Problem 1

Sugar balance Overall system: In – out + ~~gen~~ –~~cons~~ = ~~accum~~

$$0.5F - 0.65P = 0 \quad \rightarrow \quad P = \frac{0.5(50000\frac{kg}{h})}{0.65} = 38462\,\frac{kg}{h}$$

Water balance Overall system:

$$0.5F - 0.35P - (W1 + W2 + W3 + W4) = 0$$

assuming $W = W1 + W2 + W3 + W4$ (Eq. 1)

$$\rightarrow \quad W = 0.5\left(50000\,\frac{kg}{h}\right) - 0.35\left(38462\,\frac{kg}{h}\right) = 11538\,\frac{kg}{h}$$

From the problem we know that $W1 = W2$ and $W3 = W4$

Where $W4 = 0.1(0.5F)$ $\rightarrow$ $W4 = (0.1)(0.5)\left(50000\,\frac{kg}{h}\right) = 2500\,\frac{kg}{h}$

Substituting in Eq. 1

$$W = 2W1 + 2W4 \quad \rightarrow \quad W1 = \frac{W - 2W4}{2} = \frac{11538\frac{kg}{h} - 2(2500\frac{kg}{h})}{2} = 3269\,\frac{kg}{h}$$

Total balance Stage I:

$$F - W1 - A = 0 \quad \rightarrow \quad A = F - W1 = 50000\,\frac{kg}{h} - 3269\,\frac{kg}{h} = 46731\,\frac{kg}{h}$$

Sugar balance Stage I:

$$0.5F - x_{sugar,A}A = 0 \quad \rightarrow \quad x_{sugar,A} = \frac{0.5F}{A} = \frac{(0.5)(50000\frac{kg}{h})}{46731\frac{kg}{h}} = 0.5350$$

Composition balance in A:

$$x_{sugar,A} + x_{water,A} = 1 \quad \rightarrow \quad x_{water,A} = 1 - x_{sugar,A} = 1 - 0.5350 = 0.465$$

Total balance Stage II:

$$A - W2 - B = 0 \quad \rightarrow \quad B = A - W2 = 46731\,\frac{kg}{h} - 3269\,\frac{kg}{h} = 43462\,\frac{kg}{h}$$

Sugar balance Stage II:

$$0.535A - x_{sugar,B}B = 0 \;\; \rightarrow \;\; x_{sugar,B} = \frac{0.535A}{B} = \frac{(0.535)(46731\frac{kg}{h})}{43462\frac{kg}{h}} = 0.5752$$

Composition balance in B:

$$x_{sugar,B} + x_{water,B} = 1 \;\; \rightarrow \;\; x_{water,B} = 1 - x_{sugar,B} = 1 - 0.5752 = 0.4248$$

Total balance Stage III:

$$B - W3 - C = 0 \;\; \rightarrow \;\; C = B - W3 = 43462\frac{kg}{h} - 2500\frac{kg}{h} = 40962\frac{kg}{h}$$

Sugar balance Stage III:

$$0.5752B - x_{sugar,C}C = 0 \;\; \rightarrow \;\; x_{sugar,C} = \frac{0.5752B}{C} = \frac{(0.5752)(43462\frac{kg}{h})}{40962\frac{kg}{h}} = 0.6103$$

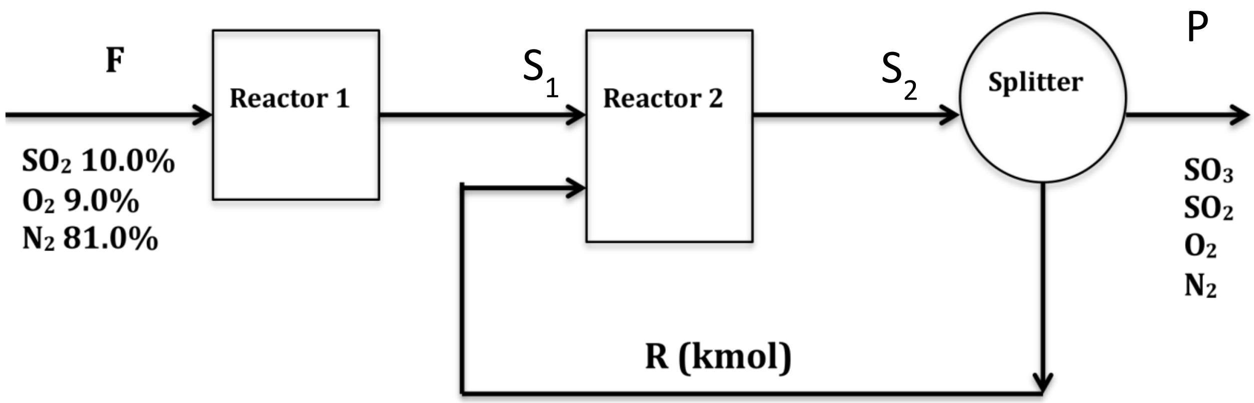
Composition balance in B:

