CHEMICAL PROCESS CALCULATIONS

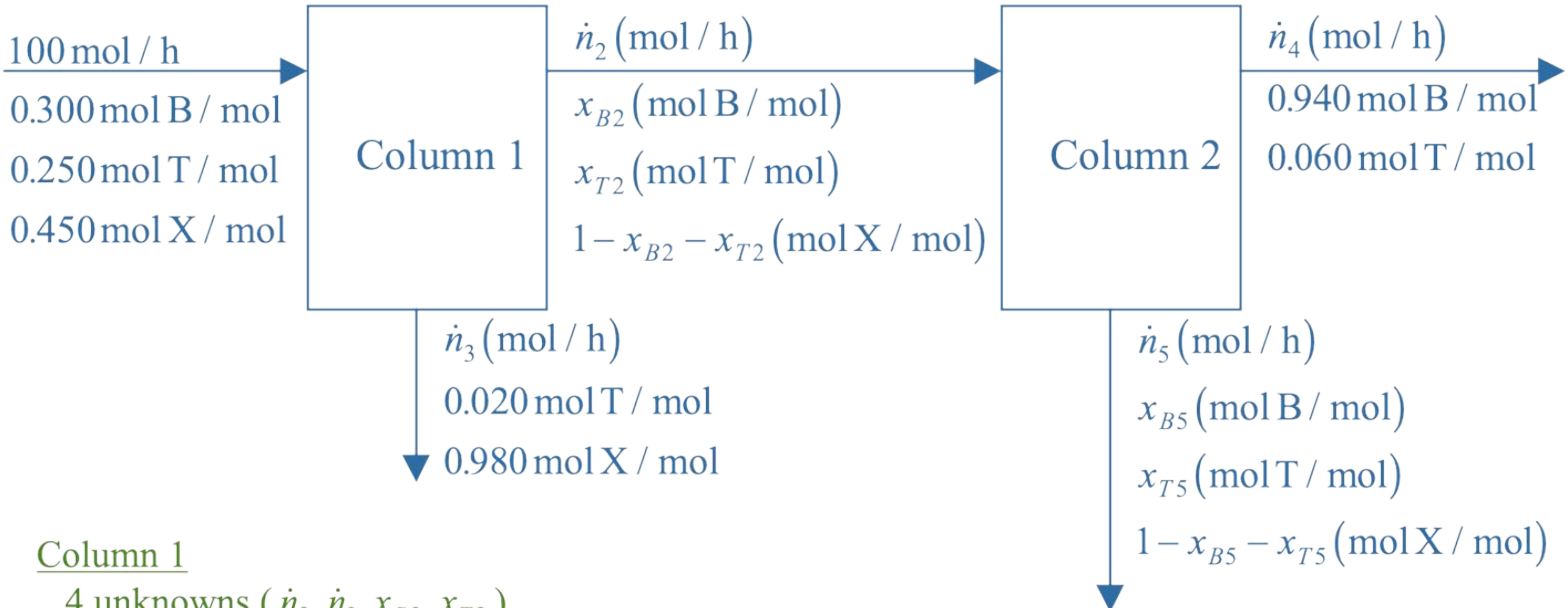
Lecture #7: August 24, 2023

A liquid mixture containing 30.0 mole% benzene (B), 25.0% toluene (T), and the balance xylene (X) is fed to a distillation column. The bottoms product contains 98.0 mole% X and no B, and 96.0% of the X in the feed is recovered in this stream. The overhead product is fed to a second column. The overhead product from the second column contains 97.0% of the B in the feed to this column. The composition of this stream is 94.0 mole% B and the balance T.

Draw and label a flowchart of this process and do the degree-of-freedom analysis to prove that for an assumed basis of calculation, molar flow rates and compositions of all process streams can be calculated from the given information. Write in order the equations you would solve to calculate unknown process variables. In each equation (or pair of simultaneous equations), highlight the variable(s) for which you would solve. Calculate:

(a) the percentage of the benzene in the process feed (i.e., the feed to the first column) that emerges in the overhead product from the second column and

(b) the percentage of toluene in the process feed that comes out in the bottom product from the second column.



Column 1

4 unknowns ($\dot{n}_2, \dot{n}_3, x_{B2}, x_{T2}$)

–3 balances

– 1 recovery of X in bot. (96%)

0 DF

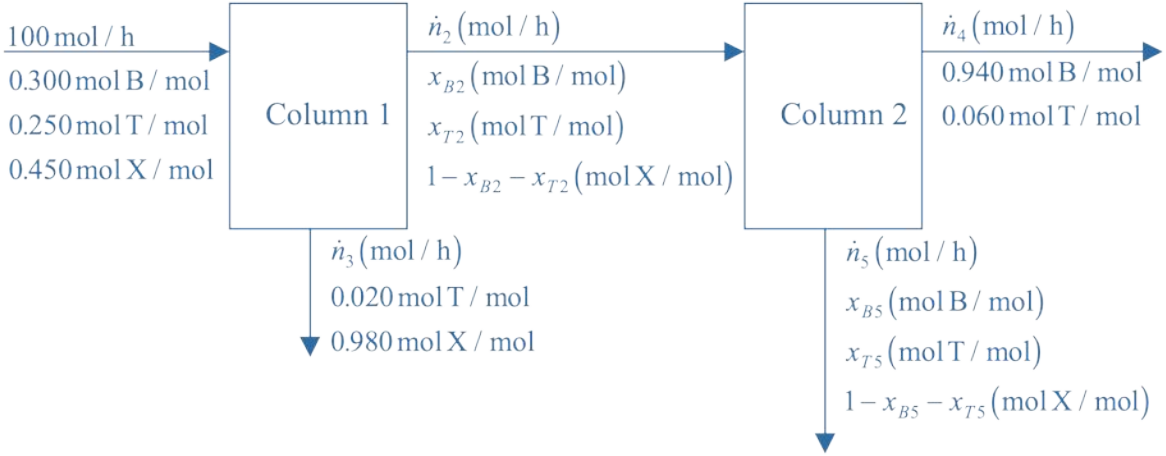
Column 2:

