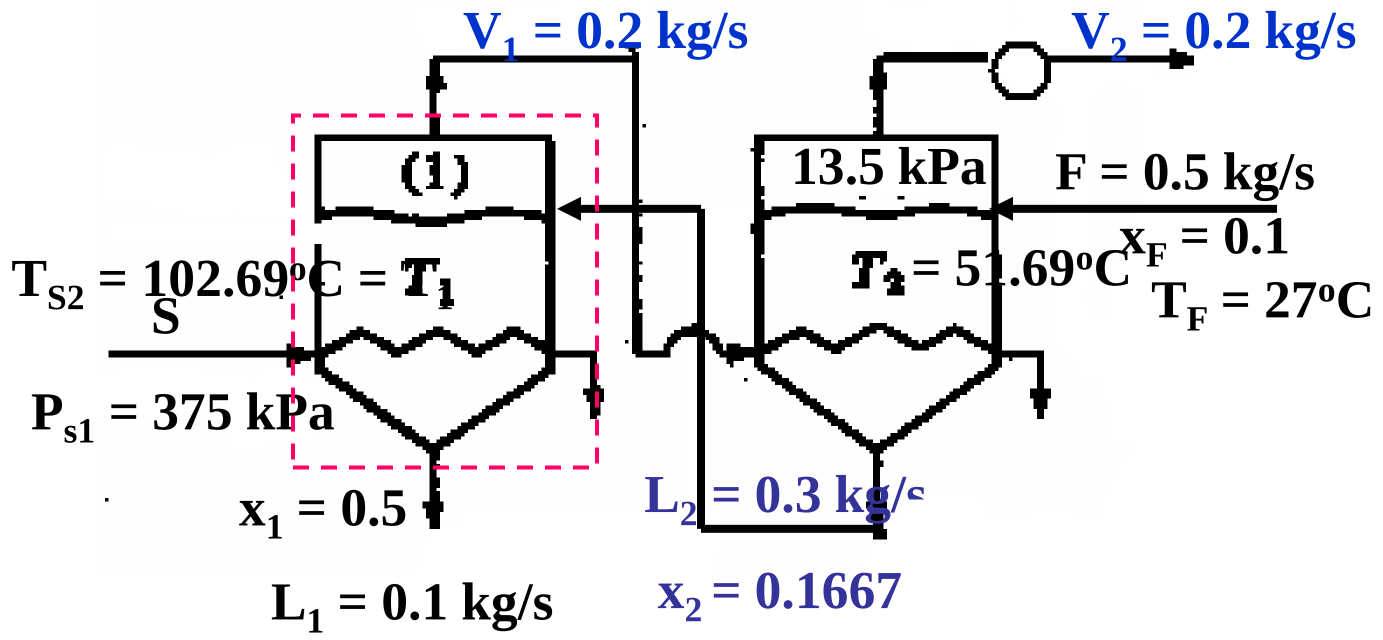
$$\therefore \lambda_{S1} = (2737.69 - 601.87) = 2135.82 \text{ kJ/kg}$$

$T_{S2} = 102.69\ ^oC$, $H_{S2} = 2680.24$ kJ/kg & $h_{S2} = 430.4$ kJ/kg.

$$\therefore \lambda_{S2} = (2680.24 - 430.4) = 2249.84 \text{ kJ/kg}$$

$H_1 = H_{S2} = 2680.24$ kJ/kg

$H_2 = H_{S3} = 2595.07$ kJ/kg



Tref. = 0°C , liquid solution (same as steam table),

h_F = 112.86 kJ/kg h_1= 429.244 kJ/kg h_2= 216.06 kJ/kg

λ_{S1} = 2135.82 kJ/kg λ_{S2} = 2249.84 kJ/kg H_1 = 2680.24 kJ/kg H_2= 2595.07 kJ/kg

Effect 1:

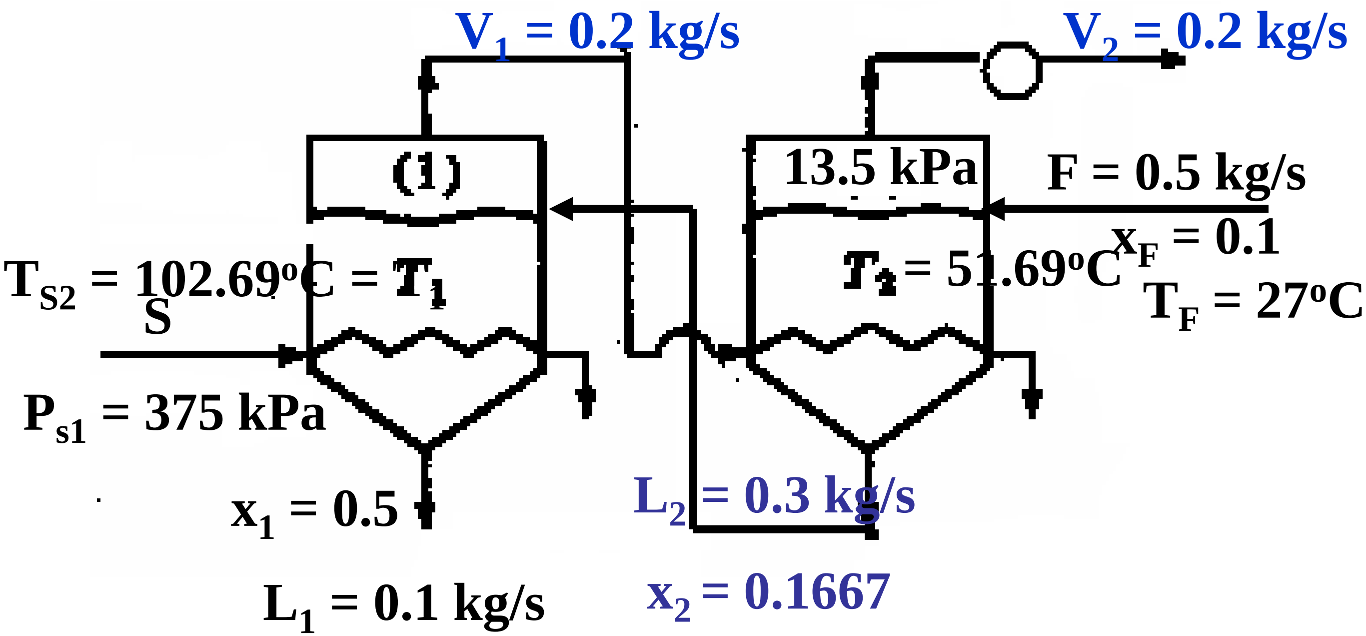
Energy balance: $L_2h_2 + S\lambda_{S1} = L_1h_1 + V_1H_1$

Material balance: $L_2 = V_1 + L_1$

$V_1 = L_2 - 0.1$

$$L_2(216.06) + S(2135.82) = 0.1(429.244) + (L_2 - 0.1)2680.24$$

$$2135.82S + 225.1 = 2689.28L_2 \quad (1)$$



Tref. = 0^{o}C (same as steam table),

$h_F = 112.86$ kJ/kg $h_1 = 429.244$ kJ/kg $h_2 = 216.06$ kJ/kg

$\lambda_{S1} = 2135.82$ kJ/kg $\lambda_{S2} = 2249.84$ kJ/kg $H_1 = 2680.24$ kJ/kg $H_2 = 2595.07$ kJ/kg

Effect 1: $2135.82S + 225.1 = 2689.28L_2$ (1)

Effect 2: Energy balance: $Fh_F + V_1\lambda_{S2} = L_2h_2 + V_2H_2$

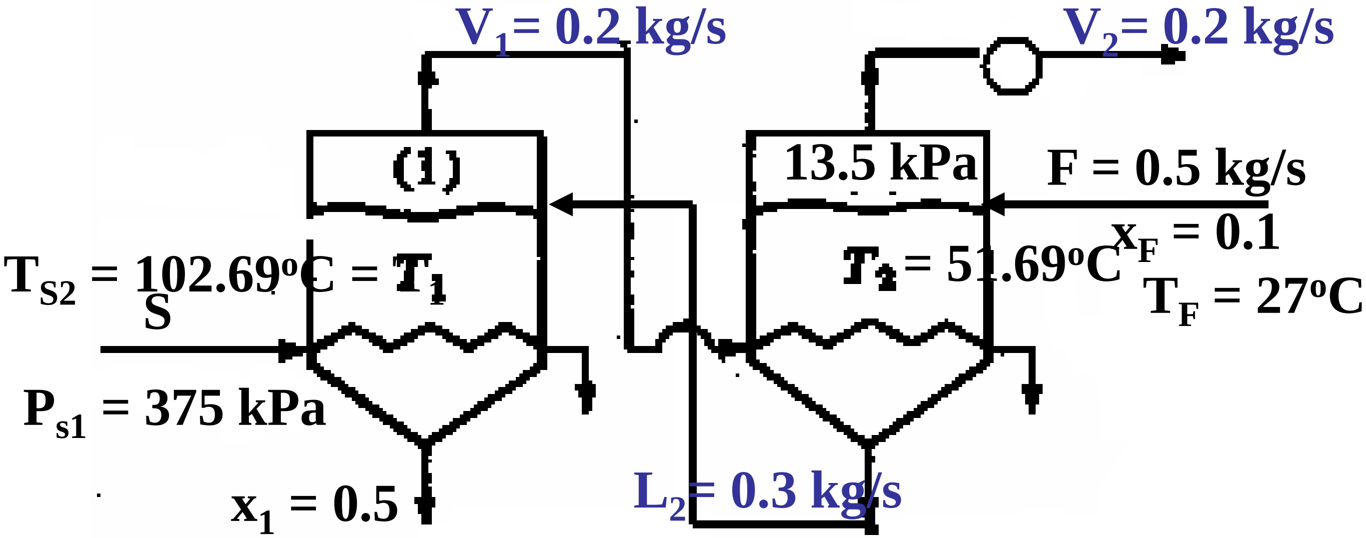
Material balance: $F = V_2 + L_2$

$V_2 = F - L_2 = 0.5 - L_2$

$$0.5(112.86) + (L_2 - 0.1)(2249.84) = L_2(216.06) + (0.5 - L_2)2595.07$$

$$L_2(2595.07 - 216.06 + 2249.84) = 1297.535 - 56.43 + 224.984$$

$\therefore L_2 = 0.3167$ kg/s $S = 0.2933$ kg/s $V_2 = 0.1833$ kg/s $V_1 = 0.2167$ kg/s



