CHEMICAL PROCESS CALCULATIONS

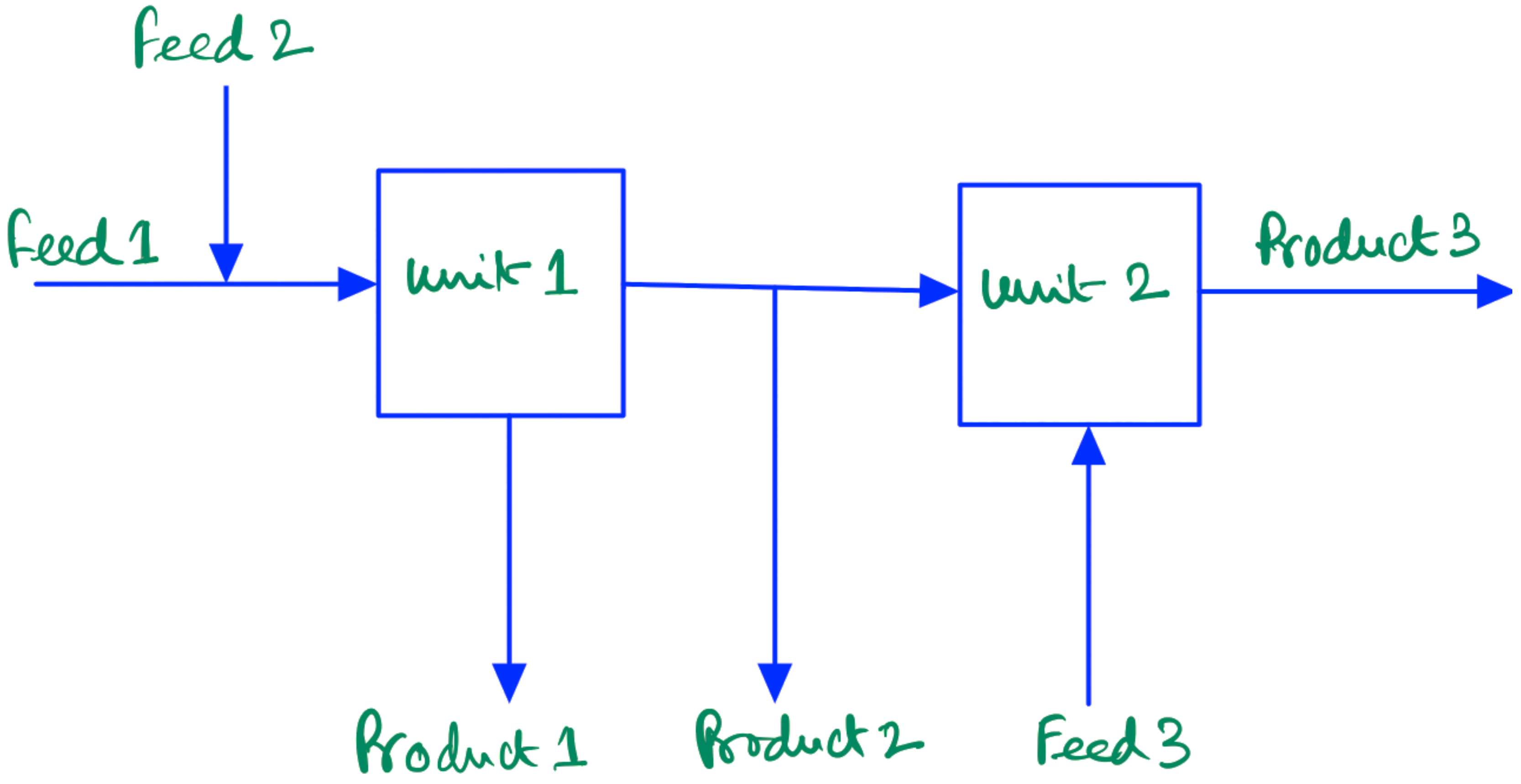
(Material Balance Calculations: Fundamentals & Single Unit)