$\dot{n}_4 \;\; \dot{n}_5 \;\; x_{B5} \;\; x_{T5}$

– 3 balances

– 1 recovery of B in top (97%)

0 DF



Column 1

96% X recovery: $0.96(0.450)(100) = 0.98\underline{\underline{\dot{n}_3}}$

Total mole balance: $100 = \underline{\underline{\dot{n}_2}} + \dot{n}_3$

B balance: $0.300(100) = \underline{\underline{x_{B2}}}\dot{n}_2$

T balance: $0.250(100) = \underline{\underline{x_{T2}}}\dot{n}_2 + 0.020\dot{n}_3$

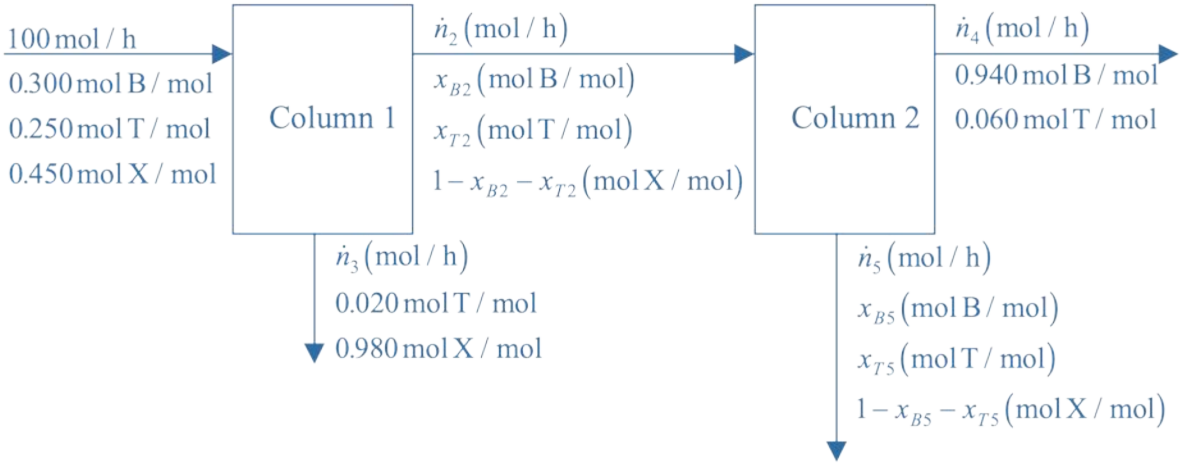
Column 2

97% B recovery: $0.97x_{B2}\dot{n}_2 = 0.940\underline{\underline{\dot{n}_4}}$

Total mole balance: $\dot{n}_2 = \dot{n}_4 + \underline{\underline{\dot{n}_5}}$

B balance: $x_{B2}\dot{n}_2 = 0.940\dot{n}_4 + \underline{\underline{x_{B5}}}\dot{n}_5$

T balance: $x_{T2}\dot{n}_2 = 0.060\dot{n}_4 + \underline{\underline{x_{T5}}}\dot{n}_5$



Column 1

96% X recovery: $0.96(0.450)(100) = 0.98\dot{n}_3$

Total mole balance: $100 = \dot{n}_2 + \dot{n}_3$

B balance: $0.300(100) = x_{B2}\dot{n}_2$

T balance: $0.250(100) = x_{T2}\dot{n}_2 + 0.020\dot{n}_3$

Column 2

97% B recovery: $0.97x_{B2}\dot{n}_2 = 0.940\dot{n}_4$

Total mole balance: $\dot{n}_2 = \dot{n}_4 + \dot{n}_5$

B balance: $x_{B2}\dot{n}_2 = 0.940\dot{n}_4 + x_{B5}\dot{n}_5$

T balance: $x_{T2}\dot{n}_2 = 0.060\dot{n}_4 + x_{T5}\dot{n}_5$

$\dot{n}_3 = 44.1 \text{ mol / h}$ $\qquad$ $\dot{n}_2 = 55.9 \text{ mol / h}$

$x_{B2} = 0.536 \text{ mol B / mol}$ $\qquad$ $x_{T2} = 0.431 \text{ mol T / mol}$

$\dot{n}_4 = 30.95 \text{ mol / h}$ $\qquad$ $\dot{n}_5 = 24.96 \text{ mol / h}$

$x_{B5} = 0.036 \text{ mol B / mol}$ $\qquad$ $x_{T5} = 0.892 \text{ mol T / mol}$

Overall benzene recovery : $\dfrac{0.940(30.95)}{0.300(100)} \times 100\% = 97\%$

Overall toluene recovery : $\dfrac{0.892(24.96)}{0.250(100)} \times 100 = 89\%$

CHEMICAL PROCESS CALCULATIONS

Lecture #8: August 28, 2023

A sedimentation process is to be used to separate pulverized coal from slate. A suspension of finely divided particles of galena (lead sulfide, SG = 7.44) in water is prepared. The overall specific gravity of the suspension is 1.48.