$L_1 = 0.1$ kg/s

$\therefore L_2 = 0.3167$ kg/s (% error = 5.3)

$S = 0.2933$ kg/s

$V_1 = 0.2167$ kg/s(% error = 7.7)

$V_2 = 0.1833$ kg/s (% error = 9.1)

Given: $U_1 = 2.0\ kW/m^2.K$, $U_2 = 1.7\ kW/m^2.K$

$$q_1 = S\lambda_{S1} = U_1A_1\Delta T_1 = U_1A_1(Ts_1 - T_1)$$

$$q_1 = S\lambda_{S1} = (0.2933)(2135.82) = 626.436 = 2(A_1)(142.96 - 102.69)$$

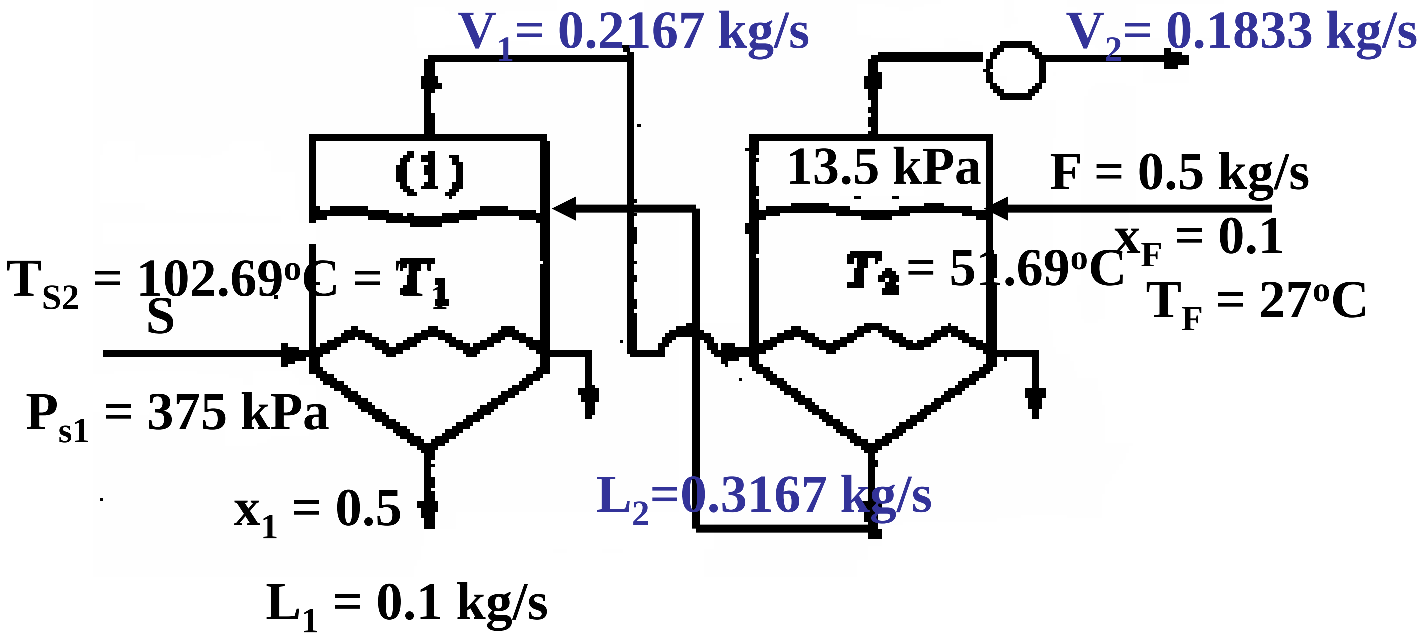
$$A_1 = 7.778\ m^2$$

$$q_2 = V_1\lambda_{S2} = U_2A_2\Delta T_2 = U_2A_2(Ts_2 - T_2)$$

$$q_2 = V_1\lambda_{S2} = (0.2167)(2249.84) = 1.7(A_2)(51)$$

$$A_2 = 5.623\ m^2$$

$$A_{ave.} = A_m = 6.7005\ m^2$$



$A_{ave.} = A_m = 6.7005\ m^2$ $\quad$ $A_1 = 7.778\ m^2$ (% error =16.1)

$A_2 = 5.623\ m^2$ (% error = 16.1)

2nd Trial:

Effect 1: **Total balance:** $L_2 = V_1 + L_1$

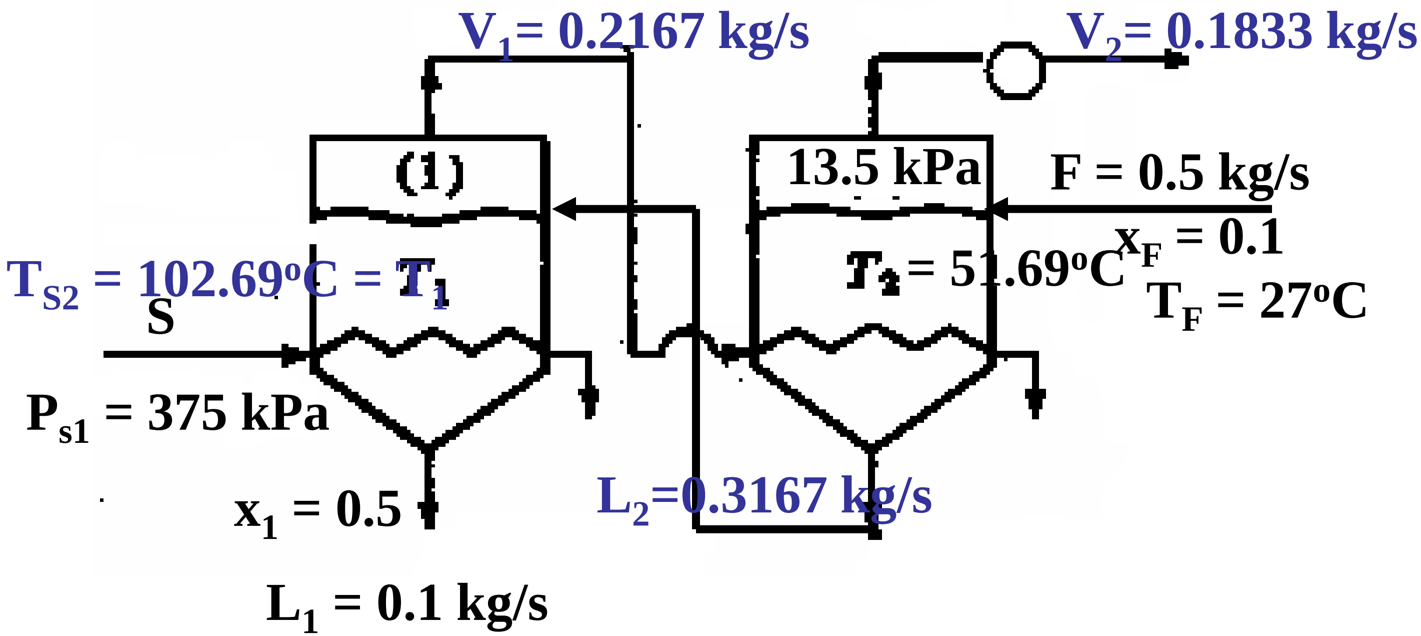
$= 0.2167 + 0.1 = 0.3167$ kg/s

Solid balance: $L_2x_2 = L_1x_1$

$0.3167x_2 = 0.1(0.5)$

$x_2 = 0.1579$ kg/kg

$\sum\Delta T = T_{S1} - T_{S3} = 142.96 - 51.69 = 91.27^oC$



$A_{ave.} = A_m = 6.7005\ m^2 \qquad A_1 = 7.778\ m^2 \qquad A_2 = 5.623\ m^2$

$\sum\Delta T = T_{S1} - T_{S3} = 142.96 - 51.69 = 91.27^{o}C$

$$\Delta T_1' = \frac{\Delta T_1 A_1}{A_m} = \frac{(40.27)7.778}{6.7005} = 46.75^{o}C$$

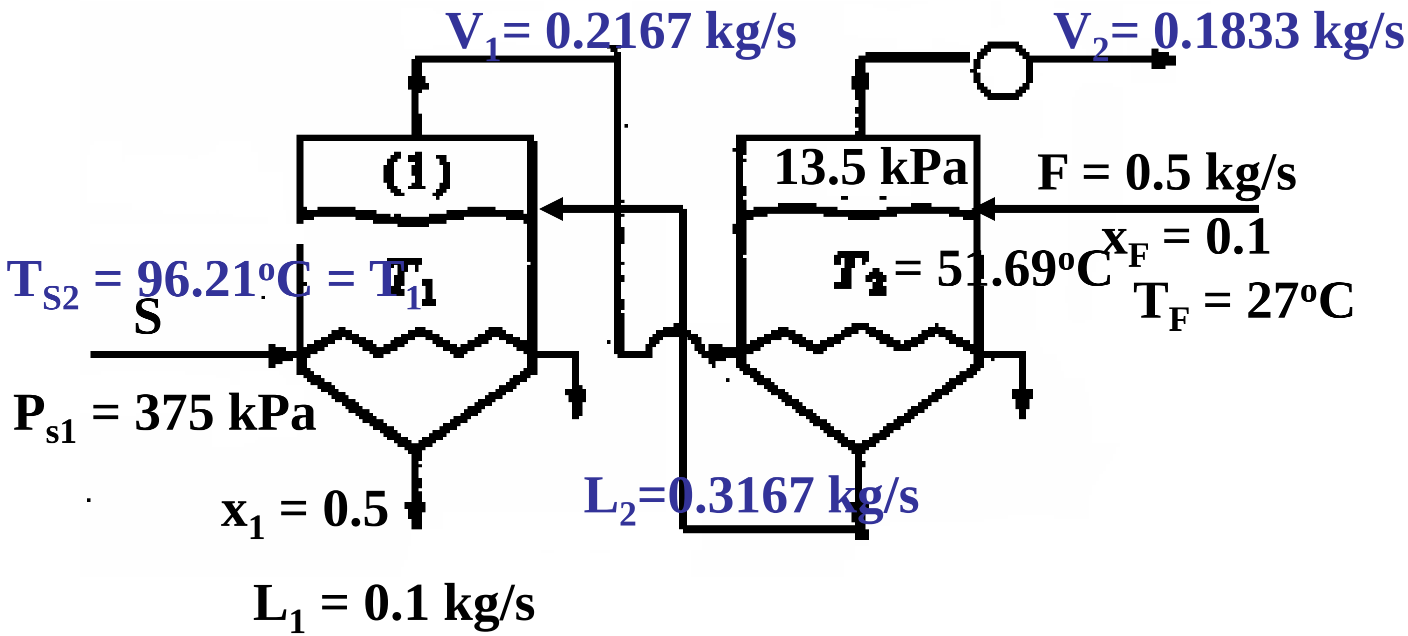
$\Delta T_2' = \Sigma\Delta T - \Delta T_1 = 91.27 - 46.75 = 44.52^{o}C$

$\Delta T_2' = T_{S2} - T_2 = T_{S2} - 51.69 = 44.52$

$\therefore T_{S2} = 96.21^{o}C = T_1$

T_{S2}=96.21 °C ,H_{S2} = 2670.04 kJ/kg & h_{S2} = 403.06 kJ/kg.

