Introduction to Chemical Engineering

Midterm - Problem 1

One of the best ways to reduce or eliminate hazardous waste is through source reduction. Generally, this means using different raw materials or redesigning the production process to eliminate the generation of hazardous byproducts. As an example, consider the following countercurrent extraction process that is shown in the figure to recover xylene from a stream that contains 10% xylene and 90% solids **by weight**.

The stream from which xylene is to be extracted enters Unit 2 at a flow rate of 2000 kg/h. To provide a solvent for the extraction, pure benzene is fed to Unit 1 at a flow rate of 1000 kg/h. The mass fractions of the xylene in the solids stream (F) and the clear liquid stream (S) have the following relations:

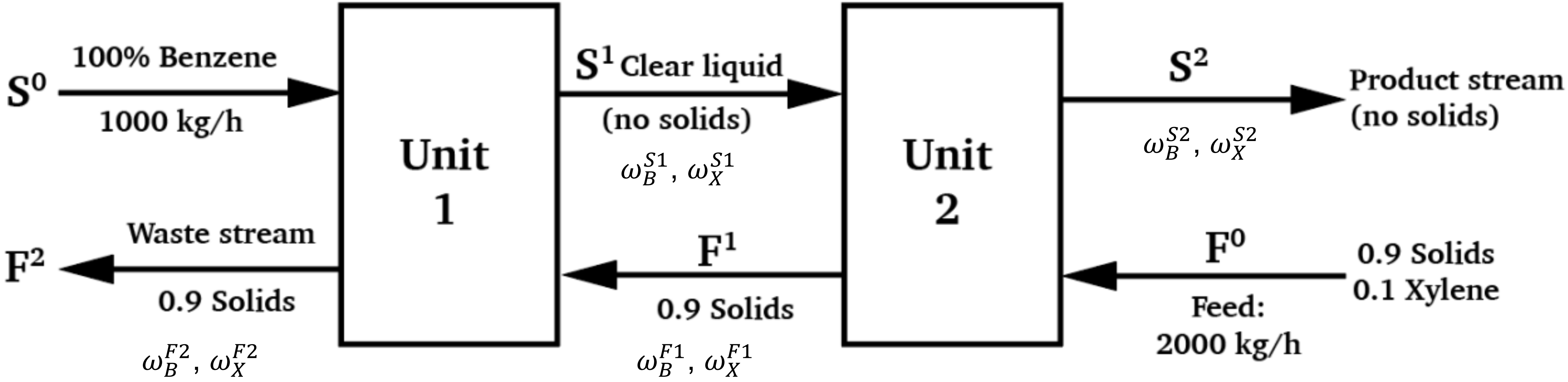
$$10\ \omega_{Xylene}^{F^1} = \omega_{Xylene}^{S^2}$$

$$10\ \omega_{Xylene}^{F^2} = \omega_{Xylene}^{S^1}$$

Questions:

a) Determine the benzene and xylene concentrations in all of the streams.
b) What is the percent recovery of the xylene entering the process at Unit 2?

Flowchart



S^0
100% Benzene
1000 kg/h
Unit 1
S^1 Clear liquid
(no solids)
ω_B^{S1}, ω_X^{S1}
Unit 2
S^2
Product stream
(no solids)
ω_B^{S2}, ω_X^{S2}
F^2
Waste stream
0.9 Solids
ω_B^{F2}, ω_X^{F2}
F^1
0.9 Solids
ω_B^{F1}, ω_X^{F1}
F^0
0.9 Solids
0.1 Xylene
Feed:
2000 kg/h

a) Determine the concentrations of benzene and xylene in all the flows

Overall and solids balances

Overall system balance: $F_0 + S_0 = F_2 + S_2 \quad \Leftrightarrow 3000 = F_2 + S_2$

Overall Solids balance : $0.9\,F_0 = 0.9F_2 \quad \Leftrightarrow F_2 = F_0 = 2000\frac{kg}{hr} \Longrightarrow S_2 = 1000\frac{kg}{hr}$