Lecture #6: September 05, 2022

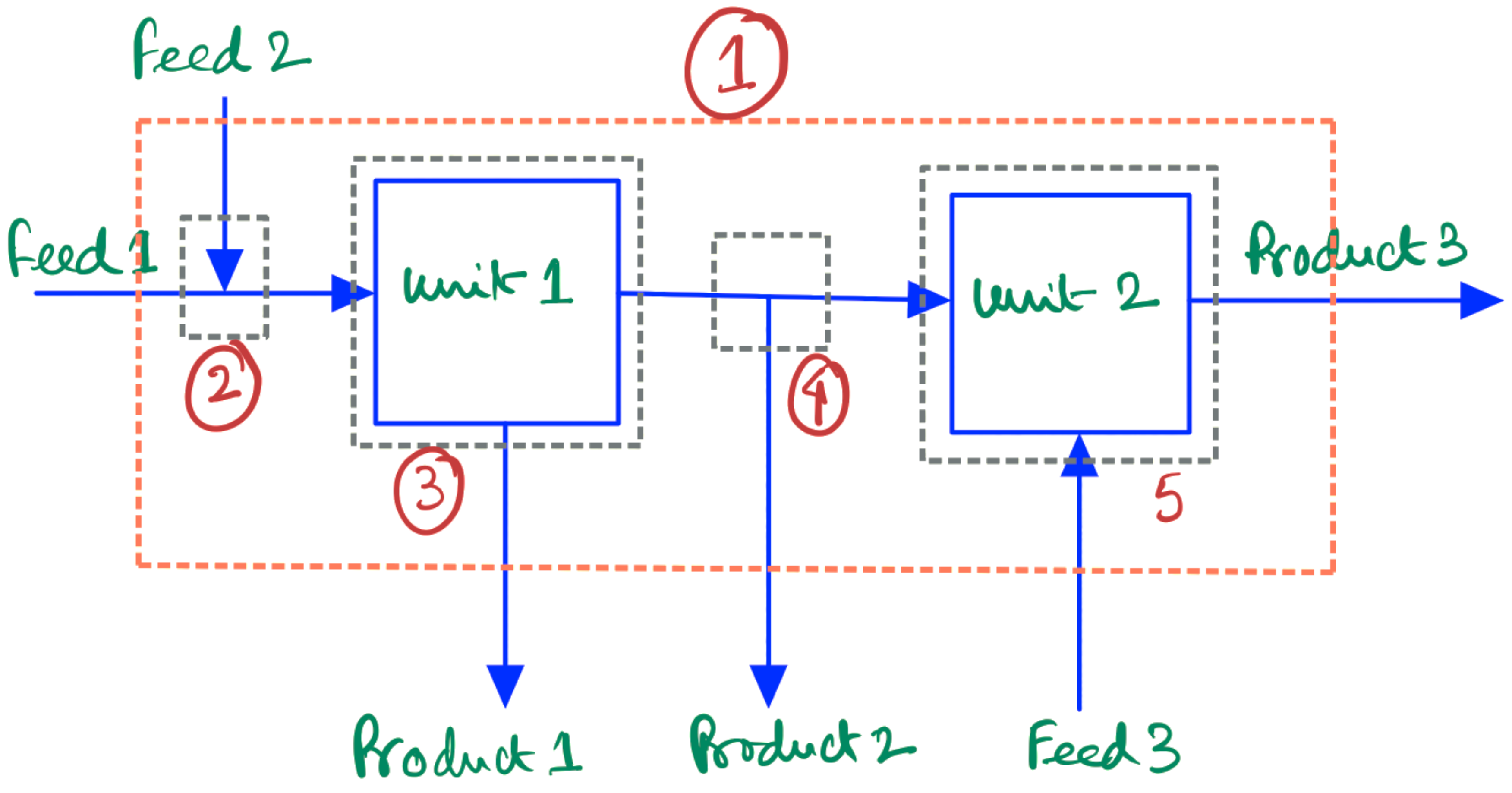
Single-Unit Process Calculations

1. Choose a basis
2. **Draw and label the flowchart**
3. Write expressions for the quantities asked in the problem statement
4. Convert mixed units to one basis
5. **Perform degree-of-freedom analysis**
6. Write system equations and outline a solution procedure
7. Calculate the unknowns
8. Calculate ***additional quantities*** requested in the problem statement