$\therefore\ \lambda_{S2} = (2670.04 - 403.06) = 2266.98$ kJ/kg



$T_{ref.} = 0^oC$ (liquid solution),

$\lambda_{S2} = 2266.98$ kJ/kg $h_F = 112.86$ kJ/kg $h_2 = 216.06$ kJ/kg

$h_1 = c_{P1}(T_1 - T_{ref.}) = 4.18(96.21 - 0) = 402.16$ kJ/kg

$H_1 = H_{S2} = 2670.04$ kJ/kg

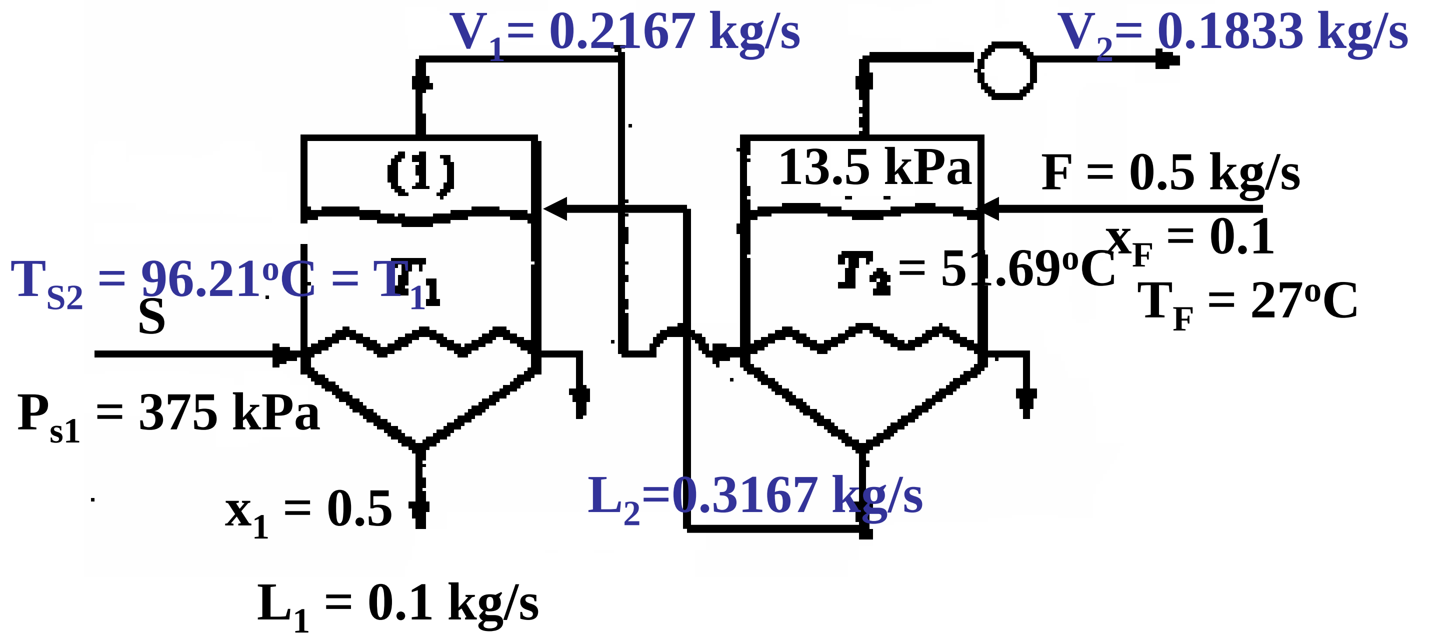
$H_2 = H_{S3} = 2595.07$ kJ/kg

Effect 2: Energy balance: $Fh_F + V_1\lambda_{S2} = L_2h_2 + V_2H_2$

Material balance: $V_2 = F - L_2 = 0.5 - L_2$

$$0.5(112.86) + (L_2 - 0.1)(2266.98) = L_2(216.06) + (0.5 - L_2)2595.07$$

$$\therefore L_2 = 0.316 \text{ kg/s}$$



Tref. = 0°C , liquid solution (same as steam table),

$h_F = 112.86$ kJ/kg $\quad h_1 = 402.16$ kJ/kg $\quad h_2 = 216.06$ kJ/kg

$\lambda_{S1} = 2135.82$ kJ/kg $\quad \lambda_{S2} = 2266.98$ kJ/kg $\quad H_1 = 2670.04$ kJ/kg $\quad H_2 = 2595.07$ kJ/kg

Effect 1: Energy balance: $L_2h_2 + S\lambda_{S1} = L_1h_1 + V_1H_1$

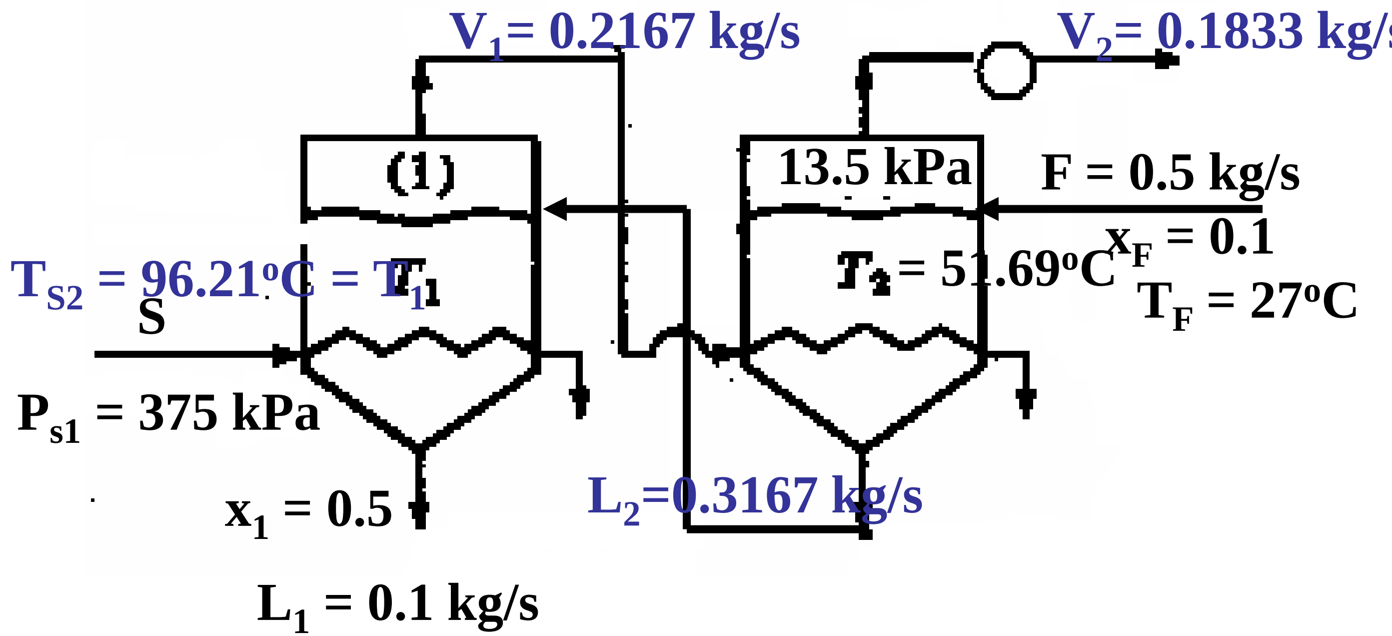
Material balance: $V_1 = L_2 - 0.1$

$$L_2(216.06) + S(2135.82) = 0.1(402.16) + (L_2 - 0.1)2670.04$$

Substituting $L_2 = 0.316$ kg/s, $S = 0.257$ kg/s

$$V_2 = F - L_2 = 0.5 - L_2 = 0.5 - 0.316 = 0.184 \text{ kg/s}$$

$$V_1 = L_2 - 0.1 = 0.316 - 0.1 = 0.216 \text{ kg/s}$$



Given: $U_1 = 2.0$ kW/m^2.K, $U_2 = 1.7$ kW/m^2.K

$L_2 = 0.316$ kg/s (% error = 0.2), $S = 0.257$ kg/s, $V_1 = 0.216$ kg/s(% error = 0.32), $V_2 = 0.184$ kg/s (% error = 0.38),