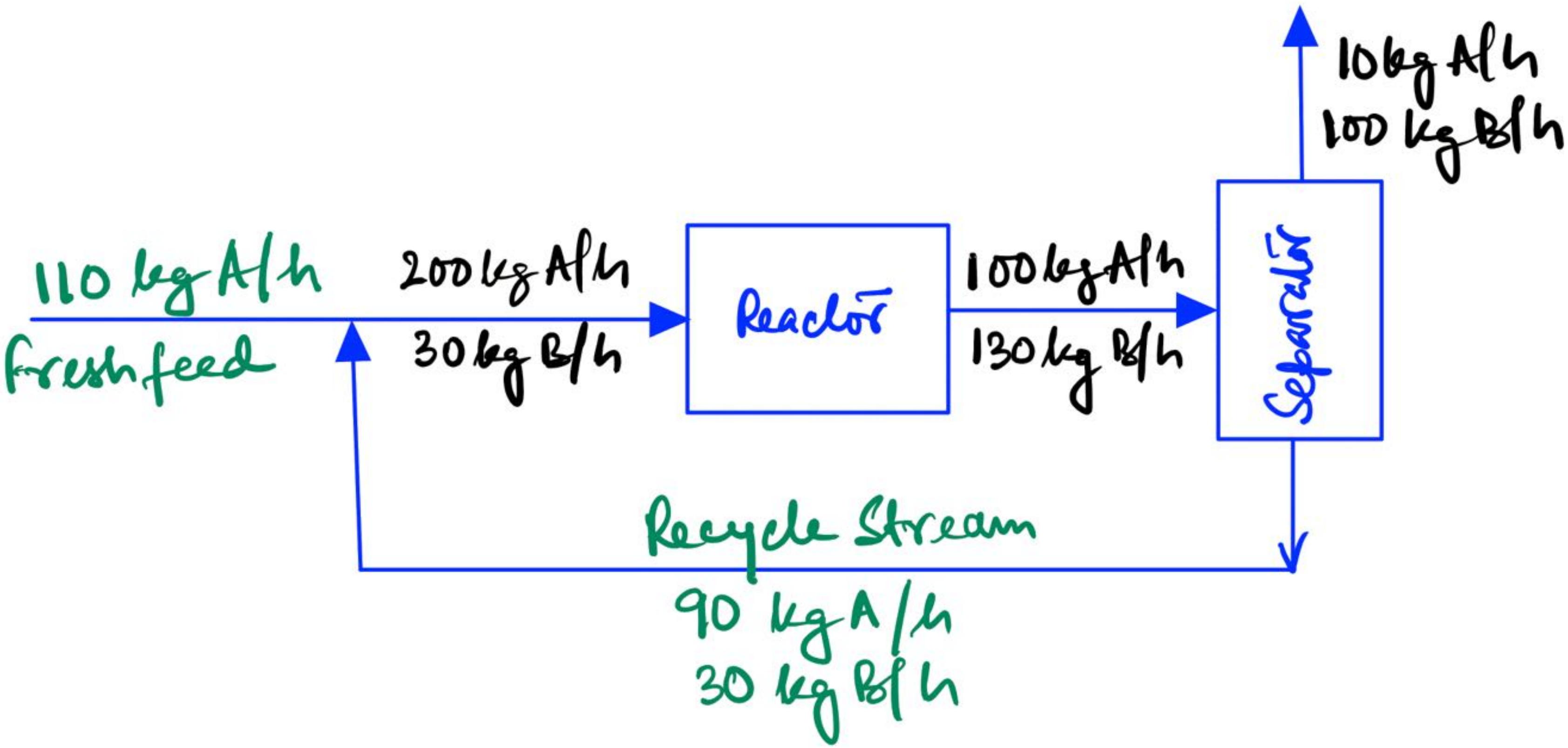
Four hundred kilograms of galena and a quantity of water are loaded into a tank and stirred to obtain a uniform suspension with the required specific gravity. Draw and label the flowchart (label both the masses and volumes of the galena and water), do the degree-of-freedom analysis, and calculate how much water (m^3) must be fed to the tank.

CHEMICAL PROCESS CALCULATIONS

(Recycle and Bypass: Material balance of recycle & bypass units)

Lecture #9: September 04, 2023

Recycle



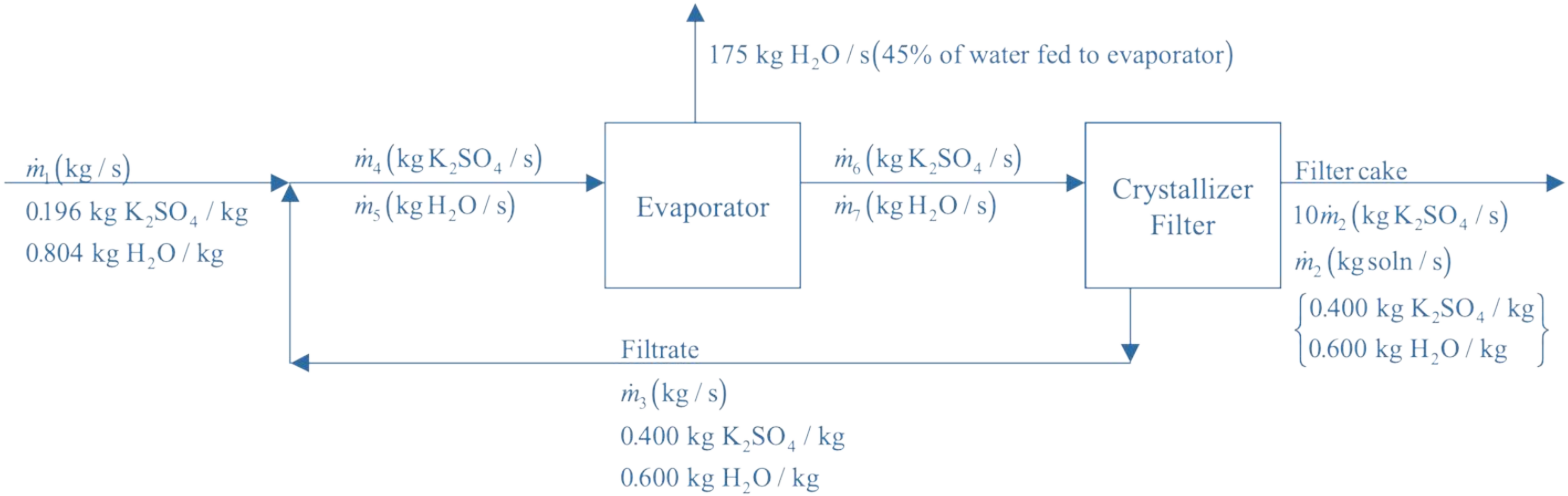
10 kg A/h
100 kg B/h
110 kg A/h
fresh feed
200 kg A/h
30 kg B/h
Reactor
100 kg A/h
130 kg B/h
Separator
Recycle Stream
90 kg A/h
30 kg B/h