Unit 1overall balance : $F_1 + S_0 = F_2 + S_1 \quad \Leftrightarrow F_1 + 1000 = 2000 + S_1$

Unit 1 solids balance : $0.9\,F_1 = 0.9F_2 \quad \Leftrightarrow F_1 = F_2 = 2000\frac{kg}{hr} \Longrightarrow S_1 = 1000\frac{kg}{hr}$

What we know now : $\boxed{F_1 = F_2 = 2000\frac{kg}{hr} \qquad S_1 = S_2 = 1000\frac{kg}{hr}}$

a) Determine the concentrations of benzene and xylene in all the flows

Xyelene balances

Overall system: $0.1\ F_0 = \omega_X^{F2} F_2 + \omega_X^{S2} S_2 \iff 200 = 2000\omega_X^{F2} + 1000\ \omega_X^{S2}$ **(1)**

Unit 1 : $\omega_X^{F1} F_1 = \omega_X^{F2} F_2 + \omega_X^{S1} S_1 \iff 2000\ \omega_X^{F1} = 2000\ \omega_X^{F2} + 1000\ \omega_X^{S1}$ **(2)**

Unit 2 : $0.1\ F_0 + \omega_X^{S1} S_1 = \omega_X^{S2} S_2 + \omega_X^{F1} F_1 \iff 200 + 1000\ \omega_X^{S1} = 1000\ \omega_X^{S2} + 2000\ \omega_X^{F1}$ **(3)**

Equilibria : $10\omega_X^{F2} = \omega_X^{S1}$ **(4)** and $10\ \omega_X^{F1} = \omega_X^{S2}$ **(5)**

a) Determine the concentrations of benzene and xylene in all the flows

Solving Xyelene balances

1. Plugging (4) in (2) : $2000\,\omega_X^{F1} = 2000\,\omega_X^{F2} + 10\,000\omega_X^{F2} = 12\,000\,\omega_X^{F2} \Rightarrow \boldsymbol{\omega_X^{F1} = 6\omega_X^{F2}}$ **(6)**

2. Plugging (5) in (1) : $200 = 2000\omega_X^{F2} + 1000\,\omega_X^{S2} \Leftrightarrow 200 = 2000\omega_X^{F2} + 10\,000\,\omega_X^{F1}$

$$\Rightarrow 200 = 2000\omega_X^{F2} + 60\,000\,\omega_X^{F2}$$
$$\Rightarrow 200 = 62\,000\omega_X^{F2}$$
$$\Rightarrow \boldsymbol{\omega_X^{F2} = 0.003}$$

3. Deduce ω_X^{F1} from (6), ω_X^{S1} from (4) and ω_X^{S2} from (5)

$$\boxed{\boldsymbol{\omega_X^{F2} = 0.003\ ,\omega_X^{F1} = 0.018,\ \omega_X^{S1} = 0.03,\ \omega_X^{S2} = 0.18}}$$

a) Determine the concentrations of benzene and xylene in all the flows

Solving for benzene concentrations

For F flows, we have that $\boldsymbol{\omega_X^F} + \boldsymbol{\omega_B^F} = \mathbf{0.1}$

For S flows, we have that $\boldsymbol{\omega_X^S} + \boldsymbol{\omega_B^S} = \mathbf{1}$

Knowing this and the xylene concentrations, all benzene concentrations can be found

Stream	Component weight fraction
S^0	Bz 1.0 Xy 0.0
S^1	Bz 0.97 Xy 0.03
S^2	Bz 0.82 Xy 0.18
F^0	Bz 0.9 Xy 0.1
F^1	Bz 0.082 Xy 0.018
F^2	Bz 0.097 Xy 0.003

b) Find recovery at the exit of unit 2

1. Option 1 : compute overall recovery

$$recovery = \frac{\omega_X^{S2} S_2}{0.1\ F_0} = \frac{180}{200} = 0.9$$

2. Option 2 : compute Unit 2 recovery

$$recovery = \frac{\omega_X^{S2} S_2}{0.1\ F_0 + \omega_X^{S1} S_1} = \frac{180}{200 + 30} = 0.77$$