$$q_1 = S\lambda_{S1} = U_1 A_1 \Delta T_1'$$

$$q_1 = S\lambda_{S1} = (0.257)(2135.82) = 2(A_1)(\ 46.75)$$

$$A_1 = 5.871 \text{ m}^2$$

$$q_2 = V_1\lambda_{S2} = U_2 A_2 \Delta T_2'$$

$$q_2 = V_1\lambda_{S2} = (0.216)(2266.98) = 1.7(A_2)(\ 44.52)$$

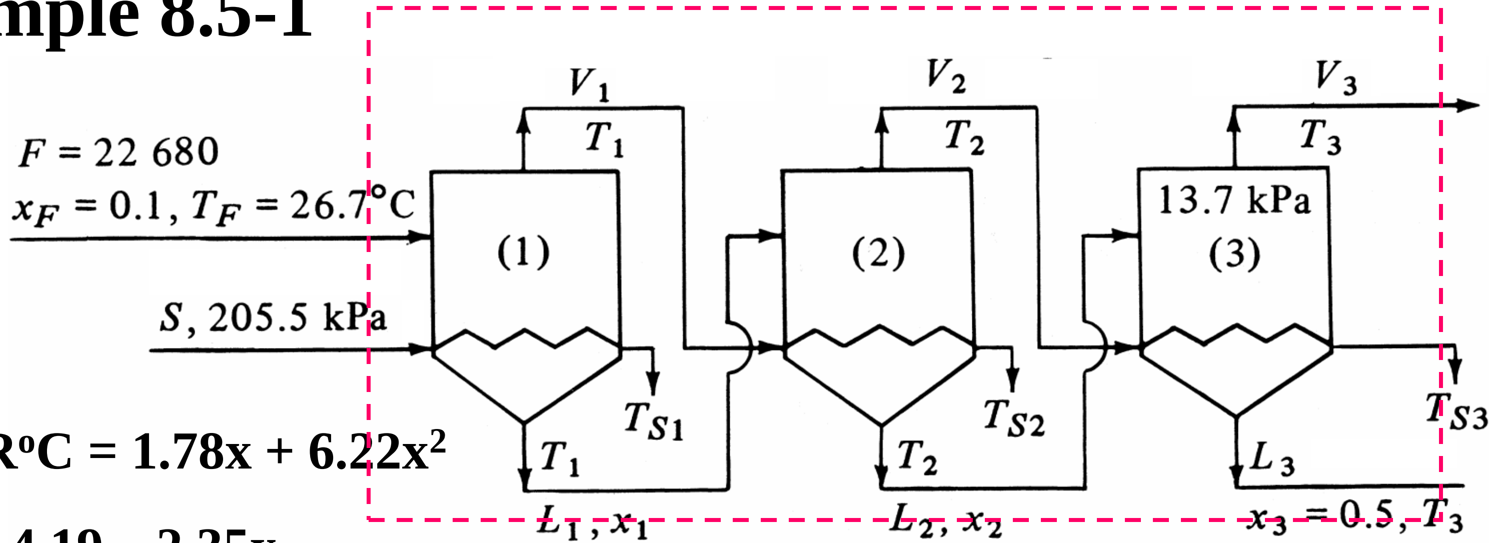
$$A_2 = 6.47 \text{ m}^2$$

$$A_{ave.} = A_m = 6.1705 \text{ m}^2$$

$A_1 = 5.871$ m^2 (% error = 5.1)

$A_2 = 6.47$ m^2 (% error = 4.86)

Example 8.5-1



Given: $BPR\,^oC = 1.78x + 6.22x^2$

$c_p = 4.19 - 2.35x$

$U_1 = 3123\ W/m^2.K$, $U_2 = 1987\ W/m^2.K$ & $U_3 = 1135\ W/m^2.K$

1. $T_{sat.}$, BPR_3 & T_3

At 13.7 kPa, $T_{sat.} = 51.67^oC$ (from A.2-9 after interpolation)

$BPR_3 = 1.78(0.5) + 6.22(0.5)^2 = 2.45^oC$

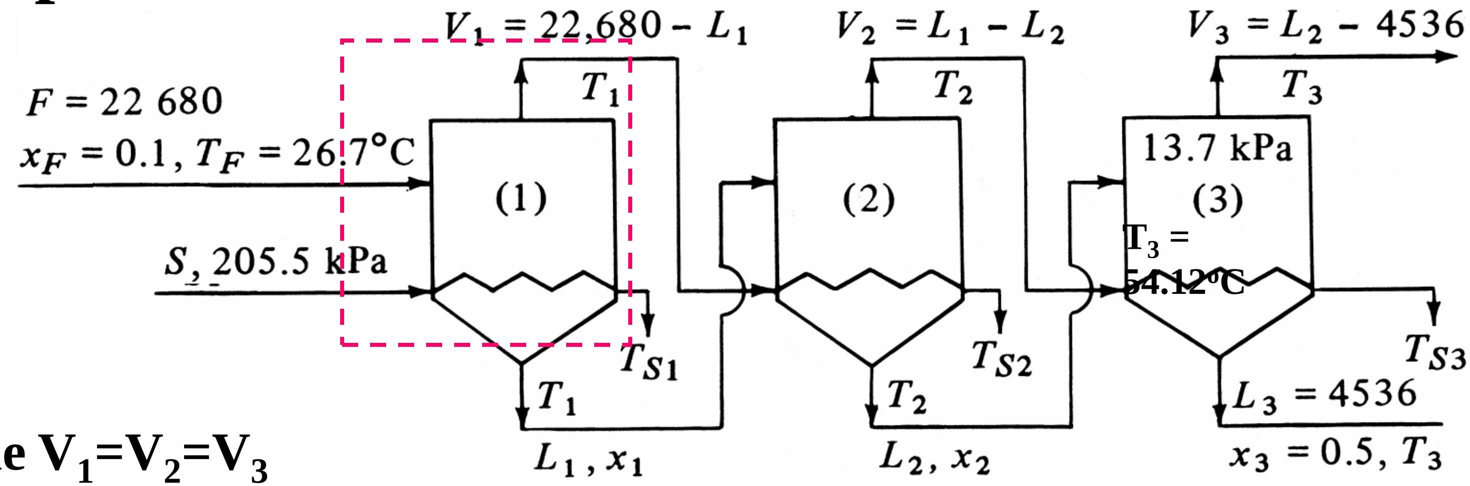
$\therefore T_3 = T_{sat.} + BPR_3 = 51.67 + 2.45 = 54.12^oC$

2. L_3 & $V_1+V_2+V_3$. Assume $V_1=V_2=V_3$

Total balance: $F = (V_1+V_2+V_3) + L_3 = 22680$ kg/h

Sugar balance: $Fx_F = L_3x_3$ $\quad 22680(0.1) = L_3(0.5)$ $\quad \therefore L_3 = 4536$ kg/h

Example 8.5-1



2. Assume $V_1=V_2=V_3$

Total balance: $22680 = (V_1+V_2+V_3) + 4536$

$(V_1+V_2+V_3) = 18\ 144$ **kg/h**

$V_1=V_2=V_3 = 18\ 144 /3 = 6048$ **kg/h**

3. L_1, L_2, x_1 & x_2

Effect 1:

Total balance:

$F = 22680 = V_1 + L_1$

$22680 = 6048 + L_1$

$L_1 = 16\ 632$ **kg/h**

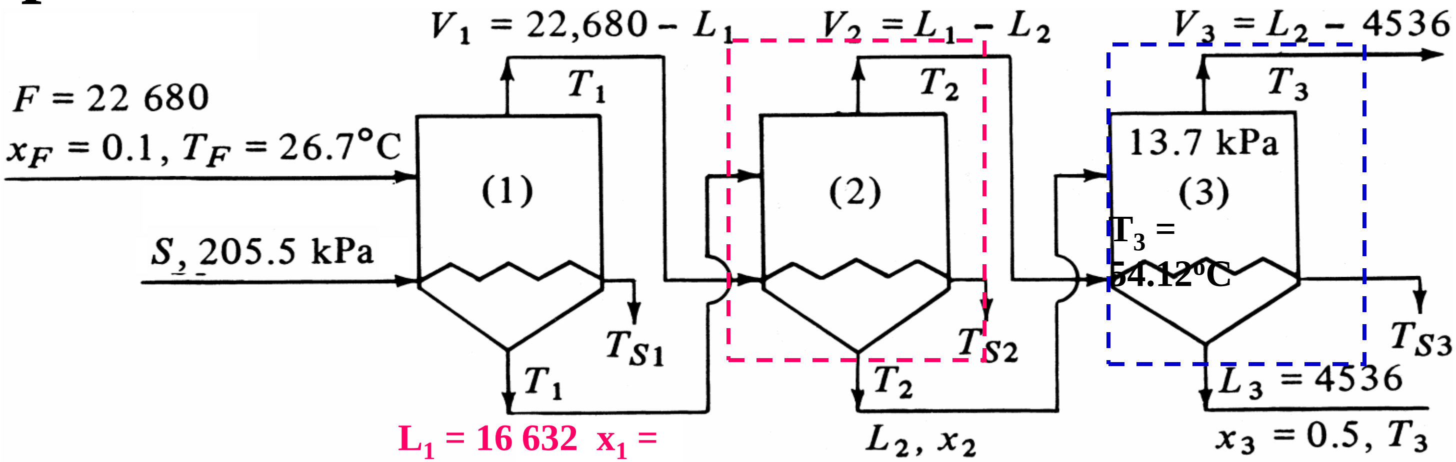
Sugar balance:

$Fx_F = L_1x_1$

$22680(0.1) = 16\ 632x_1$

$x_1 = 0.136$

Example 8.5-1



Effect 2:

Total balance: $L_1 = 16\ 632 = V_2 + L_2$

$16\ 632 = 6048 + L_2$

$L_2 = 10\ 584$ kg/h

Sugar balance: $L_1 x_1 = L_2 x_2$

$16\ 632(0.136) = 10\ 584 x_2$

$x_2 = 0.214$

Effect 3 (checking) :