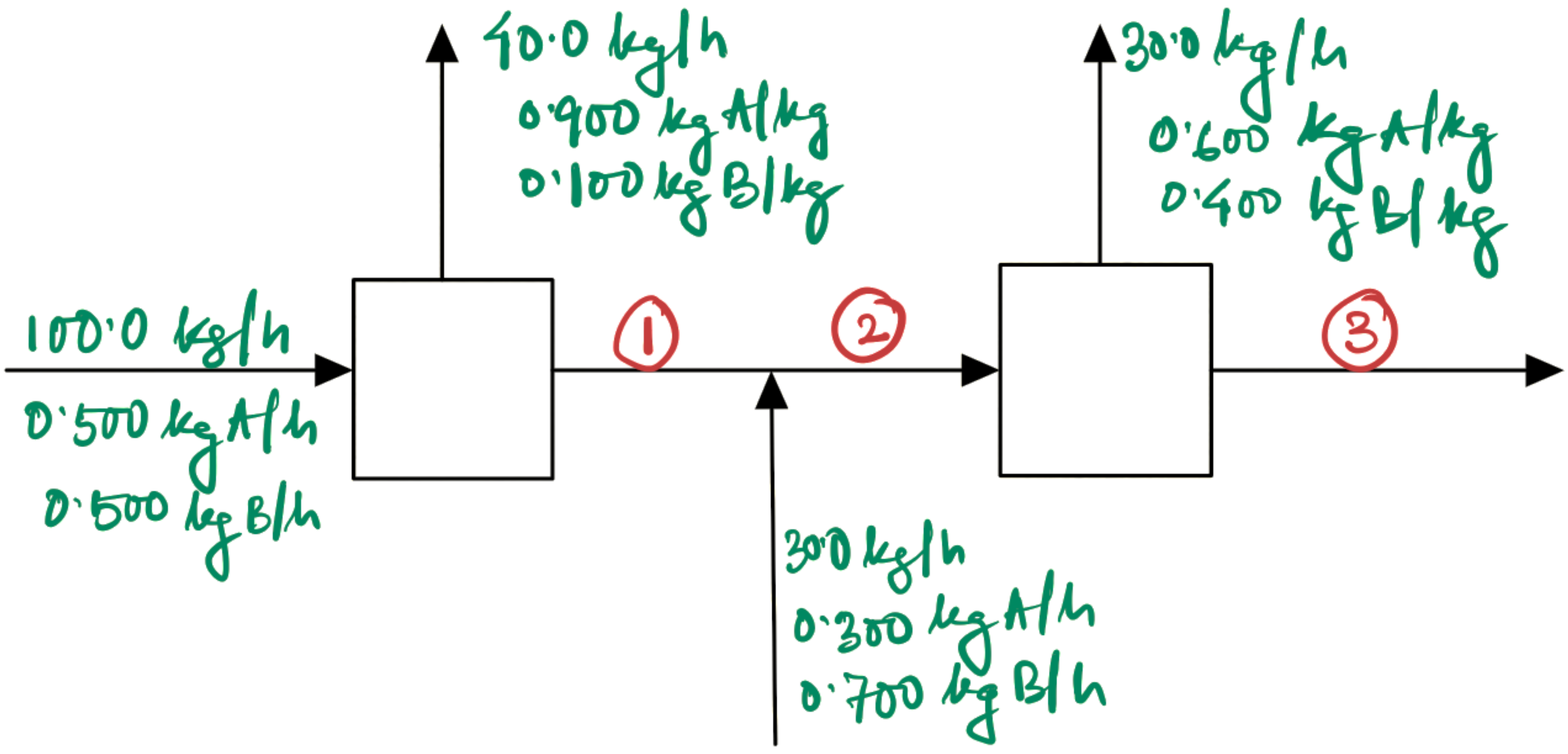
Multiple units calculations



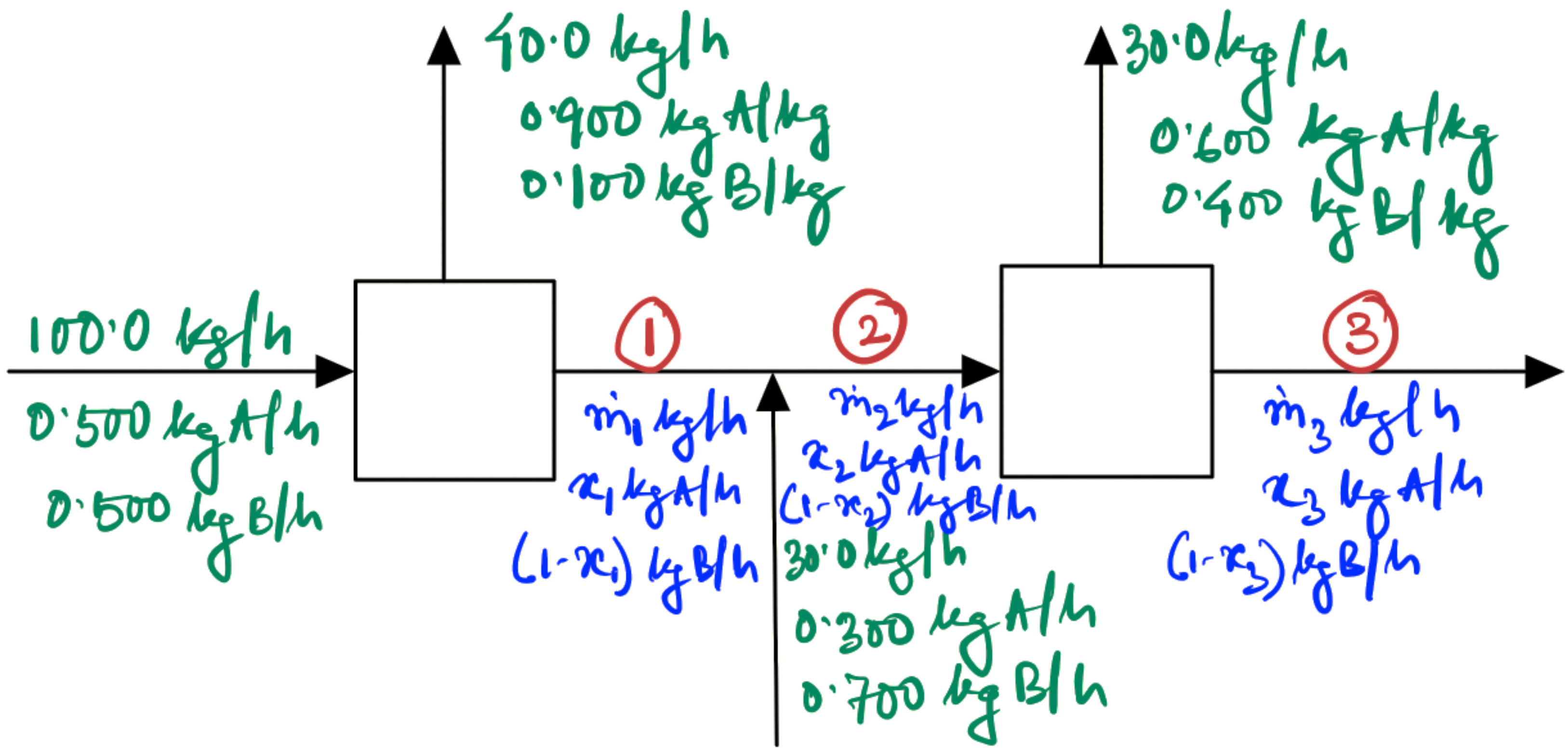
Multiple units calculations



