**Institute of Food, Nutrition and Human Health
AND
School of Engineering and Advanced Technology**

280.371 PROCESS ENGINEERING OPERATIONS

Evaporation
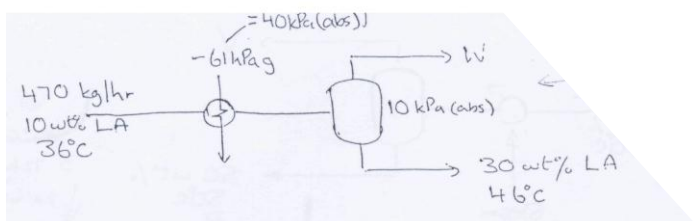# Model Answers to Tutorial Problems

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These notes are a culmination of the efforts of the following past and present staff of Massey University:

Associate Professor M.Wong
Dr Stephen White

EVAPORATION EXAMPLE SOLUTIONS

Example 1

Solute Balance

$$470 \times 0.1 = m_P \times 0.3 \qquad\qquad m_F x_F = m_\rho x_P$$
$$\Rightarrow m_P = 156.7 \ kg/hr$$

$$m_F = m_\rho + m_v$$

Water Balance

$$470 \times 0.9 = 1546.7 \times 0.7 + m_v \qquad\qquad m_F(1 - x_F) = m_p(1 - x_\rho)$$
$$\Rightarrow \qquad water \ evaporated \quad m_v = 313.3 \ kg/hr$$
$$m_v = 470 - 156.7$$

Energy Balance

$$m_F h_F + \phi = m_P h_p + m_v h_v$$

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Take θ reference $= 0°C$ (same as steam tables)

$$\Rightarrow 470 \times 4.0 \times (36 - 0) + \phi = 313.3 \times 2584.1 + 156.7 \times 4.0(46 - 0) \qquad hg - steam\ vapour$$

$$h = c_p \times \Delta\theta \qquad if \quad c_p @ 36°C = 4.0 \qquad c_p @ 46°C = 4.0$$

$$\Rightarrow \phi = 770751 kJ/hr = 214.1 kW$$

$$\phi = UA\Delta\theta \quad where \quad at\ 40kPa(abs) = 76°C$$

$$\Delta\theta = 76 - 46$$

$$= 30$$

$$\Rightarrow A = \frac{214.1 \times 10^3}{2000 \times 30} = 3.57 m^2$$

$$Evaporator\ Efficiency = \frac{m_v h_{fg}}{\phi} = \frac{313.3 \times 2392.2}{770751} \qquad h_{fg} \quad at\ 46°C$$

$$= 97.2\%$$

h from steam tables

$$Steam\ economy = \frac{m_v h_{fg\,steam}}{\phi} = \frac{313.3 \times 2318.6}{770751} \qquad h_{fg} \quad at\ 76°C$$

$$= 0.94 \frac{kg}{kg}$$
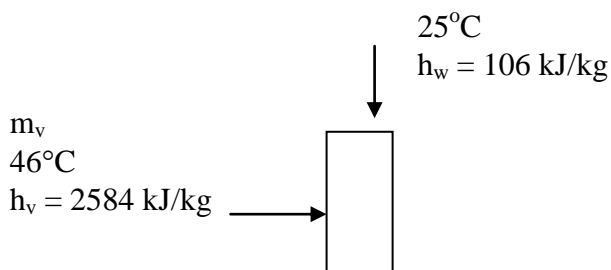
$$Steam \quad used = \frac{m_v}{steam\ economy} = \frac{313.3}{0.94} = 333\ kg/hour$$

(d)

$$\phi = m_v h_{fg}$$

$$= 313.3 \times 2392 = 208 kW$$

$$\phi = mc_p\Delta\theta$$

25°C
$h_w = 106$ kJ/kg

m_v
46°C
$h_v = 2584$ kJ/kg

Example 2

(i)
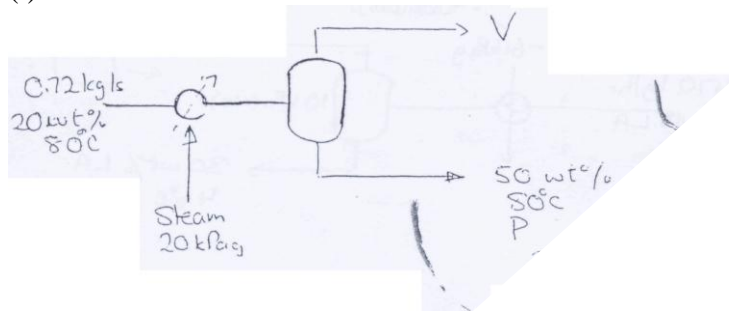
Solids balance

$0.72 \times 0.2 = m_p \times 0.5$

$\Rightarrow m_p = 0.288 \ kg/s$

Overall balance

$m_v + 0.288 = 0.72 \quad \Rightarrow m_v = 0.432 \, kg/s$

Heat balance (simplified because feed enters @ boiling point)

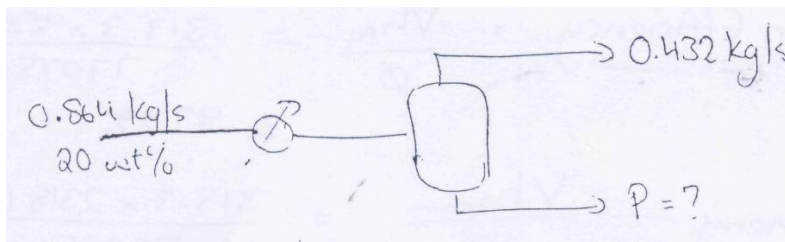$\phi = m_v h_{fg} \qquad where \, h_{fg} = 2308.3 \, kJ/kg @ 80°C$