Total balance: $L_2 = 10\ 584 = V_3 + L_3$

$10\ 584 = 6048 + L_3$

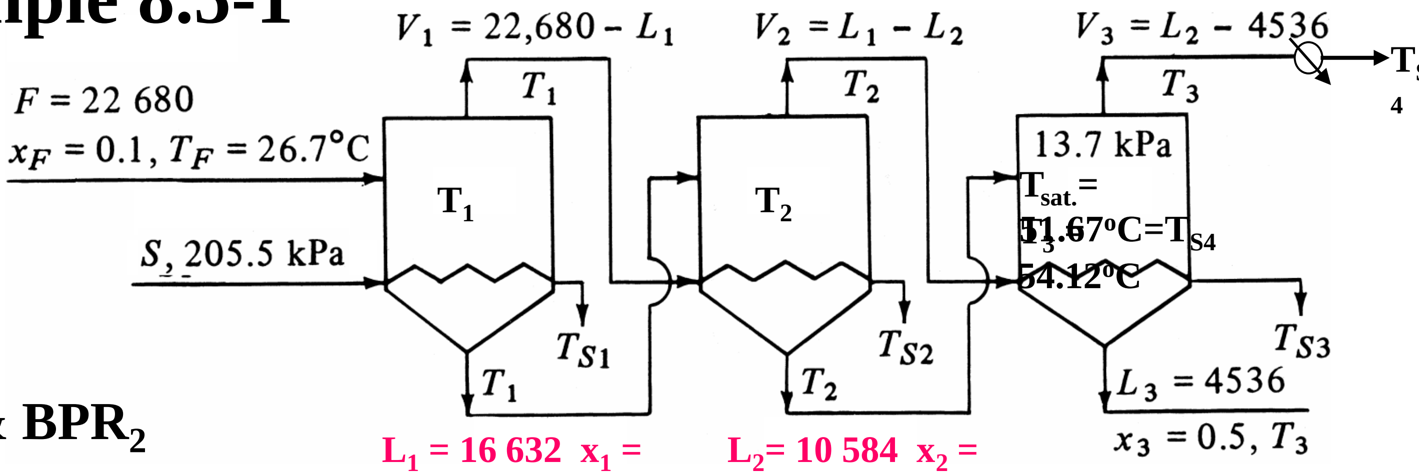
$L_3 = 4536$ kg/h

Sugar balance: $L_2 x_2 = L_3 x_3$

$10584(0.214) = 4536\ x_3$

$x_3 = 0.5$

Example 8.5-1



$L_1 = 16\ 632\quad x_1 = 0.136$

$L_2 = 10\ 584\quad x_2 = 0.214$

4. BPR_1 & BPR_2

$BPR°C = 1.78x + 6.22x^2$

$BPR_1 = 1.78x_1 + 6.22x_1^2 = 1.78(0.136) + 6.22(0.136)^2 = 0.36°C$

$BPR_2 = 1.78x_2 + 6.22x_2^2 = 1.78(0.214) + 6.22(0.214)^2 = 0.65°C$

5. $\sum\Delta T$, ΔT_1, ΔT_2 & ΔT_3. Readjust if necessary

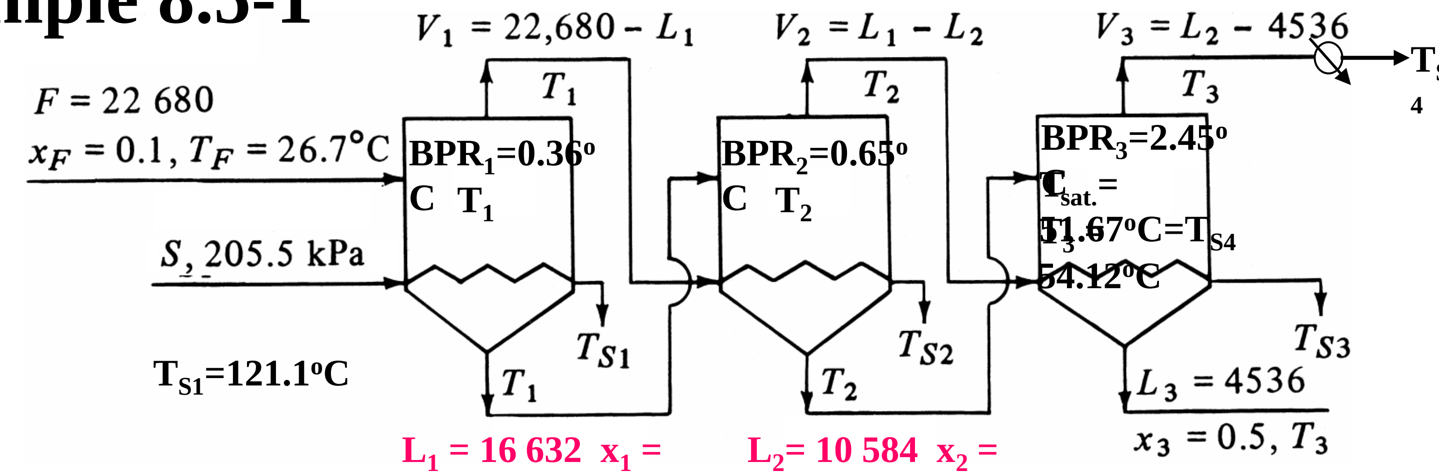
- $\Delta T_1 = T_{S1} - T_1$
- $\Delta T_2 = T_{S2} - T_2$
- $\Delta T_3 = T_{S3} - T_3$

- $\Delta T_1 = \sum\Delta T \dfrac{1/U_1}{1/U_1 + 1/U_2 + 1/U_3}$
- $\Delta T_2 = \sum\Delta T \dfrac{1/U_2}{1/U_1 + 1/U_2 + 1/U_3}$

- No BPR: $\Delta T_2 = T_1 - T_2$
- No BPR: $\sum\Delta T = T_{S1} - T_{S4}$

- BPR: $\Delta T_2 = T_1 - BPR_1 - T_2$
- BPR: $\sum\Delta T = T_{S1} - T_{S4} - (BPR_1 + BPR_2 + BPR_3)$

Example 8.5-1



BPR_1=0.36ºC T_1

BPR_2=0.65ºC T_2

BPR_3=2.45ºC

$T_{sat.}$ = 51.67ºC=T_{S4}

T_3 = 54.12ºC

T_{S1}=121.1ºC

L_1 = 16 632 x_1 = 0.136

L_2= 10 584 x_2 = 0.214

Given: U_1 = 3123 W/m^2.K, U_2 = 1987 W/m^2.K & U_3 = 1135 W/m^2.K

5. $\sum\Delta T$, ΔT_1, ΔT_2 & ΔT_3. Readjust if necessary

$$\sum\Delta T = T_{S1} - T_{S4} - (BPR_1 + BPR_2 + BPR_3) = 121.1 - 51.46 - (0.36-0.65-2.45) = 65.97^oC$$

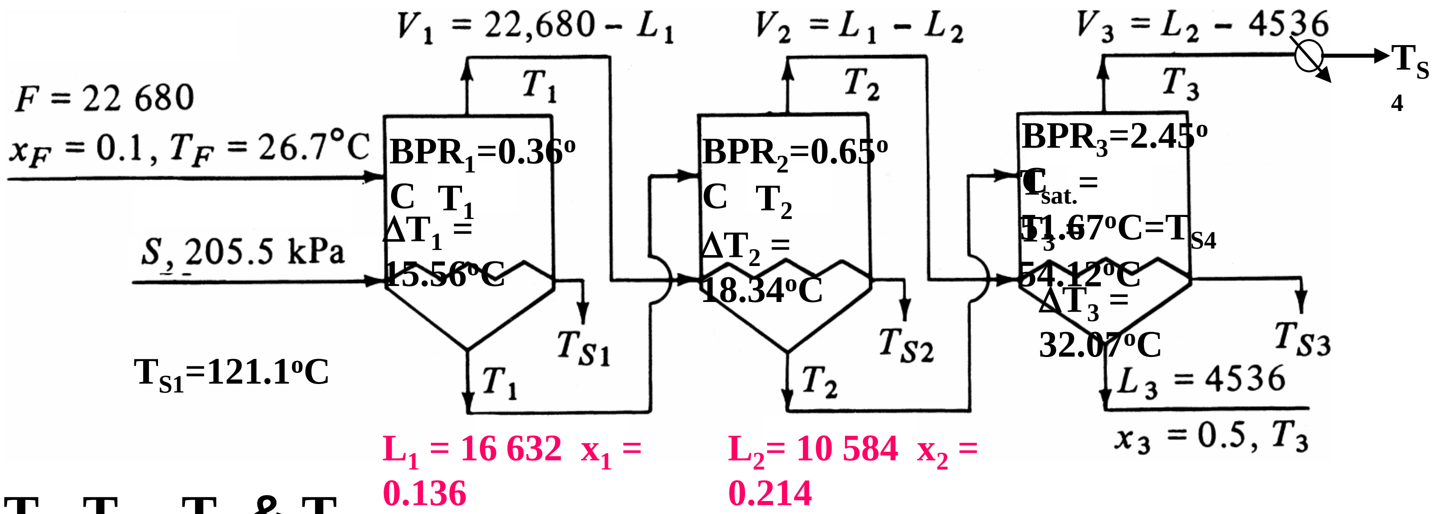
$$\Delta T_1 = \sum\Delta T \frac{1/U_1}{1/U_1 + 1/U_2 + 1/U_3} = 65.97 \frac{1/3123}{1/3123 + 1/1987 + 1/1135} = 12.40^oC$$

$$\Delta T_2 = \sum\Delta T \frac{1/U_2}{1/U_1 + 1/U_2 + 1/U_3} = 65.97 \frac{1/1987}{1/3123 + 1/1987 + 1/1135} = 19.50^oC$$

$$\Delta T_3 = \sum\Delta T \frac{1/U_3}{1/U_1 + 1/U_2 + 1/U_3} = 65.97 \frac{1/1135}{1/3123 + 1/1987 + 1/1135} = 34.07^oC$$

Since T_F=26.7ºC 〈 T_3=54.12ºC, the feed is a cold feed. Readjust as the feed need to be heated to T_1. ΔT_1 = 15.56ºC, ΔT_2 = 18.34ºC, ΔT_3 = 32.07ºC, $\sum\Delta T$ = 65.97ºC

Example 8.5-1



6. T_1, T_{S1}, T_2, T_{S2}, T_3 & T_{S3}

$\Delta T_1 = T_{S1} - T_1$ $\qquad T_1 = T_{S1} - \Delta T_1 = 121.1 – 15.56 = 105.54^oC$

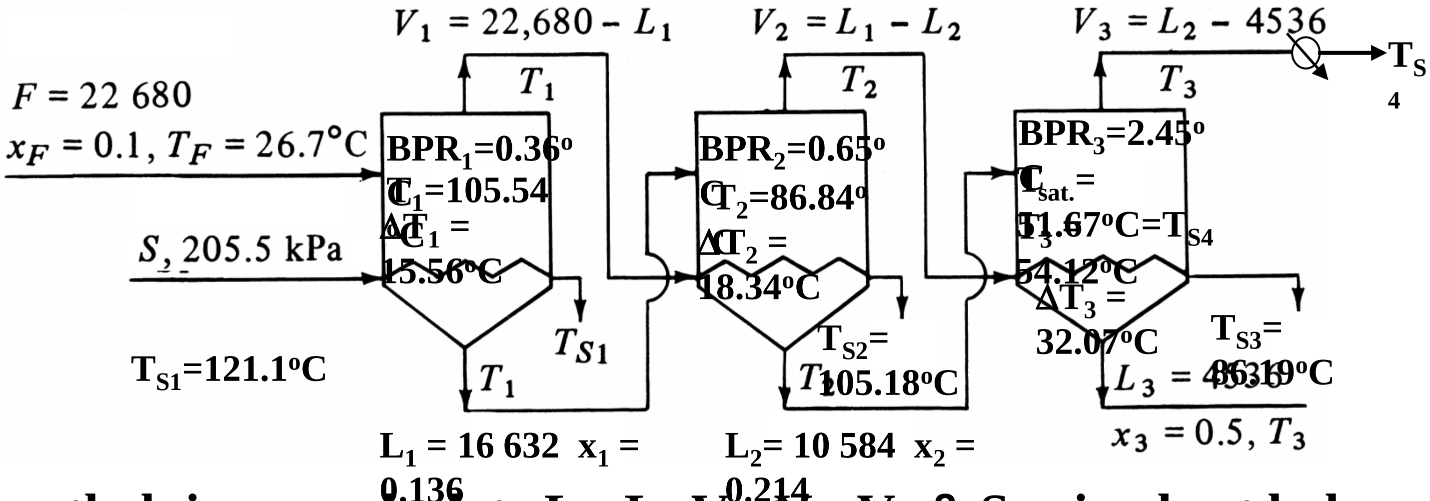
$\Delta T_2 = T_1 - BPR_1 - T_2$ $\qquad T_2 = T_1 - BPR_1 - \Delta T_2 = 105.54 – 0.36 – 18.34 = 86.84^oC$