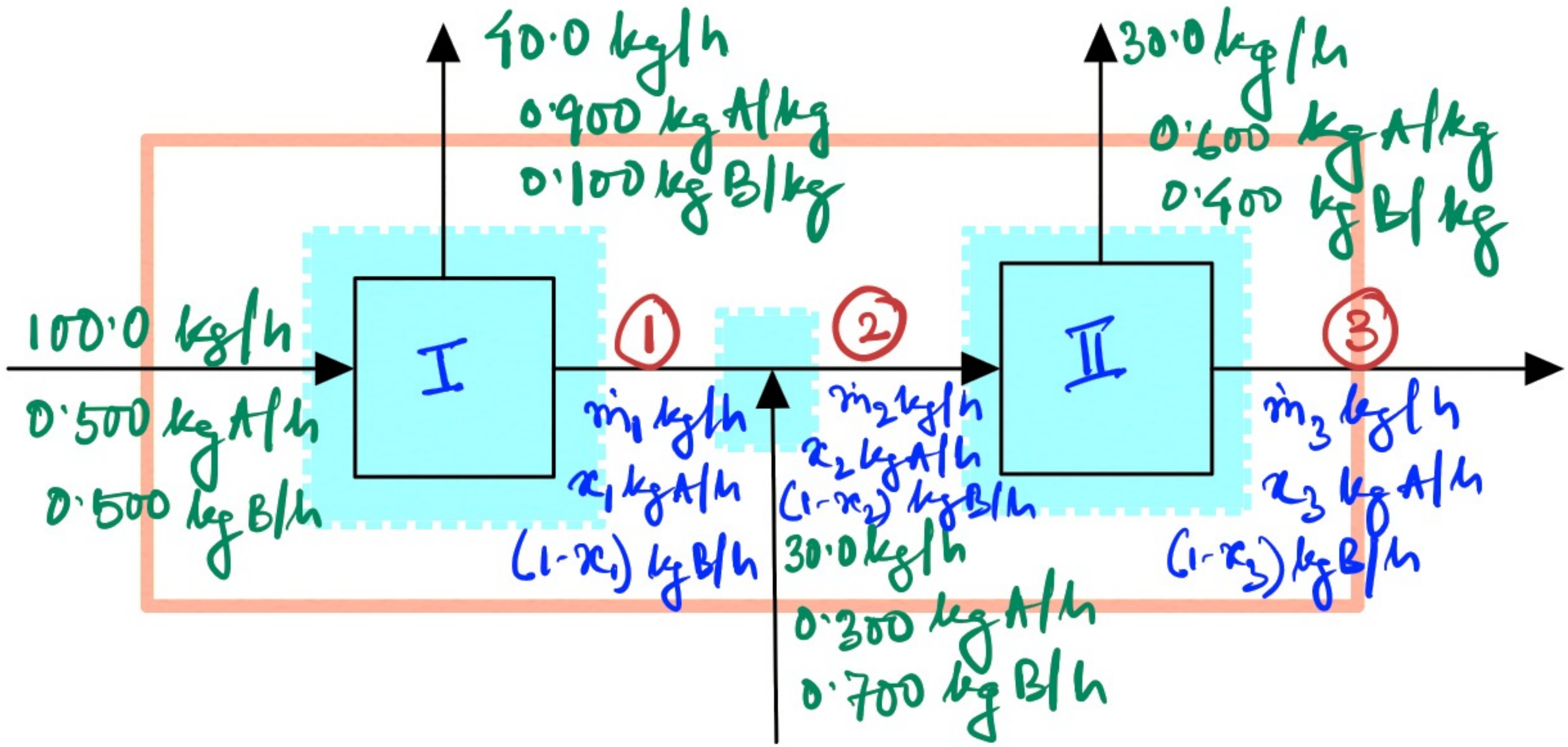
Multiple units calculations

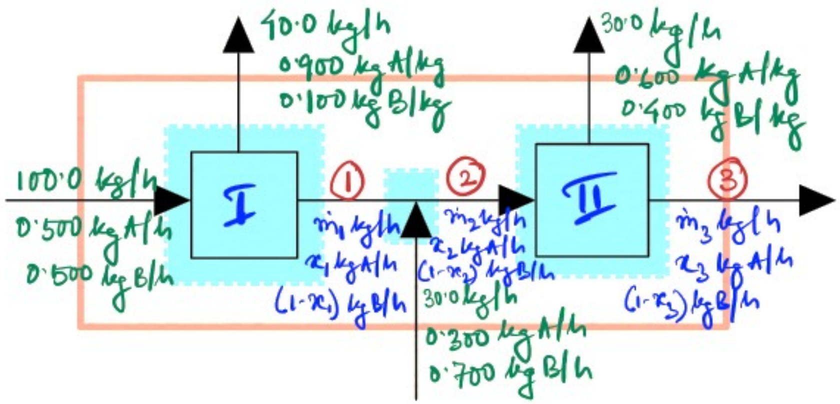


Multiple units calculations



Multiple units calculations





DOF Analysis

Overall system

2 unknowns (x_3, $\dot{m}_3$)
− 2 balances (2 species)