$\Rightarrow \phi = 0.432 \times 2308.3$

$\qquad = 997 kW$

$$U = \frac{\phi}{A \Delta \theta_{lm}} \quad = \quad \frac{997 \times 10^3}{50 \times (104.81 - 80)}$$

$\qquad \qquad \qquad \qquad \uparrow 20kPa \, gauge = 121.3 kPa(abs)$

$\qquad \qquad = \qquad 804 W/m^2 K$

(ii)

If flow rate increases by 20% but U, A and $\Delta\theta$ stay the same then ϕ must stay the same and hence m_v stays the same

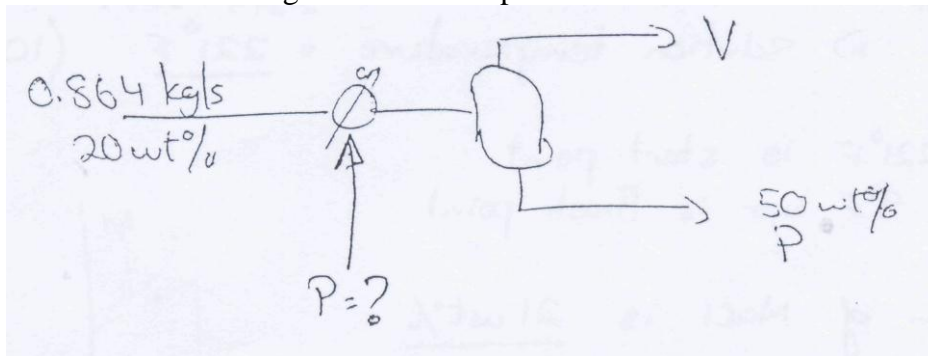Stays the same because the pressures are the same

Overall balance

$0.864 = 0.432 + m_p \qquad \Rightarrow \qquad m_p = 0.432 \, kg/s$

Solid balance

$0.864 \times 0.2 = 0.432 \times x_p \qquad \Rightarrow \qquad x_p = 0.4$

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(iii) If we want the same product concentration, then we must increase the temperature driving force to boil off the right amount of vapour

Solids balance

$$0.864 \times 0.2 = m_p \times 0.5 \qquad \Rightarrow m_p = 0.3456 \, kg/s$$

Overall balance

$$0.864 = 0.3456 + m_v \quad \Rightarrow m_v = 0.5184 \, kg/s$$

Heat balance

$$\phi = m_v h_{fg}$$

$$\phi = 0.5184 \times 2308.3 \longleftarrow \text{80°C}$$

$$= 1197 \, kW$$

$$\Rightarrow \Delta\theta = \frac{\phi}{UA} = \frac{1197 \times 10^3}{804 \times 50} = 29.77°C$$

$$\Rightarrow \text{Steam temperature} \qquad = 80 + 29.77$$

$$= 109.77°C$$

From steam tables, the steam pressure ≈ *142 kPa (absolute)*

40.7 kPa gauge

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Example 3.

(a) **Low viscosity, corrosive salt solution, crystalline product**

Heat exchanger: short vertical tube because it's relatively inexpensive and can handle crystalline product. Probably have to wear the cost of exotic materials

Separator: Gravity separation to facilitate recirculation

Fluid moving: propeller to ensure movement of crystalline product

Condenser: probably indirect if solute is not suitable for discharge into the environment

(b) **Concentrating fruit juice**
Once through long tube vertical with forced circulation to handle crystalline product and low residence time.

Separator: cyclone as once through, or gravity as cheap

Fluid moving: pump upstream of heat exchanger to ensure solids are forced through and there is no thermosyphon (natural circulation) possible in once through application.

Condenser: Spray condenser because it's cheap and discharge of natural product to the environment should be fine.

(c) **Concentrating a non corrosive liquid-solution**

Heat exchanger: long to be vertical because its' cheap.

Separator: Gravity to enable thermosyphon recirculation.

Fluid movement: Thermosyphon because it's cheap.

Condenser: Spray (assuming acceptable to discharge to the environment).

(d) **Concentrating corrosive fluid with low head room**

Heat exchanger: horizontal tube to fit under the roof

Separator: Gravity separation to maintain liquid level so that it doesn't cavitate the pump

Fluid movement: recycle with pump to increase heat transfer (reduce surface area of exotic materials)

Condenser: spray if material can be discharged to the environment

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EVAPORATION

Example 4

Atmospheric pressure

$\Rightarrow$ *boiling point of pure water* $= 100^o C\ (212^o F)$

boiling point elevation $= 9^o F$

$\Rightarrow$ *solution temperature* $= \underline{221^o F}$ $212 + 9 = 221^o F\ (105^o C)$

Using Chart $- 221^o F$ *is start point*

$9^o F\ bpr$ *is finish point*

Concentration of NaCl is $\underline{21wt\%}$

$$vapour\ enthalpy \begin{pmatrix} \theta ref = 0^o C \\ liquid\,phase \end{pmatrix} = h_{sat,steam} + Cp\theta_{bpr}$$

@100°C

2 kJ/kg K

$$= 2675.8 + 1.88 \times \frac{9}{1.8}$$

$$= 2685.2\ kJ\,/\,kg$$

$$liquid\,enthalpy \begin{pmatrix} \theta ref = 0^o C \\ liquid\,phase \end{pmatrix} = Cp(\theta_{solution} - \theta_{ref})$$

$$= 4 \times (105 - 0)$$

$$= 420\,kJ/\,kg$$

$$(^\circ F - 32)\frac{5}{9} = {}^\circ C$$

Boiling-point rise of aqueous solutions. $°C = \frac{5}{9}(°F - 32)$.

Example:
At 270° F. a 22% CaCl₂ solution has a b.p.r. of 9.7° F.