$\Delta T_2 = T_{S2} - T_2$ $\qquad T_{S2} = \Delta T_2 + T_2 = 18.34 + 86.84 = 105.18^oC$

$\Delta T_3 = T_2 - BPR_2 - T_3$ $\qquad T_3 = T_2 - BPR_2 - \Delta T_3 = 86.84 – 0.65 - 32.07 = 54.12^oC$ (checking)

$\Delta T_3 = T_{S3} - T_3$ $\qquad T_{S3} = \Delta T_3 + T_3 = 32.07 + 54.12 = 86.19^oC$

Example 8.5-1



7. c_P, enthalpies, recalculate L_1, L_2, V_1, V_2, V_3 & S using heat balances

Given: c_p (kJ/kg.K) = 4.19 – 2.35x

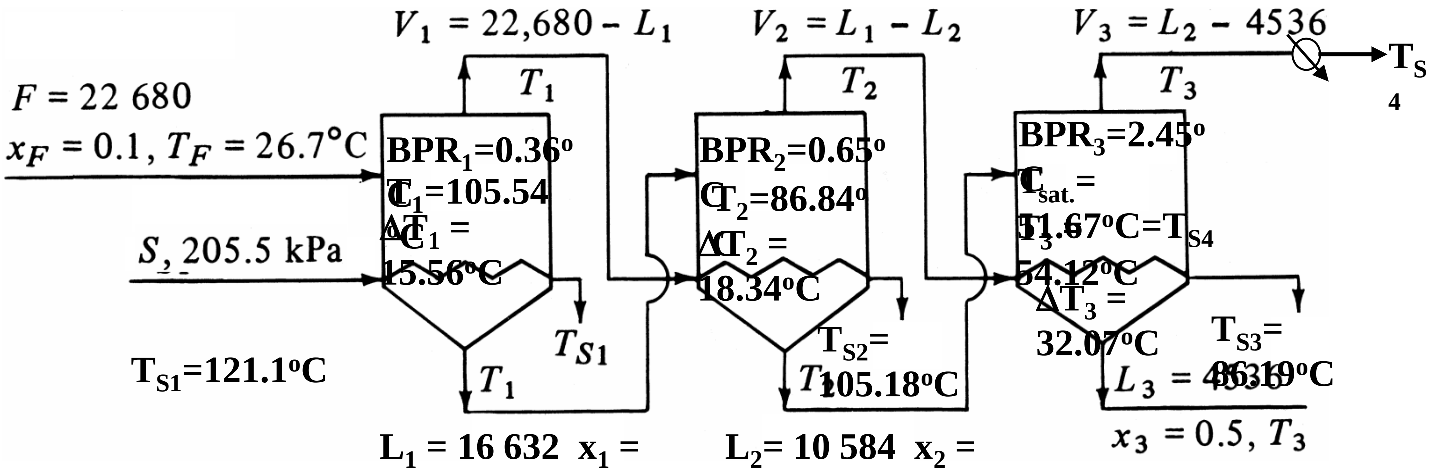
$$c_{pF} = 4.19 - 2.35x_F = 4.19 - 2.35(0.1) = 3.955 \text{ kJ/kg.K}$$

$$c_{pL1} = 4.19 - 2.35x_1 = 4.19 - 2.35(0.136) = 3.869 \text{ kJ/kg.K}$$

$$c_{pL2} = 4.19 - 2.35x_2 = 4.19 - 2.35(0.214) = 3.684 \text{ kJ/kg.K}$$

$$c_{pL3} = 4.19 - 2.35x_3 = 4.19 - 2.35(0.5) = 3.015 \text{ kJ/kg.K}$$

Example 8.5-1



c_{pF} = 3.955 kJ/kg.K c_{pL1}= 3.869 kJ/kg.K c_{pL2}= 3.684 kJ/kg.K c_{pL3}= 3.015 kJ/kg.K

$$h = c_P(T - T_{ref.})$$

Tref. = 0°C (same as steam table),

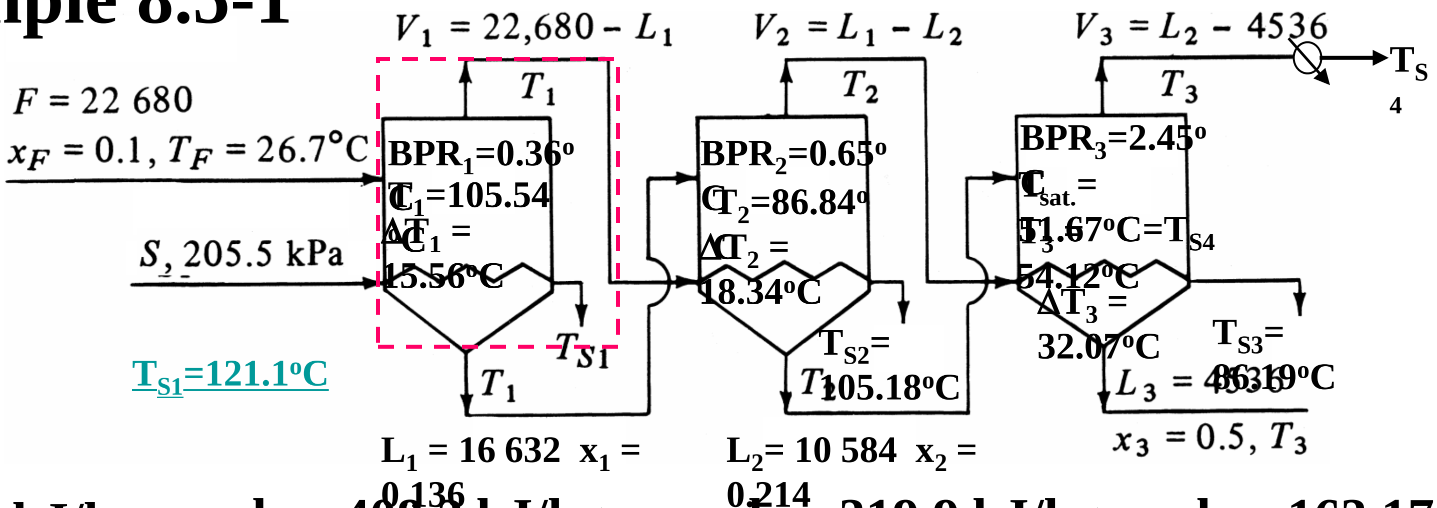
$$h_F = c_{PF}(T_F - T_{ref.}) = 3.955(26.7 - 0) = 105.6 \text{ kJ/kg}$$

$$h_1 = c_{PL1}(T_1 - T_{ref.}) = 3.869(105.54 - 0) = 408.3 \text{ kJ/kg}$$

$$h_2 = c_{PL2}(T_2 - T_{ref.}) = 3.684(86.84 - 0) = 319.9 \text{ kJ/kg}$$

$$h_3 = c_{PL3}(T_3 - T_{ref.}) = 3.015(54.12 - 0) = 163.17 \text{ kJ/kg}$$

Example 8.5-1



h_F = 105.6 kJ/kg h_1= 408.3 kJ/kg h_2= 319.9 kJ/kg h_3= 163.17 kJ/kg

Tref. = 0°C (same as steam table),

Effect 1: Energy balance: $Fh_F + S(H_{S1} – h_{S1}) = L_1h_1 + V_1H_1$

$$22680h_F + S\lambda_{S1} = L_1h_1 + V_1H_1$$

Material balance: $22680 = V_1 + L_1$

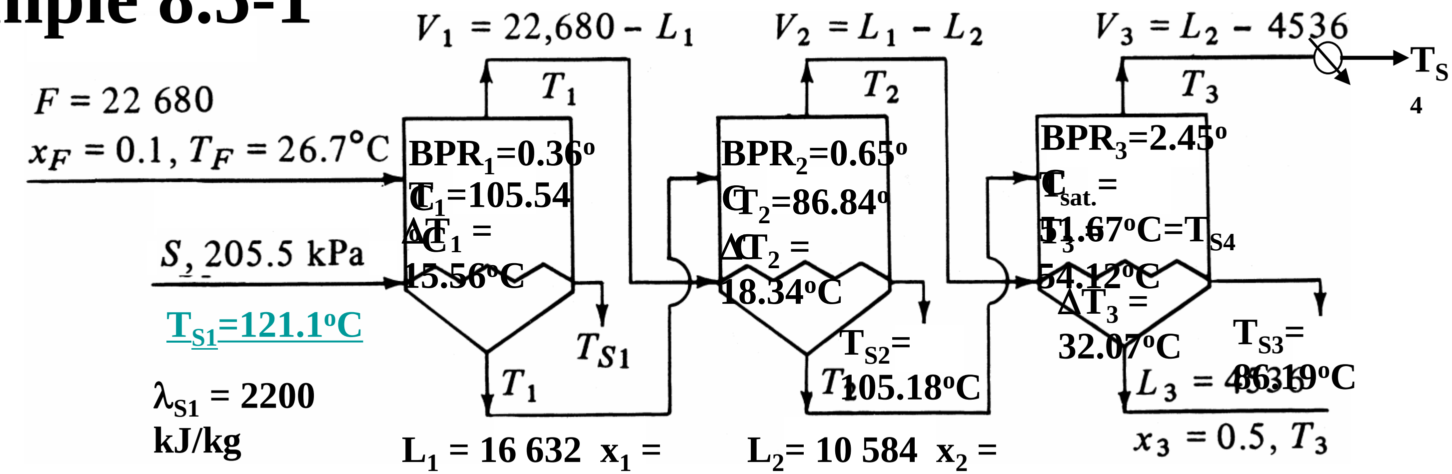
$$V_1 = 22680 - L_1$$

$$22680h_F + S\lambda_{S1} = L_1h_1 + (22680-L_1)H_1$$

$$22680(105.6) + S\lambda_{S1} = L_1(408.3) + (22680-L_1)H_1$$

From the steam table (A.2-9) at T_{S1}=121.1°C after interpolation, H_{S1} = 2708 kJ/kg and h_{S1} = 508 kJ/kg. ∴ λ_{S1} = (2708-508) = 2200 kJ/kg