0 DOF

Mixing point

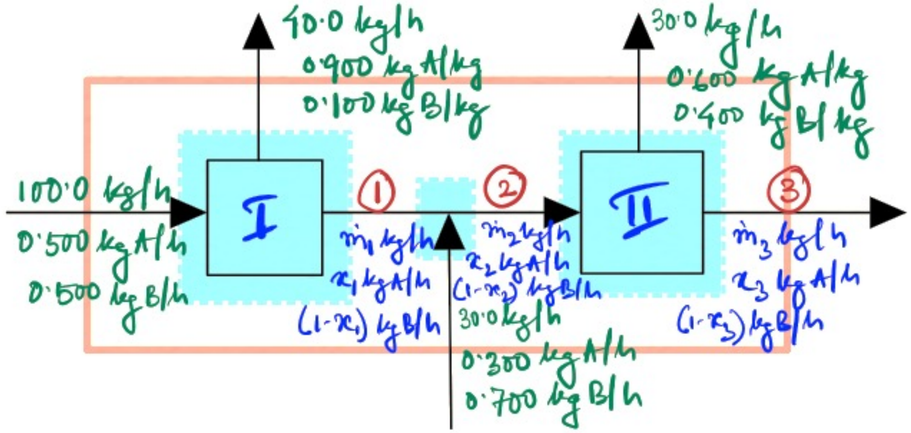
4 unknowns (x_1, x_2, $\dot{m}_1$, $\dot{m}_2$)
− 2 balances (2 species)

2 DOF

Unit I

2 unknowns (x_1, $\dot{m}_1$)
− 2 balances (2 species)

0 DOF



Mixing point

2 unknowns $(x_2, \dot{m}_2)$
− 2 balances (2 species)

0 DOF

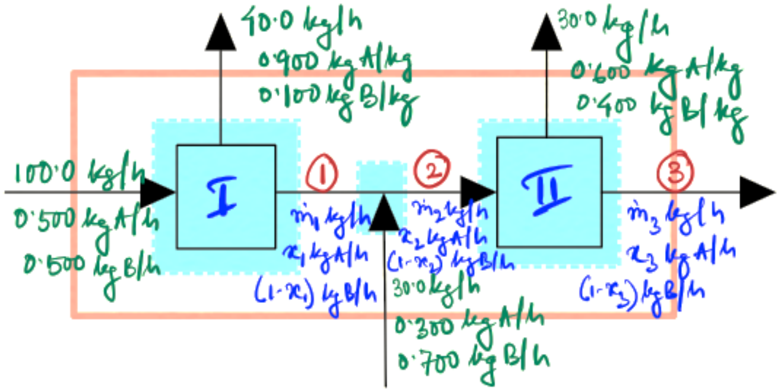
Overall mass balance

$$(100.0 + 30.0)\ \text{kg/h} = (40.0 + 30.0)\ \text{kg/h} + \dot{m}_3$$

$$\Rightarrow \dot{m}_3 = 60.0\ \text{kg/h}$$

Overall A balance

$$0.500 \times 100.0 + 0.300 \times 30.0 = 0.900 \times 40.0 + 0.600 \times 30.0 + x_3 \times \underline{60.0}$$