Note: Points shown are based mainly on atmospheric boiling point
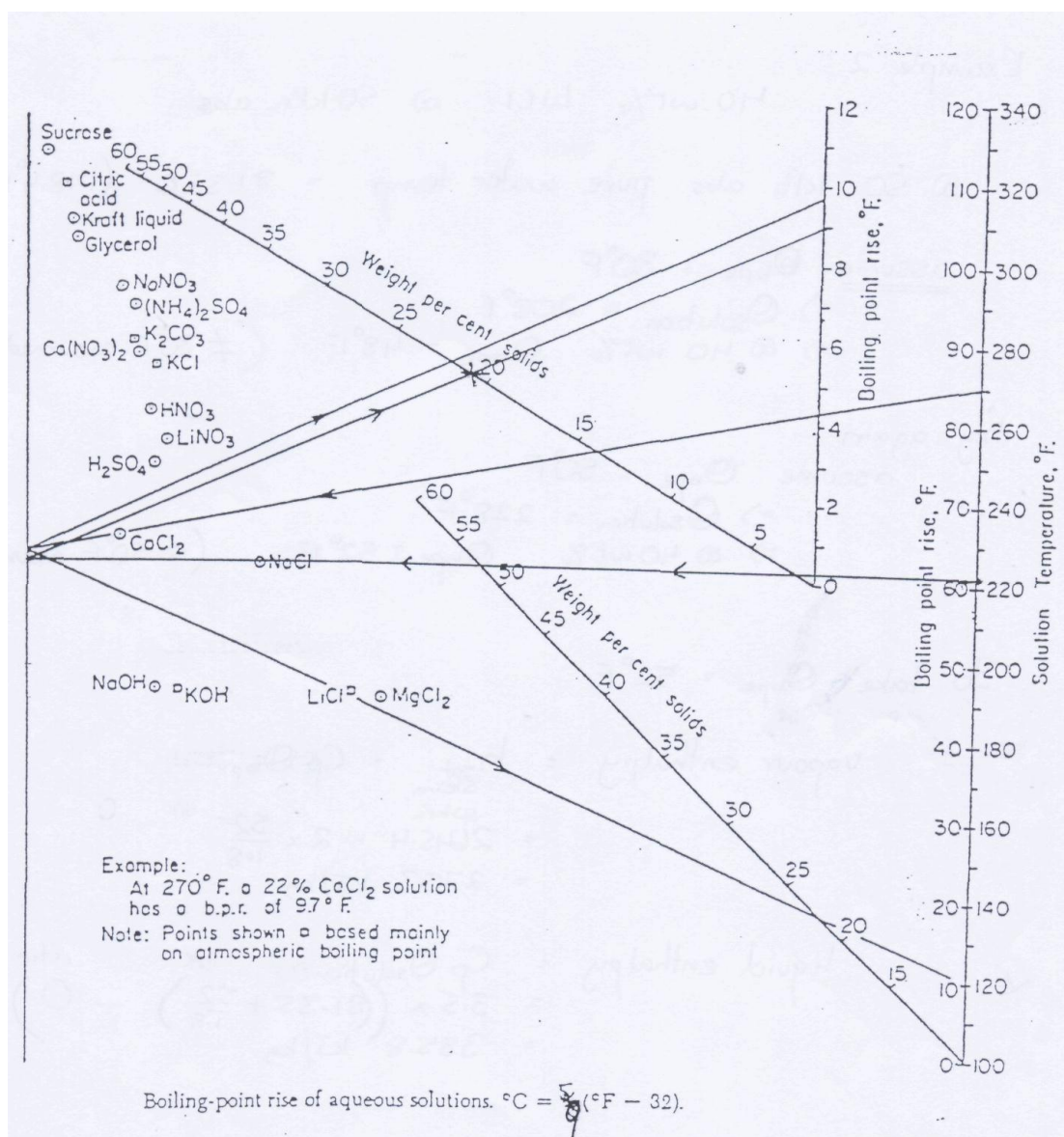
Example 5