Example 8.5-1



h_F = 105.6 kJ/kg h_1= 408.3 kJ/kg h_2= 319.9 kJ/kg h_3= 163.17 kJ/kg

Tref. = 0°C (same as steam table),

Effect 1:

$$22680(105.6) + S\lambda_{S1} = L_1(408.3) + (22680-L_1)H_1$$

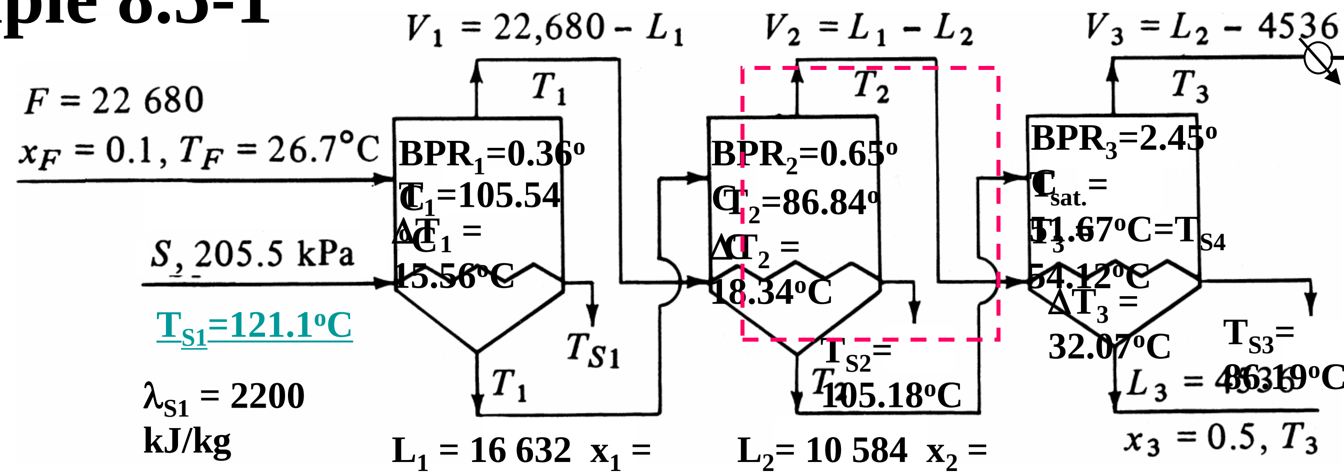
$$H_1 = H_{S2} + 1.884(BPR_1)$$

From the steam table A.2-9 at T_{S2}=105.18°C, H_{S2} = 2684 and h_{S2} = 441 kJ/kg

$$H_1 = 2684 + 1.884(0.36) = 2685 \text{ kJ/kg}$$

$$22680(105.6) + S(2200) = L_1(408.3) + (22680-L_1)2685 \quad (1)$$

Example 8.5-1



h_F = 105.6 kJ/kg h_1= 408.3 kJ/kg h_2= 319.9 kJ/kg h_3= 163.17 kJ/kg

h_{S2} = 441 kJ/kg H_1 = 2685 kJ/kg

Tref. = 0°C (same as steam table),

Effect 2:

$$L_1h_1 + V_1(H_1 - h_{S2}) = L_2h_2 + V_2H_2$$

$$L_1h_1 + (22680-L_1)(H_1 - h_{S2}) = L_2h_2 + (L_1-L_2)H_2$$

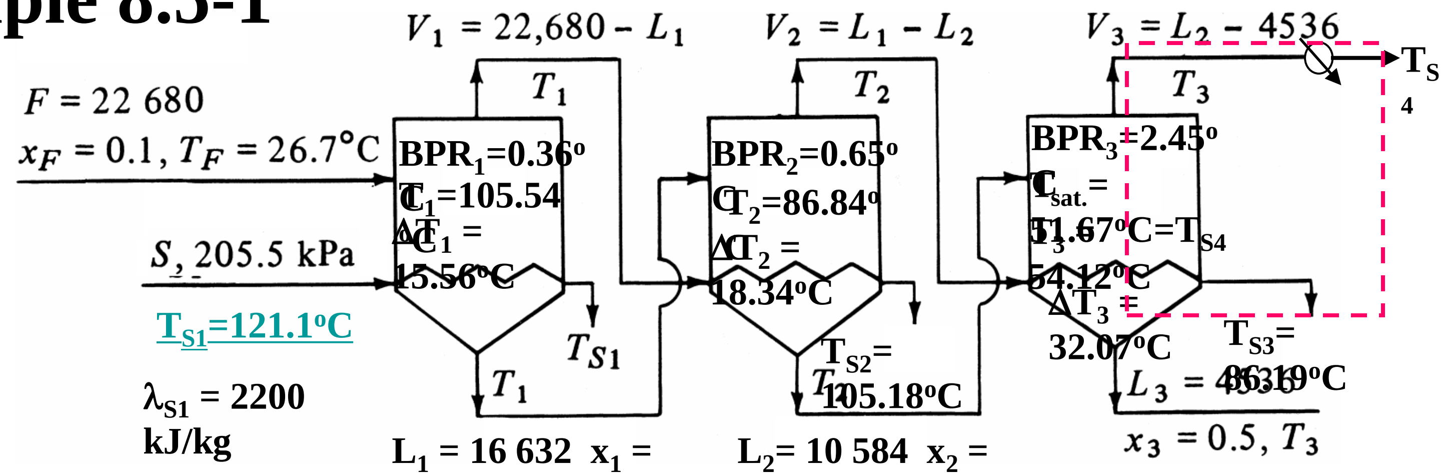
$$H_2 = H_{S3} + 1.884(BPR_2)$$

From the steam table A.2-9 at T_{S3}=86.19°C, H_{S3} = 2654 and h_{S3} = 361 kJ/kg

$$H_2 = 2654 + 1.884(0.65) = 2655 \text{ kJ/kg}$$

$$\therefore L_1(408.3) + (22680-L_1)(2685 - 441) = L_2(319.9) + (L_1-L_2)(2655) \qquad (2)$$

Example 8.5-1



h_F = 105.6 kJ/kg h_1= 408.3 kJ/kg h_2= 319.9 kJ/kg h_3= 163.17 kJ/kg

h_{S2} = 441 kJ/kg H_1 = 2685 kJ/kg H_2 = 2655 kJ/kg h_{S3} = 361 kJ/kg

Tref. = 0°C (same as steam table),

Effect 3:

$$L_2h_2 + V_2(H_2 - h_{S3}) = L_3h_3 + V_3H_3$$

$$L_2h_2 + (L_1\text{-}L_2)(H_2 - h_{S3}) = L_3h_3 + (L_2\text{-}4536)H_3$$

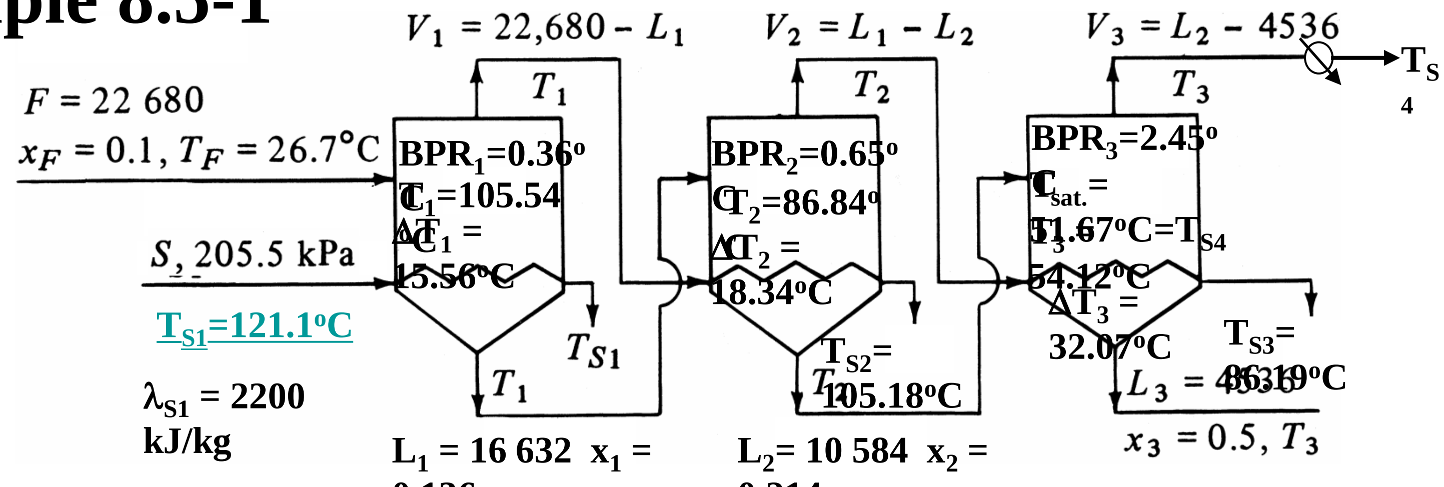
$$H_3 = H_{S4} + 1.884(BPR_3)$$

From the steam table A.2-9 at T_{S4}=51.67°C, H_{S4} = 2595

$$H_3 = 2595 + 1.884(2.45) = 2600\text{kJ/kg}$$

$$\therefore\ L_2(319.9) + (L_1\text{-}L_2)(2655 - 361) = L_3(163.17) + (L_2\text{-}4536)(2600) \qquad (3)$$

Example 8.5-1



$$22680(105.6) + S(2200) = L_1(408.3) + (22680-L_1)2685 \qquad (1)$$

$$L_1(408.3) + (22680-L_1)(2685 - 441) = L_2(319.9) + (L_1-L_2)(2655) \qquad (2)$$

$$L_2(319.9) + (L_1-L_2)(2655 - 361) = L_3(163.17) + (L_2-4536)(2600) \qquad (3)$$