An evaporation–crystallization is used to obtain solid potassium sulfate from an aqueous solution of this salt. The fresh feed to the process contains 19.6 wt% K_2SO_4. The wet filter cake consists of solid K_2SO_4 crystals and a 40.0 wt% K_2SO_4 solution, in a ratio 10 kg crystals/kg solution. The filtrate, also a 40.0% solution, is recycled to join the fresh feed. Of the water fed to the evaporator, 45.0% is evaporated. The evaporator has a maximum capacity of 175 kg water evaporated/s.

(a) Assume the process is operating at maximum capacity. Draw and label a flowchart and do the degree-of-freedom analysis for the overall system, the recycle–fresh feed mixing point, the evaporator, and the crystallizer. Then write in an efficient order of the equations that you would solve to determine all unknown stream variables. In each equation, highlight the variable for which you would solve.

(b) Calculate the maximum production rate of solid K_2SO_4, the rate at which fresh feed must be supplied to achieve this production rate, and the ratio kg recycle/kg fresh feed.

(c) Calculate the composition and feed rate of the stream entering the crystallizer if the process is scaled to 75% of its maximum capacity.



Basis of calculation – 175 kg W evaporated/s

Overall process

2 unknowns ($\dot{m}_1, \dot{m}_2$)

− 2 balances

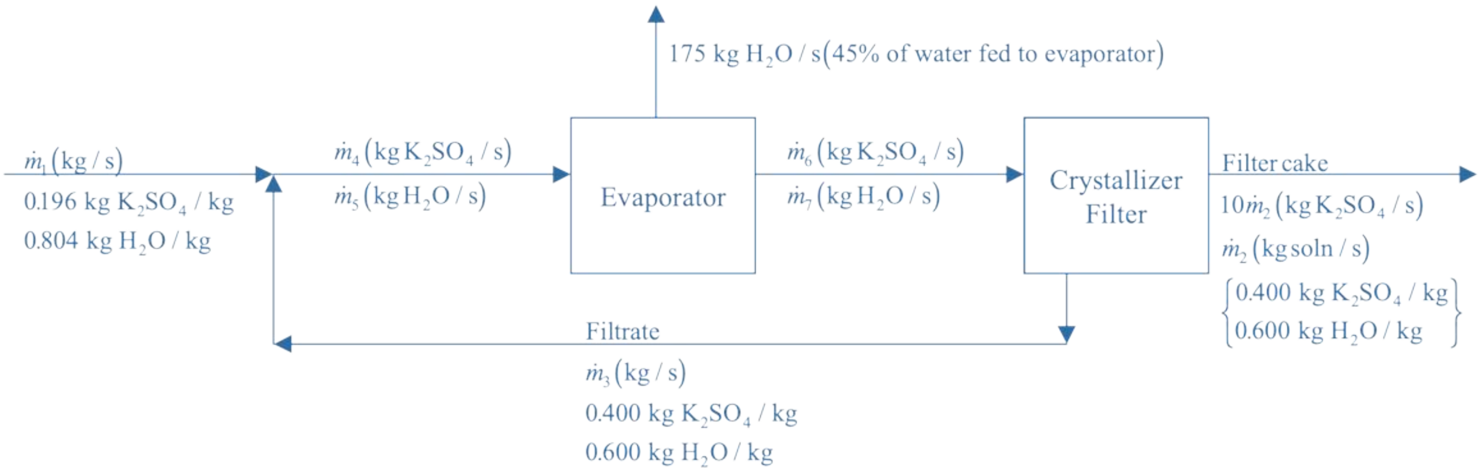
0 DoF

Mixing point

4 unknowns ($\dot{m}_1, \dot{m}_3, \dot{m}_4, \dot{m}_5$)

− 2 balances

2 DoF



Evaporator

4 unknowns ($\dot{m}_4, \dot{m}_5, \dot{m}_6, \dot{m}_7$)
− 2 balances
− 1 % evaporation