$\Rightarrow x_3 = 0.0833 \text{ kg A/kg}$

Mass balance: Unit I

$$100.0 = 40.0 + \dot{m}_1 \Rightarrow \dot{m}_1 = 60.0 \text{ kg/h}$$

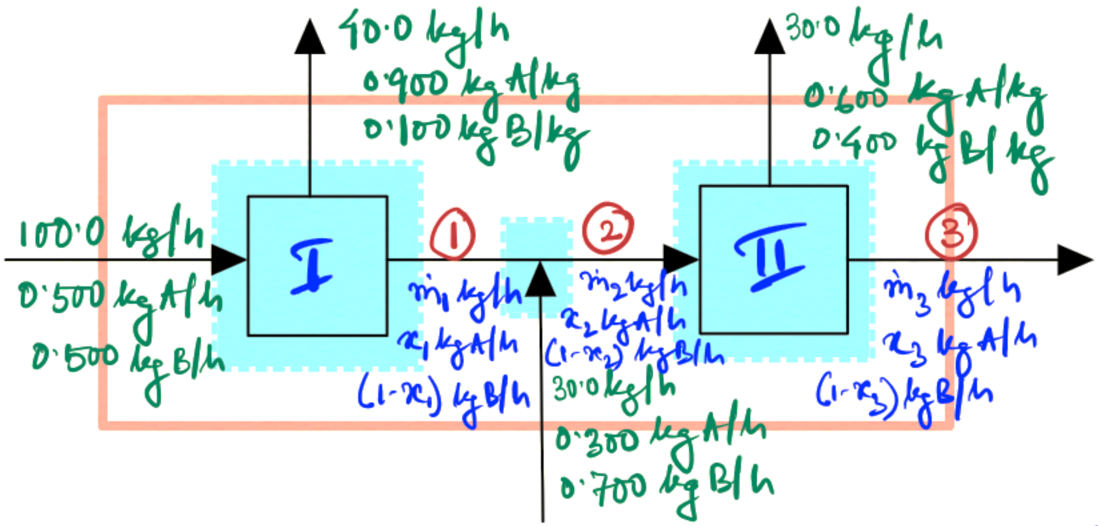
A balance: Unit I

$$0.500 \times 100.0 = 0.900 \times 40.0 + x_1 \times 60.0$$

$$\Rightarrow x_1 = 0.233 \text{ kg A/kg}$$

Mass balance: Mixing point

$$\dot{m}_1 + 30.0 = \dot{m}_2 \Rightarrow \dot{m}_2 = 90.0 \text{ kg/h}$$



A balance : Mixing point

$$\dot{m}_1 x_1 + 30.0 \times 0.300 = \dot{m}_2 x_2$$

$$\Rightarrow 60.0 \times 0.233 + 30.0 \times 0.300 = 90.0 \times x_2$$

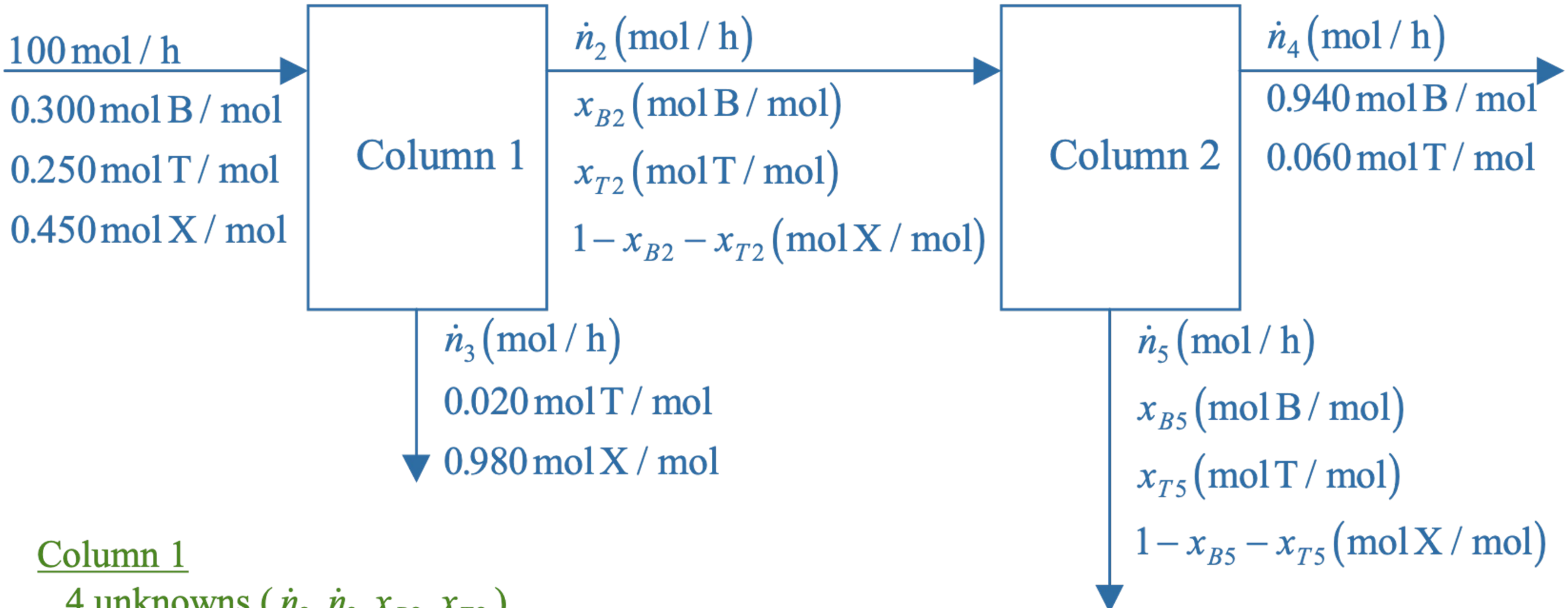
$$\Rightarrow \quad x_2 = 0.255 \text{ kg A/kg}$$