$40 wt\%$ $LiCl@50kPa(abs)$

$@50kPa(abs)$ pure water temp $= 81.35°C(178.4°F)$

assume $\theta_{bpe} = 30°F$

$\Rightarrow \theta_{solution} = 208°F$

$\Rightarrow @40wt\% \theta_{bpe} = 48°F (\neq 30°F \text{ assumed})$

try again

assume $\theta_{bpe} = 50°F$

$\Rightarrow \theta_{solution} = 228°F$

$\Rightarrow @40wt\% \theta_{bpe} = 52°F (\neq 50°F \text{ assumed})$

So take $\theta_{bpe} = 52°F$

vapour enthalpy $= h_{sat\,steam} + Cp\theta_{bpr}$ ⟵ 50kPa
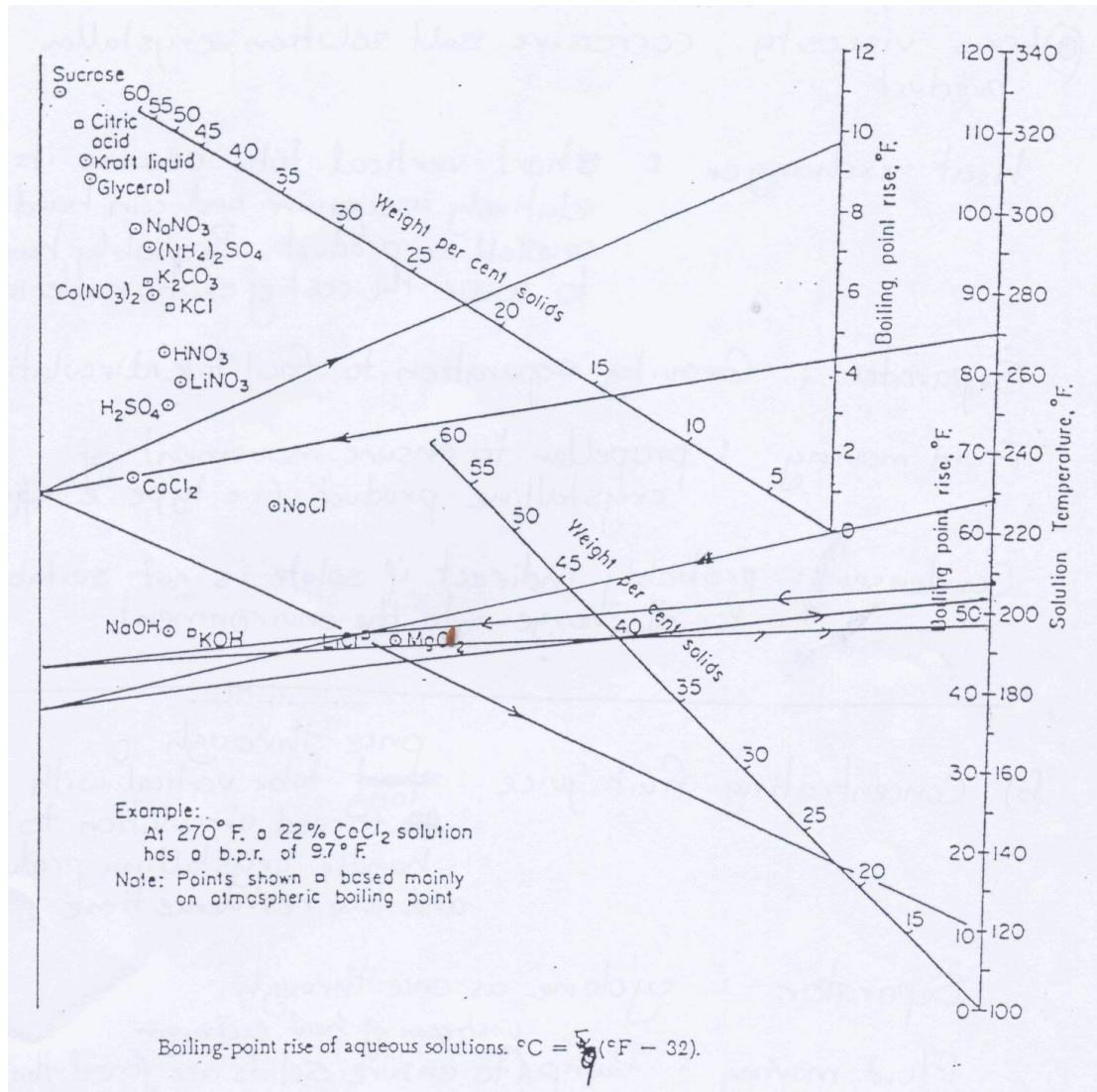
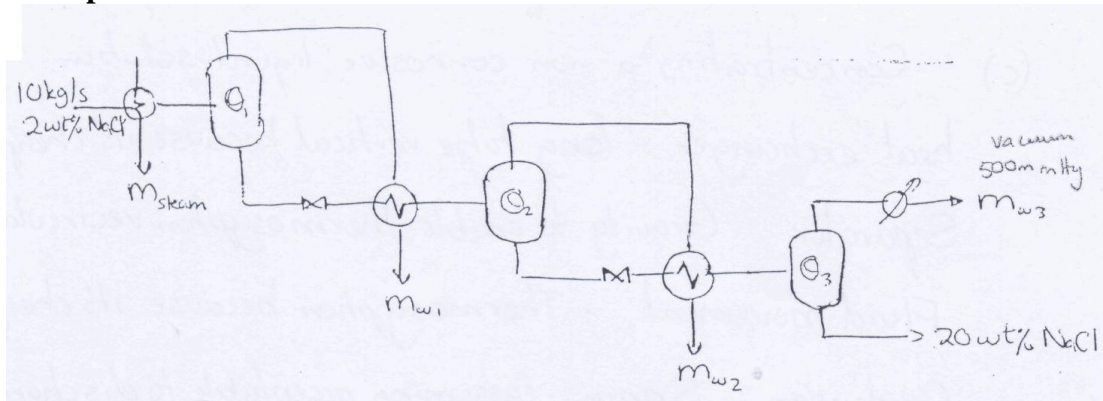$= 2645.4 + 2 \times \dfrac{52}{1.8}$

$= 2703\, kJ/kg$

liquid enthalpy $= Cp(\theta_{solution} - \theta_{ref})$ ⟵ reference

$= 3.5 \times \left(\left(81.35 + \dfrac{52}{1.8} \right) - 0 \right)$

$= 385.8\, kJ/kg$

Boiling-point rise of aqueous solutions. $°C = \frac{5}{9}(°F - 32)$.

Example:
At 270° F. a 22% CaCl$_2$ solution has a b.p.r. of 9.7° F.
Note: Points shown □ based mainly on atmospheric boiling point