1 DOF

Crystallizer

4 unknowns ($\dot{m}_2, \dot{m}_3, \dot{m}_6, \dot{m}_7$)
− 2 balances

2 DOF

Overall balance

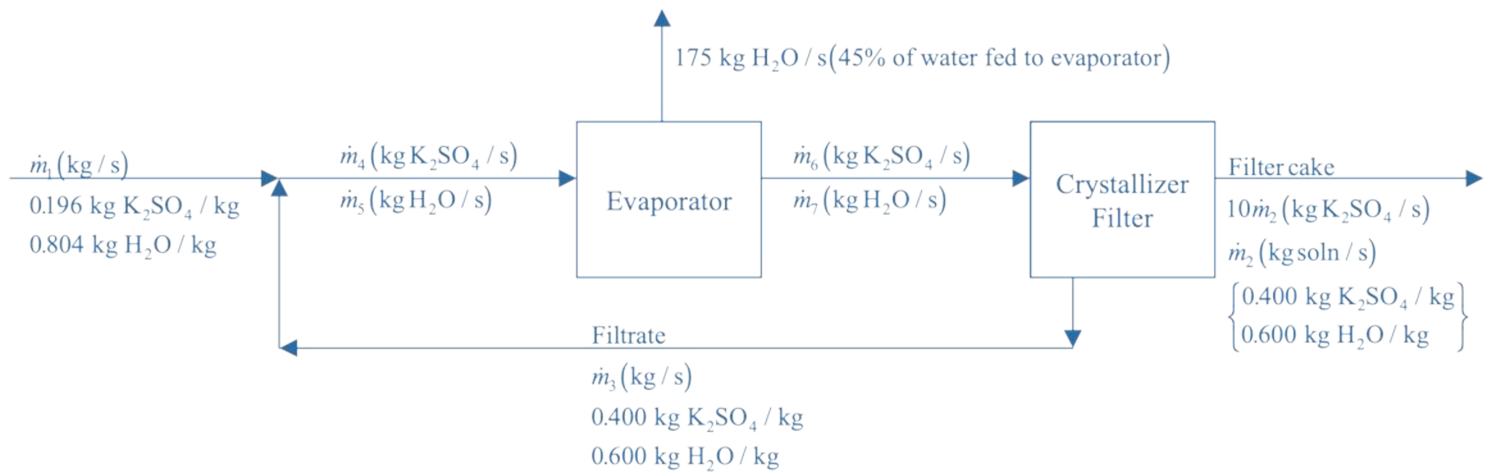
→ mass
→ component } $\dot{m}_1, \dot{m}_2$

% evaporation

⇒ $\dot{m}_5$

Mixing point balance

→ mass
→ component } $\dot{m}_3, \dot{m}_4$



% evaporation

$175\ kg/s = 0.450\,\dot{m}_5$

Evaporator balance

→ K balance

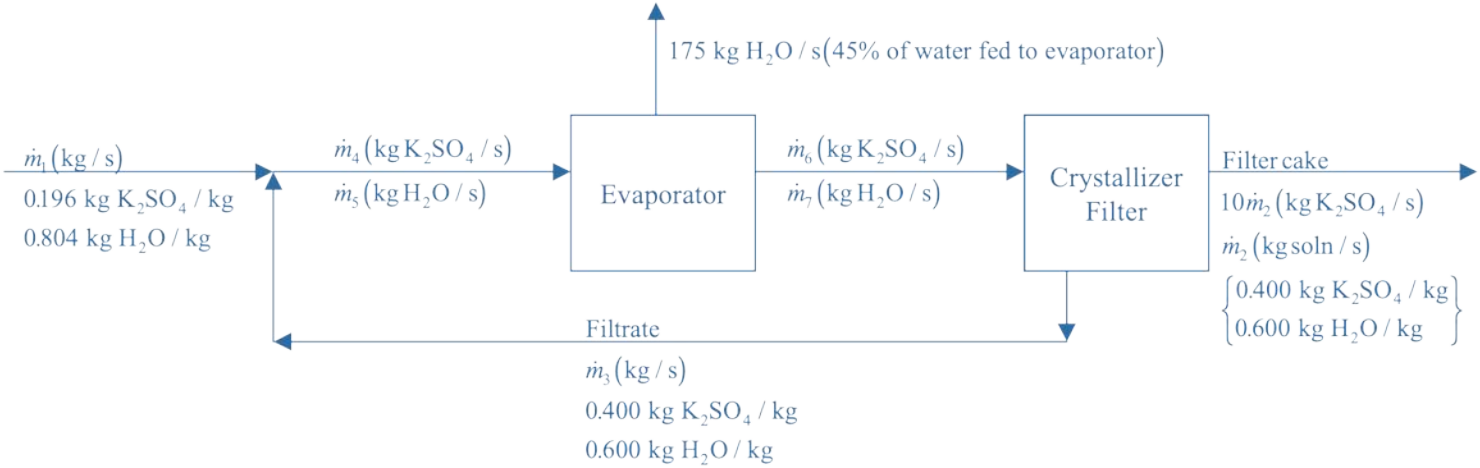
→ W balance $\Big\}\ \dot{m}_6, \dot{m}_7$

Overall mass balance

$\dot{m}_1 = 175 + 10\dot{m}_2 + \dot{m}_2$

Overall K balance

$0.196\,\dot{m}_1 = 10\dot{m}_2 + 0.400\,\dot{m}_2$



Mixing point – W balance

$$0.804\,\dot m_1 + 0.600\,\dot m_3 = \dot m_5$$

Mixing point – mass balance

$$\dot m_1 + \dot m_3 = \dot m_4 + \dot m_5$$

Evaporator – K balance

$$\dot m_6 = \dot m_4$$

Evaporator – W balance

$$\dot m_5 = 175 + \dot m_7$$

Fresh feed rate

$\rightarrow \dot m_1$ kg/s

Production rate

$\rightarrow 10\,\dot m_2$ kg K/s

Recycle ratio

$\rightarrow \dfrac{\dot m_3}{\dot m_1}$ $\dfrac{\text{kg recycle}}{\text{kg fresh feed}}$