$$x_{sugar,C} + x_{water,C} = 1 \;\; \rightarrow \;\; x_{water,C} = 1 - x_{sugar,C} = 1 - 0.6103 = 0.3897$$

Results table:

	F	P	W1	W2	W3	W4	A	B	C
Flow (kg/h)	50000	38462	3269	3269	2500	2500	46731	43462	40962
Composition Sugar (%w/w)	0.5	0.65					0.5350	0.5752	0.6103
Composition water (%w/w)	0.5	0.35	1	1	1	1	0.465	0.4248	0.3897

Problem 2



a) Total system balance

$P_{SO3} = X_{SO2,F} * F * X_{overall} = 0.1 * 100 * 0.95 = 9.5$ kmol

$P_{SO2} = X_{SO2,F} * F * (1 - X_{overall}) = 0.1 * 100 * (1 - 0.95) = 0.5$ kmol

$$P_{O2} = \frac{X_{O2,F} * F * -(X_{SO2,F} * F * X_{overall})}{v'} = \frac{0.09 * 100 - 0.1 * 100 * 0.95}{2} = 4.25 \text{ kmol}$$

$P_{N2} = X_{N2,F} * F = 0.81 * 100 = 81$ kmol

$P = P_{SO3} + P_{SO2} + P_{O2} + P_{N2} = 95.25$ kmol

Reactor 1 balance

$S1_{SO2} = X_{SO2,F} * F (1 - X_{R1}) = 0.1 * 100 * (1-0.75) = 2.5$ kmol

$S1_{SO3} = X_{SO2,F} * F * X_{R1} = 0.1 * 100 * 0.75 = 7.5$ kmol

$$S1_{O2} = \frac{X_{O2,F} * F - (X_{SO2,F} * F * X_{R1})}{v} = \frac{0.09 * 100 - 0.1 * 100 * 0.75}{2} = 5.25\ kmol$$

$S1_{N2} = X_{N2,F} * F = 0.81 * 100 = 81$ kmol

$S1 = 96.25$ kmol

b)

$$X_{R2} = 0.65 = \frac{[S1 * X_{SO2,S1} + R * X_{SO2,R}] - S2 * X_{SO2,R}}{[S1 * X_{SO2,S1} + R * X_{SO2,R}]}$$

$S2 = P + R$

Composition of streams P and R are identical

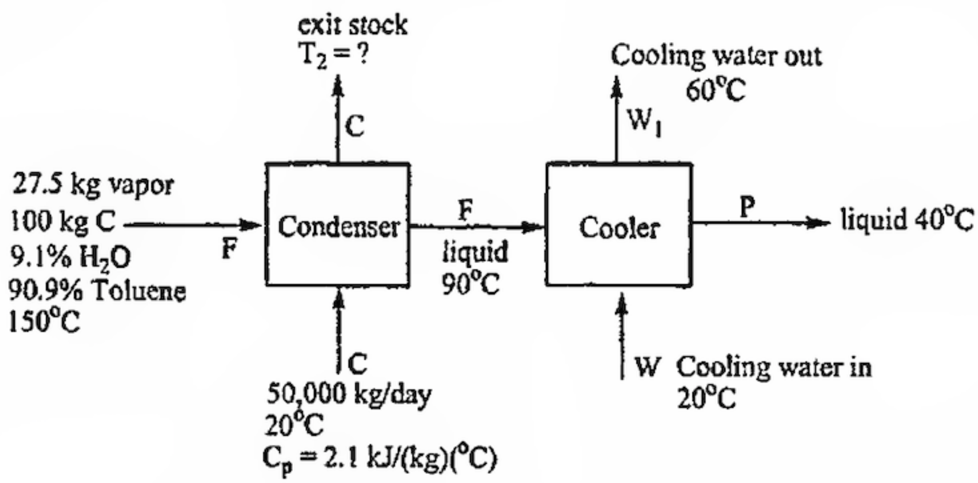
$$X_{SO2,R} = X_{SO,P} = \frac{P_{SO2}}{P_{SO3} + P_{SO3} + P_{O2} + P_{N2}} = 2.25 * 10^{-3} \left[\frac{kmol}{kmol}\right]$$