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Example 6

Solute Balance

$$10 \times 0.02 = m_p \times 0.2$$
$$\Rightarrow m_p = 1\,kg/s$$

Overall Balance

$$m_{v1} + m_{v2} + m_{v3} \quad = 10 - 1$$
$$= 9\,kg/s$$

Steam temperature $(@150kPa) = 111.4°C$

Steam temperature in final stage $(m_{v3} @ 260mm\,Hg) = 72.5°C$

$$P(abs) = 760mm\,Hg - 500mm\,Hg$$
$$= 260mm\,Hg = 34.7kPa$$

Constantarea

$$\Rightarrow \theta_2 - \theta_3 = \frac{\dfrac{1}{U_3}}{\dfrac{1}{U_1} + \dfrac{1}{U_2} + \dfrac{1}{U_3}}(\theta_s - \theta_3) = \frac{\dfrac{1}{800}}{\dfrac{1}{1000} + \dfrac{1}{900} + \dfrac{1}{800}}(111.4 - 72.5)$$

$$= 14.47°C$$

$$\theta_1 - \theta_2 = \frac{\dfrac{1}{900}}{\dfrac{1}{1000} + \dfrac{1}{900} + \dfrac{1}{800}}(111.4 - 72.5) = 12.86°C$$

$$\Rightarrow \quad \theta_2 = 72.5 + 14.47 = 87°C$$
$$\theta_1 = 87 + 12.86 = 99.9°C$$
$$h_{fg1} = 2258kJ/kg(@99.9°C)$$
$$h_{fg2} = 2291(@87°C)$$
$$h_{fg3} = 2325kJ/kg(@72°C)$$

$$m_{v1} = \frac{\dfrac{1}{h_{fg1}}}{\dfrac{1}{h_{fg1}} + \dfrac{1}{h_{fg2}} + \dfrac{1}{h_{fg3}}}(m_{v1} + m_{v2} + m_{v3})$$

$$= \left(\frac{\dfrac{1}{2258}}{\dfrac{1}{2258} + \dfrac{1}{2291} + \dfrac{1}{2325}}\right) \times 9$$

$$= 3.044 kg/s$$

$$m_{v2} = \left(\frac{\dfrac{1}{2291}}{\dfrac{1}{2258} + \dfrac{1}{2291} + \dfrac{1}{2325}}\right) \times 9 = 3.000 kg/s$$

$$m_{v3} = \left(\frac{\dfrac{1}{2325}}{\dfrac{1}{2258} + \dfrac{1}{2291} + \dfrac{1}{2325}}\right) \times 9 = 2.956 kg/s$$

Note: if we had just split the flow three ways (3kg/s from each stage) the error would only have been 1.5%!!

$$\phi = m_{v1}h_{fg1} = 3.044 \times 2258 = 6872 kW$$

$$A = \frac{\phi}{U\Delta\theta} = \frac{6873 \times 10^3}{1000(\theta_s - \theta_1)} = \frac{6873 \times 10^3}{(111.4 - 99.9)1000} = 597.7 m^2$$

(This could have been done with any of the other heat exchangers because of it's constant area)

i.e. $A = \dfrac{6873 \times 10^3}{900 \times 12.86} = 593.8 m^2$ (close enough!)

Increasing pressure to $200 kPa (\theta_s = 120.2^\circ C)$

$$\theta_2 - \theta_3 = \left(\frac{\dfrac{1}{800}}{\dfrac{1}{1000} + \dfrac{1}{900} + \dfrac{1}{800}}\right)(120 - 72.5) = 17.74^\circ C$$

$$(\theta_1 - \theta_2) = \left(\frac{\dfrac{1}{900}}{\dfrac{1}{1000} + \dfrac{1}{900} + \dfrac{1}{800}}\right)(120 - 72.5) = 15.77^\circ C$$

$$\Rightarrow \quad \theta_2 = 72.5 + 17.74$$
$$= 90.24^\circ C$$

$$\phi = UA\Delta\theta = 900 \times 594 \times 17.74 = 8430 kW$$

Calculating m_{v2} (and multiply by 3 rather than calculate each one individually)

$$m_{v2} = \frac{8430 \times 10^3}{2283 \times 10^3} = 3.69 \, kg/s$$

$\Rightarrow$ *total evaporation rate* $= 3 \times 3.69 = 11.08 \, kg/s$

Assuming that we are producing product of the same composition from feed of the same composition

Product rate increase $= \dfrac{11.08 - 9}{9} = 23\%$

Also calculate the increase in m_F and m_P

$$m_F = m_{vtotal} + m_P \qquad (1)$$
$$m_F x_F = m_P x_P$$
$$m_F \times 0.02 = m_P \times 0.2 \qquad (2)$$

Solve equations 1 and 2 for m_F and m_P

Substituting Equation 2 into equation 1
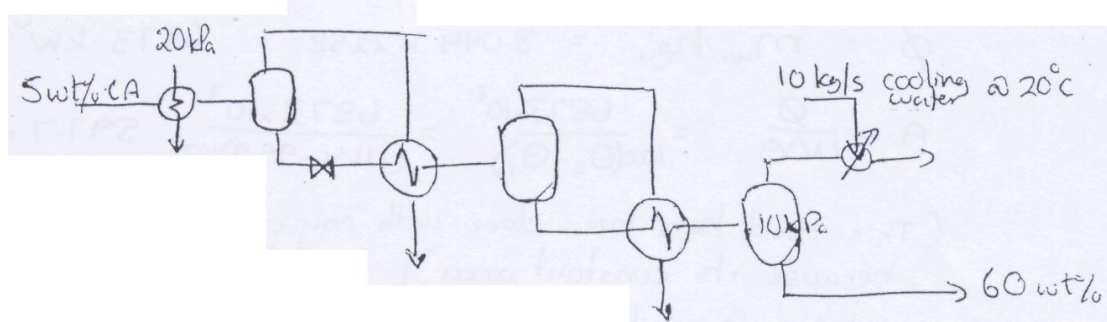$$(11.08 + m_P) \times 0.02 = m_P \times 0.2$$
$$0.2216 + 0.02 m_P = 0.2 m_P$$
$$0.2216 = m_P (0.2 - 0.02)$$
$$m_P = 1.23$$
$$m_F = 11.08 + 1.23 = 12.31$$

Product rate increase $= \dfrac{1.23 - 1}{1} = 23\%$ the same as when calculated for the increase in vapour production.