SCALING

CHEMICAL PROCESS CALCULATIONS

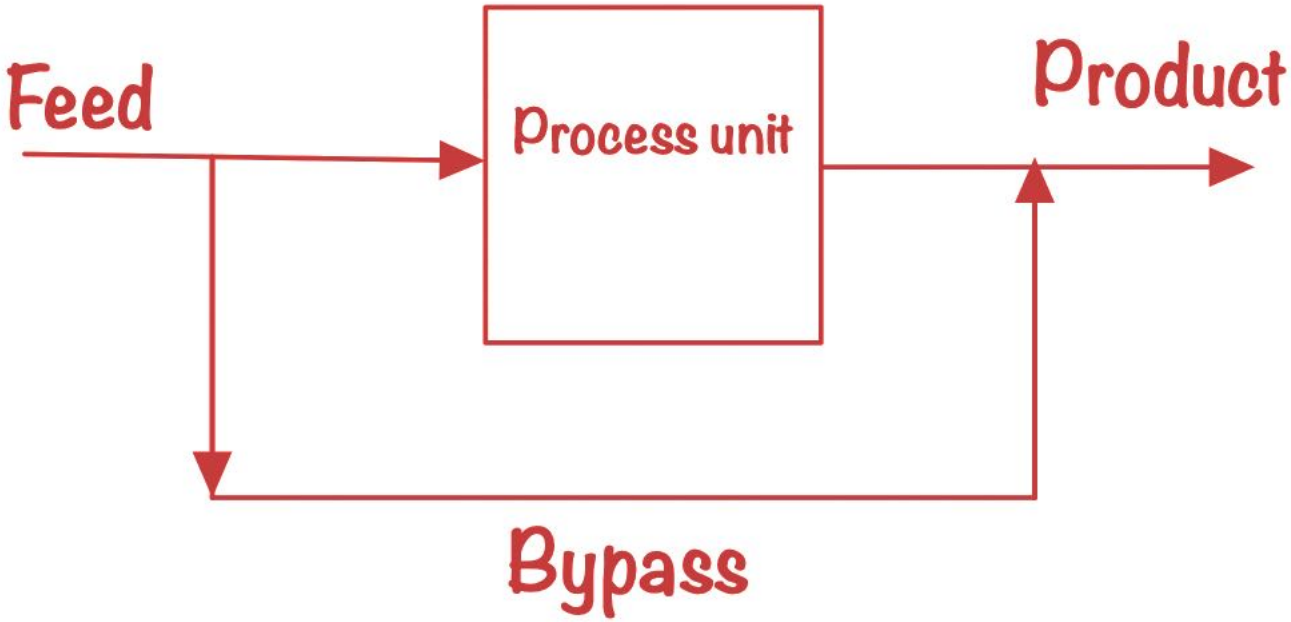
(Recycle and Bypass: Material balance of recycle & bypass units)