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

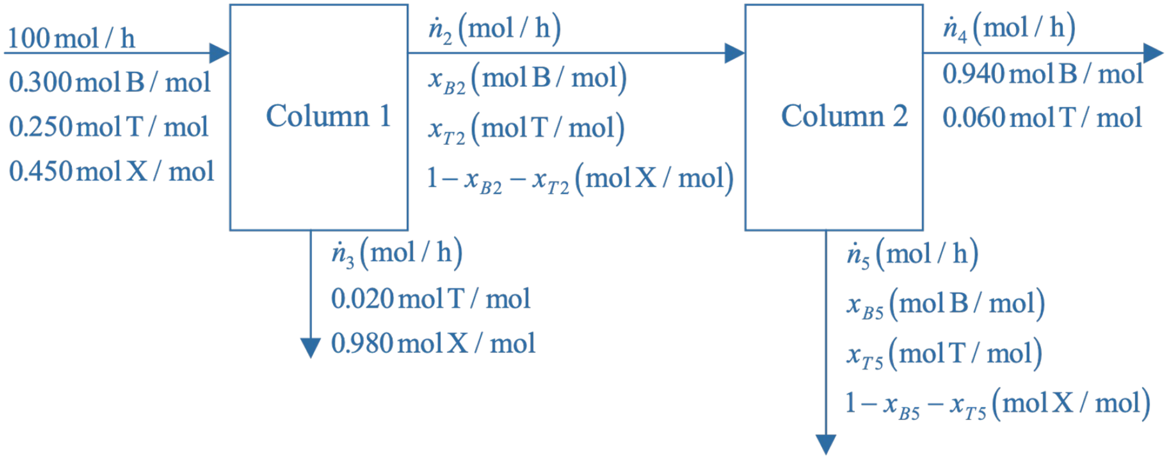
Column 2:

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

– 3 balances

– 1 recovery of B in top (97%)

0 DF



<u>Column 1</u>

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

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

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

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

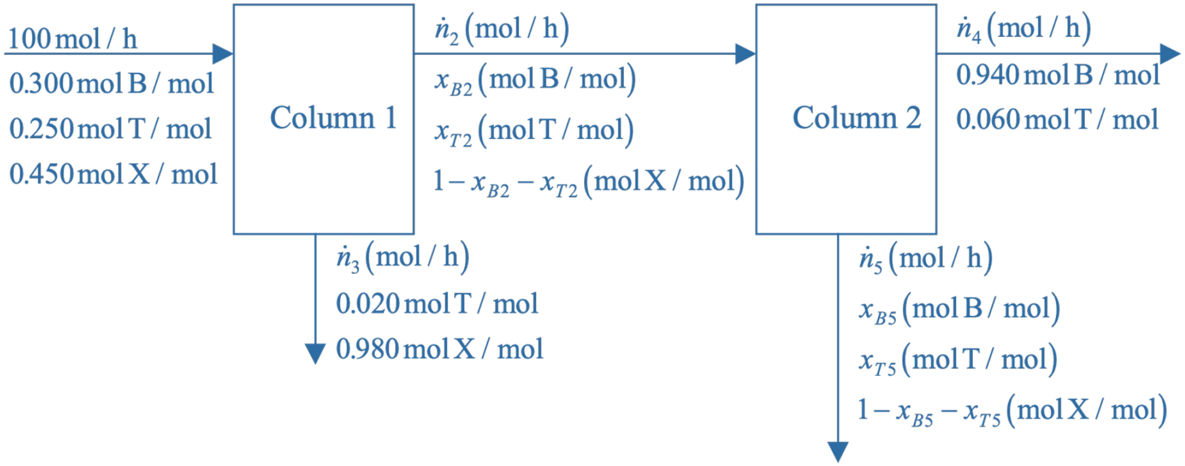
<u>Column 2</u>

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

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

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

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



Column 1

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

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

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

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

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

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

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

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

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