Example 7

Exit water temp @ 10kPa = 45.8°C
Amount of heat that can be removed with 10kg/s of cooling water assuming it is heated to 45.8°C
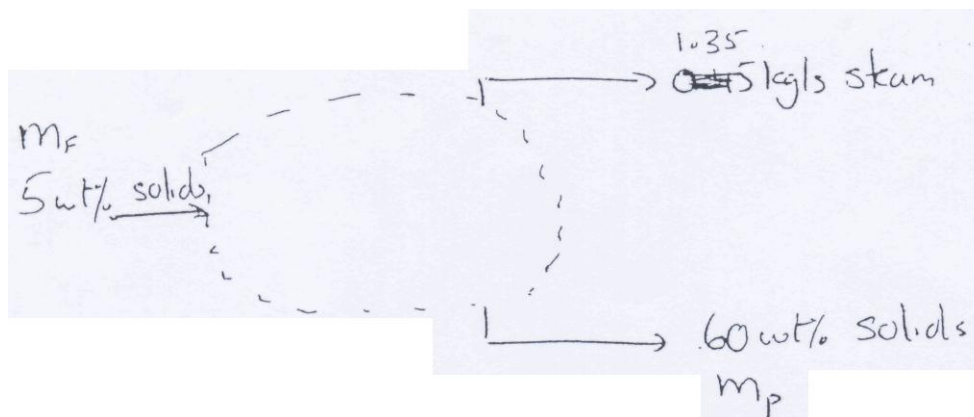
$$\phi_{condenser} = 10 \times 4.186 \times (45.8 - 20)$$
$$= 1080 kW$$

$$\phi = m_{cond} h_{fg3}$$

$$\Rightarrow water\ vapour\ removed\ in\ front\ stage \qquad = \frac{1080 \times 10^3}{2393 \times 10^3}$$

$$= 0.45 kg/s$$

$$assume\ total\ water\ removed \approx 3 \times 0.45$$

$$= 1.35 kg/s$$

SoluteBalance

$$m_F \times 0.05 = m_p \times 0.6 \underline{\hspace{3cm}}(1)$$

Overall Balance

$$m_F = m_p + 1.35 \underline{\hspace{3cm}}(2)$$

Solving eq 1 & 2 gives $\qquad m_p(0.6 - 0.05) = 1.35 \times 0.05$

$$\Rightarrow m_p = 0.123 kg/s$$

$$\Rightarrow m_F = 1.473 kg/s$$

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$U = 1000 W \, / \, m^2 K$

$\theta_p = \theta_{pure} + \theta_{bpe}$

$\theta_{pure} = 45.8^o C \qquad (114.4^o F)$

$assume \, \theta_{bpe} = 10^o F \Rightarrow \theta_{solution} = 124.4^o F$

$60wt\% \; CitricAcid \; gives \, \theta_{bpe} = 7^o F \qquad (\neq 10^o F)$

$assume \theta_{bpe} = 7^o F \, (ends \; up \; good \; guess)$

$\Rightarrow \theta_p \;\; = 121.4^o F = \theta_3$

$\qquad = 49.7^o C$

$\theta s \, @ 121kPa$
$= 104.8°C$

$\theta_s - \theta_3 = 104.8 - 49.7 = 55.1$

$constant \; temperature \; difference \Rightarrow \theta_s - \theta_1 = \theta_1 - \theta_2 = \theta_2 - \theta_3 = 18.4°C$

$\Rightarrow \theta_2 = 49.7 + 18.4 = 68.1°C \Rightarrow h_{fg2} = 2347 kJ \, / \, kg$

$\Rightarrow \phi = m_{w2} h_{fg2} \approx \dfrac{1.35}{3} \times 2347 = 1056 kW$

$\qquad \phi = UA\Delta\theta$

$\Rightarrow A = \dfrac{350.7 \times 10^3}{1000 \times 18.4} = 57.4 m^2$

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Question 8:   Evaporation 2006

(a)   Refer to notes

(b)
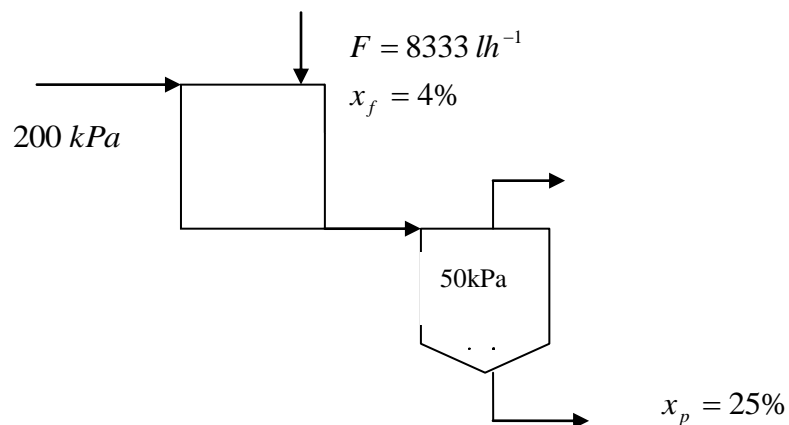
(i) $Area = 68m^2$

$F = 833\ lh^{-1}$ $\theta_f = 70^0 C$

$x_f = 0.04$

$x_p = 0.25$

$P_{steam} = 200\ kPa.a$

$m_F = 2.4\ Kgs^{-1}$ $\left[8333\dfrac{l}{h} \times \dfrac{m^3}{1000l} \times \dfrac{1040kg}{m^3} \times \dfrac{1hr}{3600_s} \right]$

$c_p = 3.8\ kJ\ kg^{-1}K^{-1}$

$m_F x_F = m_p x_p$

$2.4 \times 0.04 = m_p \times 0.25$

$\therefore m_p = 0.384\ kgs^{-1}$

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$$m_v = m_F - m_p = 2.016 \, kgs^{-1}$$