Solve for R

R = 110 [kmol]

Problem 3

24.35



Basis: 1 day

$$\frac{27.5 \text{ kg F}}{100.0 \text{ kg C}}\left|\frac{50{,}000 \text{ kg C}}{\text{day}}\right|\frac{1 \text{ day}}{} = 13{,}750 \text{ kg F}$$

$$\frac{13{,}750 \text{ kg F}}{}\left|\frac{9.1 \text{ kg } H_2O}{100 \text{ kg F}}\right. = 1{,}251.25 \text{ kg } H_2O$$

13,750 kg F − 1251.25 kg H_2O = 12,498.75 kg toluene.

<u>Energy balance at condenser:</u>

The energy balance reduces to $\Delta H = 0$

$\Delta H_C + \Delta H_F = 0$

(continued)

$$m_C\int_{20}^{T_2}C_p dT + m_{H_2O}\left[\int_{150}^{100}C_p dT - \Delta H_{vap\ at\ 100°C} + \int_{100}^{90}C_p dT\right]$$

$$+m_{tol}\left[\int_{150}^{111}C_p dT - \Delta H_{vap\ at\ 111°C} + \int_{111}^{90}C_p dT\right] = 0$$

$$\frac{50{,}000\ \text{kg}}{}\left|\frac{2.1\ \text{kJ}}{(\text{kg})\ (°\text{C})}\right|\frac{T_2 - 20°\text{C}}{}$$

$$+ 1{,}251.25\ \text{kg}\ H_2O\left[\frac{2.1\ \text{kJ}}{(\text{kg})\ (°\text{C})}\left|\frac{(100-150)°\text{C}}{}\right. - \frac{2260\ \text{kJ}}{\text{kg}} + \frac{4.2\ \text{kJ}}{(\text{kg})\ (°\text{C})}\left|\frac{(90-100)\ °\text{C}}{}\right.\right]$$

$$+ 12{,}498.75\ \text{kg tol}\left[\frac{1.3\ \text{kJ}}{(\text{kg})(°\text{C})}\left|\frac{(111-150)\ °\text{C}}{}\right. - \frac{230\ \text{kJ}}{\text{kg}} + \frac{1.7\ \text{kJ}}{(\text{kg})\ (°\text{C})}\left|\frac{(90-111)°\text{C}}{}\right. = 0\right]$$

$$105{,}000\ T_2 - 2{,}100{,}000 - 3{,}011{,}758.75 - 3{,}954{,}604.5 = 0$$

(a) $$T_2 = \frac{9{,}066{,}363.25}{105{,}000} = \boxed{86.3°\text{C}}$$

Enthalpy balance at cooler:

$$\Delta H = 0$$

$$(\Delta H_W^{out} - \Delta H_W^{in}) - (\Delta H_p - \Delta H_F) = 0$$

$$m_W\int_{20}^{60}C_p dT - \left[m_{H_2O}\int_{86.34}^{40}C_p dT - m_{tol}\int_{86.34}^{40}C_p dT\right] = 0$$

$$\frac{m_W}{}\left|\frac{4.2\ \text{kJ}}{(\text{kg})(°\text{C})}\right|\frac{(60-20)°\text{C}}{} = \frac{1{,}251.25\ \text{kg}\ H_2O}{}\left|\frac{4.2\ \text{kJ}}{(\text{kg})(°\text{C})}\right|\frac{(40-90)°\text{C}}{}$$

$$+\frac{12498.75\ \text{kg tol}}{}\left|\frac{1.7\ \text{kJ}}{(\text{kg})(^\circ\text{C})}\right|\frac{(40-90)^\circ\text{C}}{}$$

$$m_W\ 168\ \frac{\text{kJ}}{\text{kg}} - 262{,}762\ \text{kJ} - 1{,}062{,}394\ \text{kJ}$$

$$m_w = \frac{1{,}325{,}156\ \text{kJ}}{168\ \text{kJ/kg}} = \boxed{7{,}887\ \text{kg}\ H_2O}$$