Solving simultaneously eq. (2) and (3):

$$L_1 = 17078 \text{ kg/h and } L_2 = 11068 \text{ kg/h}$$

From eq. (1) after substituting L_1 =17078 kg/h and L_2 = 11068 kg/h , S = 8936 kg/h

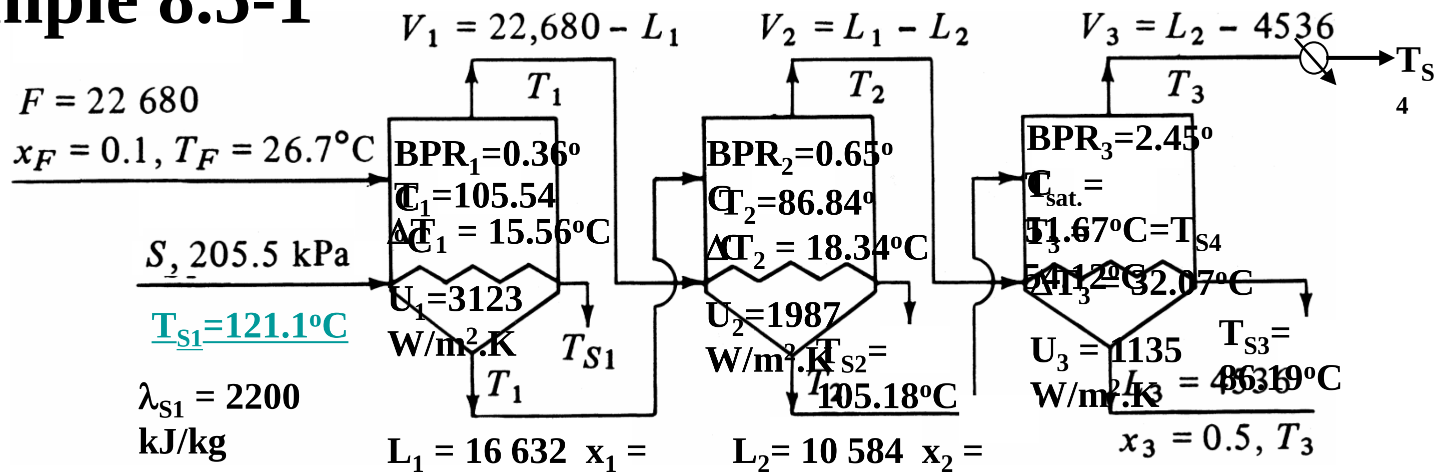
Substituting L_1 & L_2 into the material balances of each effect:

$$V_1 = 22680 - L_1 = 22680 - 17078 = 5602 \text{ kg/h}$$

$$V_2 = L_1 - L_2 = 17078 - 11068 = 6010 \text{ kg/h}$$

$$V_3 = L_2 - 4536 = 11068 - 4536 = 6532 \text{ kg/h}$$

Example 8.5-1



Latest calculations: L_1 =17078 kg/h, L_2 = 11068 kg/h , S = 8936 kg/h , V_1 = 5602 kg/h, V_2 = 6010 kg/h and V_3 = 6532 kg/h

Previous calculations: L_1 =16632 kg/h (% error = 2.6) , L_2 = 10584 kg/h (% error = 4.4) , V_1 = 6048 kg/h (% error = 8.0), V_2 = 6048 kg/h (% error = 0.6) and V_3 = 6048 kg/h (% error = 7.4)

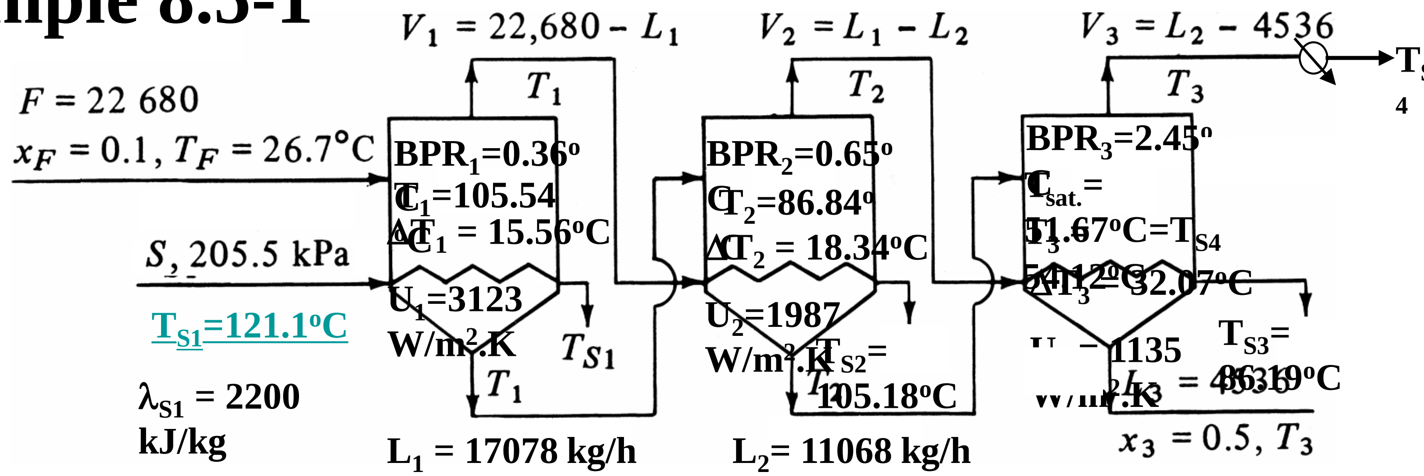
9. If errors ⟨ 10%, calculate q_1, q_2 , q_3 , A_1, A_2, A_3 & $A_{ave.}$ If errors ⟩10%, revise ΔTs.

$$q_1 = S\lambda_{S1} = U_1A_1\Delta T_1$$

$$q_1 = S\lambda_{S1} = \frac{8936\ \text{kg}}{\text{h}}\left|\frac{2200\ \text{kJ}}{\text{kg}}\right|\frac{1\text{h}}{3600\text{s}} = 5460\ \text{kJ/s}$$

$$A_1 = \frac{5460 \times 10^3\ \text{W}}{15.56\ \text{K}}\left|\frac{\text{m}^2.\text{K}}{3123\ \text{W}}\right. = 112.4\ \text{m}^2$$

Example 8.5-1



Latest calculations: L_1 =17078 kg/h , L_2 = 11068 kg/h , S = 8936 kg/h , V_1 = 5602 kg/h, V_2 = 6010 kg/h and V_3 = 6532 kg/h

q_1 =5460 kJ/s $\quad$ $A_1 = 112.4\ m^2$ $\quad$ $A_{ave.} = A_m = 104.4\ m^2$

$$q_2 = V_1\lambda_{S2} = \frac{5602\ \cancel{kg}}{\cancel{h}}\left|\frac{2244\ kJ}{\cancel{kg}}\right|\frac{\cancel{1h}}{3600s} = 3492\ kJ/s$$

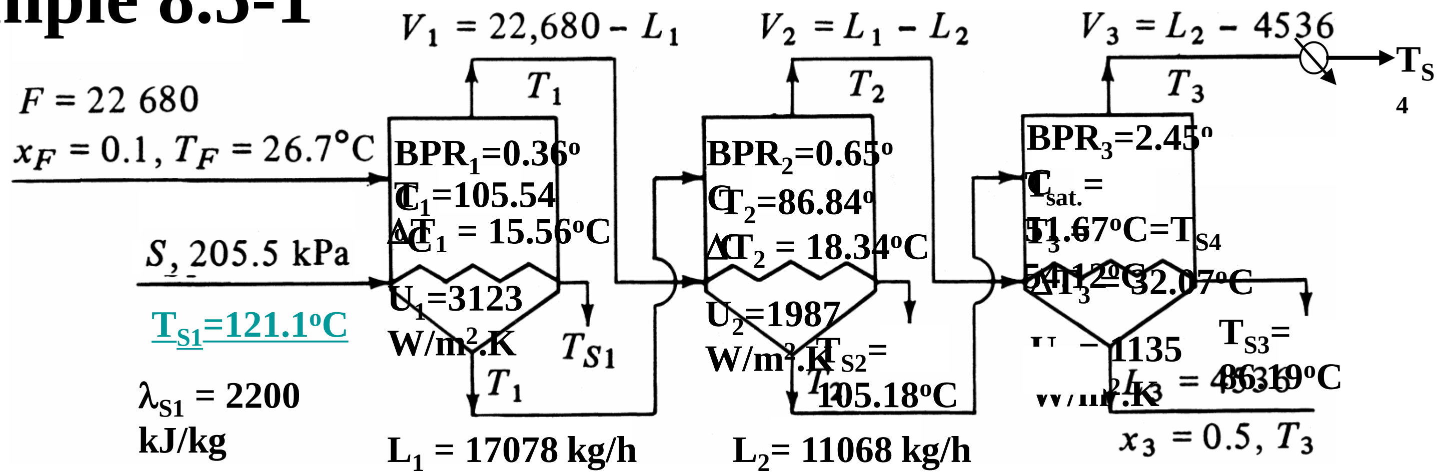
$A_{ave.} = A_m = 104.4\ m^2$

$$A_2 = \frac{3492 \times 10^3\ \cancel{W}}{18.34\ \cancel{K}}\left|\frac{m^2.\cancel{K}}{1987\ \cancel{W}}\right. = 95.8\ m^2$$

$$q_3 = V_2\lambda_{S3} = \frac{6010\ \cancel{kg}}{\cancel{h}}\left|\frac{2294\ kJ}{\cancel{kg}}\right|\frac{\cancel{1h}}{3600s} = 3830 kJ/s$$

$$A_3 = \frac{3830 \times 10^3\ \cancel{W}}{32.07\ \cancel{K}}\left|\frac{m^2.\cancel{K}}{1135\ \cancel{W}}\right. = 105.1\ m^2$$

Example 8.5-1



Latest calculations: L_1 =17078 kg/h , L_2 = 11068 kg/h , S = 8936 kg/h , V_1 = 5602 kg/h, V_2 = 6010 kg/h and V_3 = 6532 kg/h

9. If % errors for A_1, A_2, A_3 〉10%, revise ΔTs

q_1 =5460 kJ/s	A_1 = 112.4 m^2	(% error =7.7)
q_2= 3492 kJ/s	A_2 =95.8 m^2	(% error =8.2)
q_3= 3830kJ/s	A_3= 105.1 m^2	(% error =0.7)

$A_{ave.} = A_m = 104.4\ m^2$

$\therefore A = 104.4\ m^2$