(ii)

$$\theta_{so\ln} = \theta_{sat} + \Delta\theta_{bpr}$$
$$= 81.5 + 0.25 \times 25$$
$$= 87.75^0 C$$

(iii)

$$h_v = 2646.4 + 1.88 \times (25 \times 0.25)$$
$$= 2658 \, kJkg^{-1}$$

$$\phi = m_p h_p - m_f h_f + m_v h_v$$

$$= 0.384 \times (3.8 \times 87.75) - 2.4 \times 3.8 \times 70 + 2.016 \times 2658$$
$$= \quad 128 \qquad\qquad - \quad 638.4 \quad + \quad 5358$$
$$= 4848 \, kW$$

$$\phi = m_s h_{fg \, steam} \qquad h_{fg \, steam} = 2203 \, kJkg^{-1}$$
$$m_s = 2.2 \, kgs^{-1}$$

(iv) $\quad \phi = UA\Delta\theta$

$$U = \frac{4848}{68(120 - 87.75)} = 2210 \, Wm^{-2}K^{-1}$$

$$\eta_S = \frac{m_v}{m_s} = \frac{2.016}{2.2} = 0.91$$
$$= 91\%$$

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Question 9: Evaporation 2007

$5000\,kghr^{-1}$
$x_f = 0.08$

80kPa

60kPa $U = 3000\ Wm^{-2}K^{-1}$

50kPa

40kPa

$x_p = 0.45$
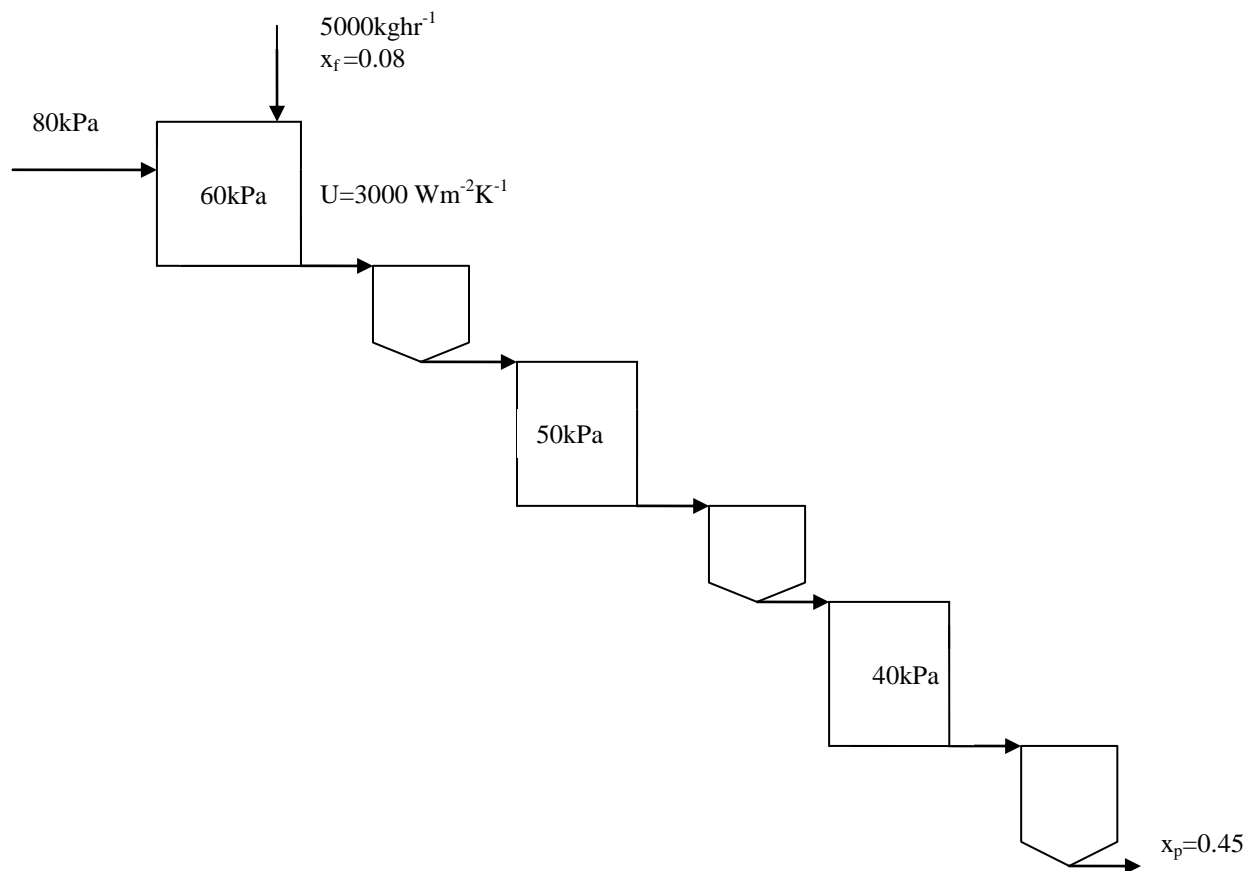
(a) $m_f x_f = m_p x_p$

$1.39 \times 0.08 = m_p \times 0.45$

$m_p = 0.247\ kgs^{-1} = 890\,kgh^{-1}$

$steam\ \ 80kPa\ absolute = 93.5^0\,C$

h_{fg}

			h_{fg}
θ_1	60kPa	86^0C	2291 kJkg^{-1}
θ_2	40kPa	82^0C	2301 kJkg^{-1}
θ_3	40kPa	76^0C	2316 kJkg^{-1}