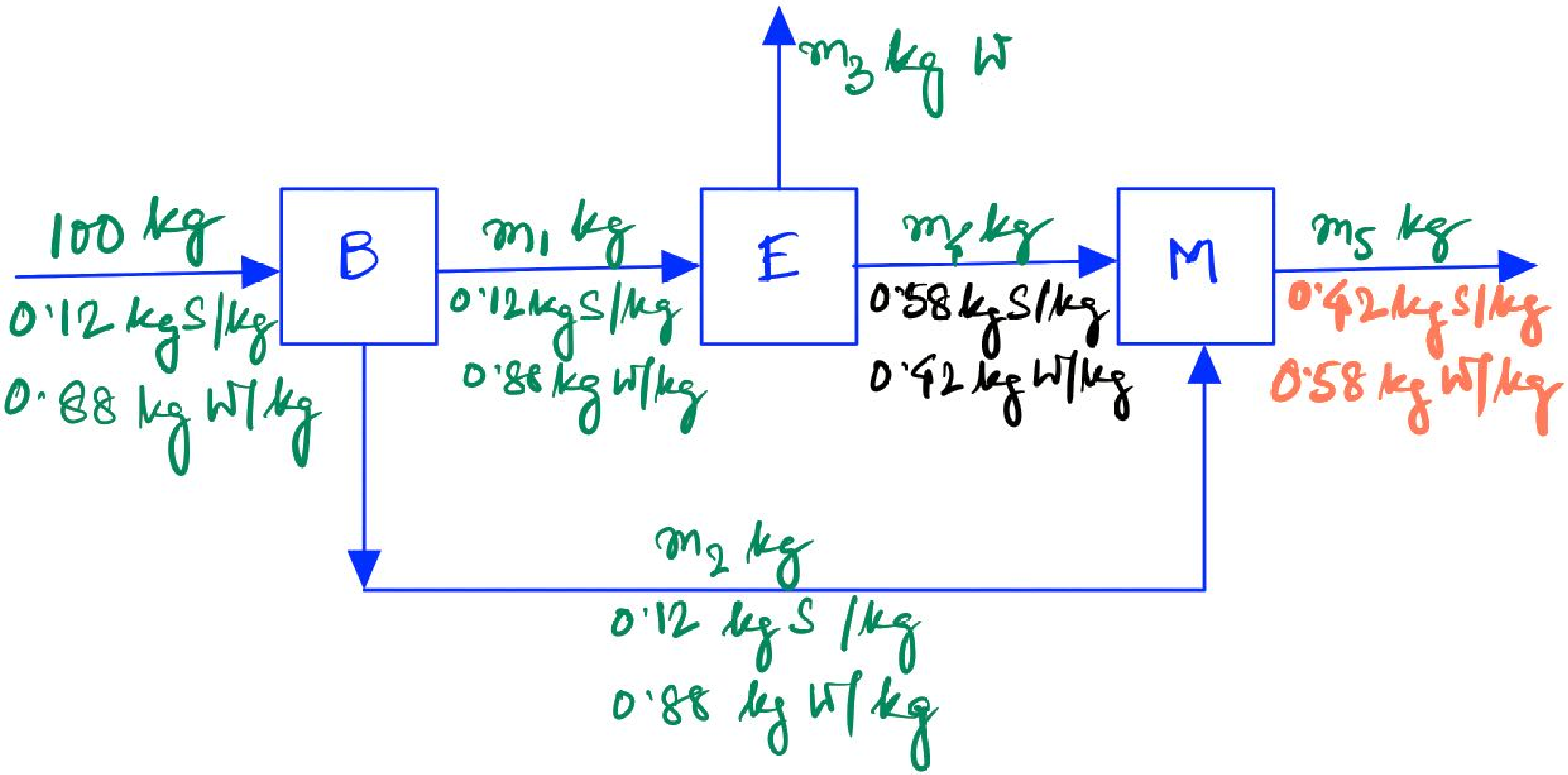
Lecture #10: September 11, 2023

Fresh orange juice contains 12.0 wt% solids and the balance water, and concentrated orange juice contains 42.0 wt% solids. Initially a single evaporation process was used for the concentration, but volatile constituents of the juice escaped with the water, leaving the concentrate with a flat taste. The current process overcomes this problem by bypassing the evaporator with a fraction of the fresh juice. The juice that enters the evaporator is concentrated to 58 wt% solids, and the evaporator product stream is mixed with the bypassed fresh juice to achieve the desired final concentration.

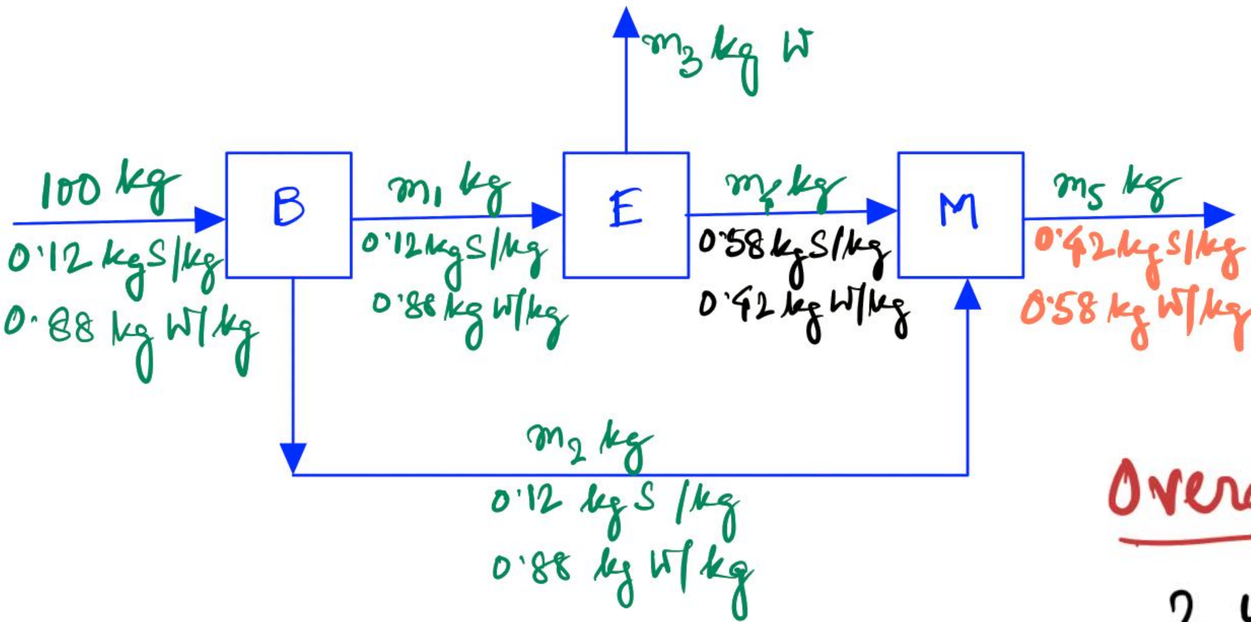
(a) Draw and label a flowchart of this process, neglecting the vaporization of everything in the juice but water. Then perform the degree-of-freedom analysis for the overall system, the evaporator, and the bypass–evaporator product mixing point, and write in order the equations you would solve to determine all unknown stream variables. In each equation, highlight the variable for which you would solve.

(b) Calculate the amount of product (42% concentrate) produced per 100 kg fresh juice fed to the process and the fraction of the feed that bypasses the evaporator.


Feed
Process unit
Product
Bypass



m_3 kg W
100 kg
0'12 kg S/kg
0'88 kg W/kg
B
m_1 kg
0'12 kg S/kg
0'88 kg W/kg
E
m_4 kg
0'58 kg S/kg
0'42 kg W/kg
M
m_5 kg
0'42 kg S/kg
0'58 kg W/kg
m_2 kg
0'12 kg S/kg
0'88 kg W/kg



Overall process

2 unknowns (m_3, m_5)

$-$ 2 balances

0 DOF

Bypass

2 unknowns (m_1, m_2)