$m_{v\ total} = 1.39 - 0.247 = 1.143\ kgs^{-1}$

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$$m_{v1} = \frac{\frac{1}{2291}}{\frac{1}{2291} + \frac{1}{2301} + \frac{1}{2316}} \left[m_{v\,total}\right] = 0.383 \quad kgs^{-1}$$

$$m_{v2} = \frac{\frac{1}{2301}}{\frac{1}{2291} + \frac{1}{2301} + \frac{1}{2316}} (1.143) = 0.381 \quad kgs^{-1}$$

$$m_{v3} = \frac{\frac{1}{2316}}{\frac{1}{2291} + \frac{1}{2301} + \frac{1}{2316}} (1.143) = 0.379 \quad kgs^{-1}$$

(b) Stage 1 $\phi = m_v h_{fg_1} = 0.383 \times 2291 \times 10^3$

$$= 877 kW$$

$$\frac{\phi}{h_{fg\,steam}} = m_{steam} = \frac{877 \times 10^3}{2273 \times 10} = 0.386\ kgs^{-1} = 1390\ kgh^{-1}$$

(c) $\phi = U_1 A(\theta_{steam-} \theta_{soln})$

$$A = \frac{877 \times 10^3}{3000(93.5 - 86)} = 39\ m^2$$

$\phi = U_2 A(\theta_1 - \theta_2)$

$$U_2 = \frac{877 \times 10^3}{39(86 - 82)} = 5621 Wm^{-2}K^{-1}$$

$\phi = U_3 A(\theta_2 - \theta_3)$

$$U_3 = \frac{877 \times 10^3}{39(82 - 76)} = 3758\ Wm^{-2}K^{-1}$$

(d) $m_v = 1.143\ kgs^{-1}$

$@\ 40kPa, \quad 76^o C \qquad h_g = 2637\ kJkg^{-1}$

$m_v h_v + m_w h_w = (m_v + m_w)h_{vw}$

$$water \ @ \ 10^0 C$$
$$h_w = 42 \ kJkg^{-1}$$

$$if \ tempature \ of \ condensed \ water = 30^0 C$$
$$h_{vw} = 2556 \ kJkg^{-1}$$

$$1.143 \times 2637 + m_w \times 42 = (1.143 + m_w)2556$$
$$3014 + 42m_w = 292105 + 2556m_w$$
$$m_w = 0.04 \ kgs^{-1}$$
$$= 132 \ kgh^{-1}$$

Question 10 – (Evaporation 2008)

(a)

$$m_v = 1500 \, kg \, h^{-1}$$
$$= 0.417 \, kg \, s^{-1}$$

$$\phi = m_v \, h_{fg} \qquad h_{fg} \, @ \, 100^0 C = 2257 \, kJ \, kg^{-1}$$
$$= 0.417 \times 2257 \times 10^3 = 941.2 \, kW$$

$$\theta_s \, @ \, 100 \, kPag \qquad 0.2013 \, MPa.a$$
$$\therefore \theta_s = 120^0 C$$

$$U = \frac{\phi}{A(\theta_{steam} - \theta_s)}$$
$$= \frac{941.2 \times 10^3}{20(120 - 100)} \qquad = 23\,5\,3 \, Wm^{-2} \, K^{-1}$$

(b)

$$20m^3 \, cleaning \, solution$$
$$assume \, density = 1000 \, kg \, m^{-3}$$

$$mass = 20 \times 10^3 \, kg$$
$$concentrated \, in \, 16 \, hrs$$

$$M_f = \frac{20 \times 10^3}{16 \times 3600} = 0.347 \, kg \, s^{-1}$$

$$m_p = \frac{m_f x_f}{x_p} = \frac{0.347 \times 0.005}{0.15} = 0.0116 \, kg \, s^{-1}$$

$From \, During \, chart \, det \, er \, min \, e \; \Delta\theta_{bpr}$

$$100^0 C = 212^o F$$
$Guess \; \Delta\theta_{bpr} \; 6^o F \quad confirmed \, on \, During \, chat$

$$\Delta\theta_{bpr} = 3.33^o C$$

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$$\theta_{so\ln} = 103.33^{o}C$$

$$h_{v} = h_{vsat} + c_{pg}(\Delta\theta_{bpr})$$

$$= 2676 + 2.04(3.33)$$
$$= 2683\,kJ\,kg^{-1}$$

$$h_{f} = 4200 \times 60 = 252\,kJ\,kg^{-1}$$
$$h_{p} = 431.6\,kJ\,kg^{-1}$$

$$\phi = m_{p}h_{p} + m_{v}h_{v} - m_{f}\,h_{f}$$

$$= 0.0116 \times 431.6 + 0.3354 \times 2683 - 0.347 \times 252$$
$$= 817.4\,kW$$

$$A = \frac{817.4 \times 10^{-3}}{2353(120 - 103.33)} = 20.8m^{2}$$

Evaporator has insufficie nt area to do job required as evaporator is only $20m^{2}$

(C)

$$x_{f} = 0.1$$
$$x_{f} = 0.2$$

$$m_{f} \times 0.1 = m_{p} \times 0.2$$

$$m_{f} = m_{p} + m_{v}$$
$$= m_{p} + 0.417$$

$$0.1(m_{p} + 0.417) = 0.2m_{p}$$
$$m_{p} = 0.417\,kg\,s^{-1}$$
$$m_{f} = 0.834$$

$$h_f = 252 \, kJ \, kg^{-1}$$
$$h_p = 419.2 \, kJ \, kg^{-1} \, @ \, 100^o C \, no \, BPR$$
$$h_v = 2676 \, kJ \, kg^{-1} \, @ \, 100^o C$$

$$\phi = m_p h_p + m_v h_v - m_f h_f$$

$$= 0.417 \times 419.2 + 0.417 \times 2676 - 0.834 \times 252$$
$$= 1080.5 \, .kw$$

$$\eta = \frac{m_v h_{fg} \, @ \, 100^0 C}{\phi}$$
$$= \frac{0.417 \times 2257}{1080.5}$$

$$= 0.87$$
$$= 87\%$$

(ii)   Refer to notes