$-$ 1 balance

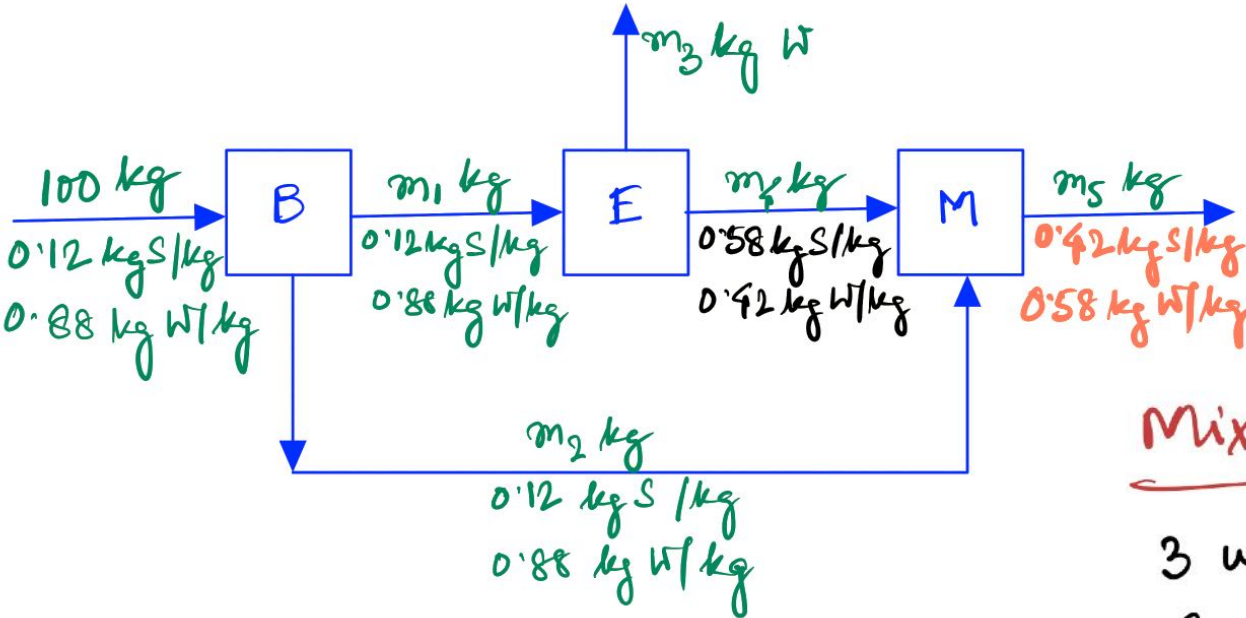
1 DOF

Evaporator

3 unknowns (m_1, m_3, m_4)

$-$ 2 balances

1 DOF



Mixing point

3 unknowns (m_2, m_4, m_5)

$-$ 2 balances

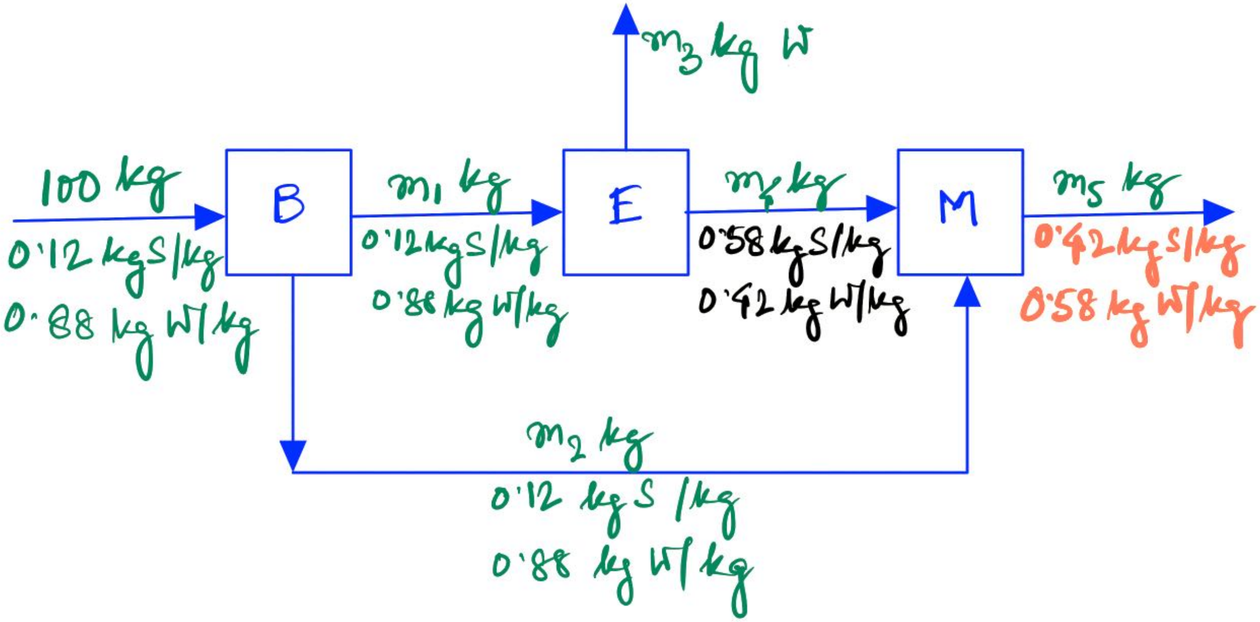
1 DOF

Overall S : $0.12 \times 100 = 0.42 \times m_5$

″ mass : $100 = m_3 + m_5$

Mixing point mass: $m_4 + m_2 = m_5$

″ S : $0.58\, m_4 + 0.12\, m_2 = 0.42\, m_5$



Bypass mass : $100 = m_1 + m_2$

Answer : m_5

Bypass fraction : $\frac{m_2}{100}$

A stream containing 5.15 wt% chromium (Cr) is contained in the wastewater from a metal finishing plant. The wastewater stream is fed to a treatment unit that removes 95% of the chromium in the feed and recycles it to the plant. The residual liquid stream leaving the treatment unit is sent to a waste lagoon. The treatment unit has a maximum capacity of 4500 kg wastewater/h. If wastewater leaves the finishing plant at a rate higher than the capacity of the treatment unit, the excess (anything above 4500 kg/h) bypasses the unit and combines with the residual liquid leaving the unit, and the combined stream goes to the waste lagoon.

(a) Without assuming a basis of calculation, draw and label a flowchart of the process.

(b) Wastewater leaves the finishing plant at a rate 6000 kg/h. Calculate the flow rate of liquid to the waste lagoon, and the mass fraction of Cr in this liquid.