CHEMICAL PROCESS CALCULATIONS

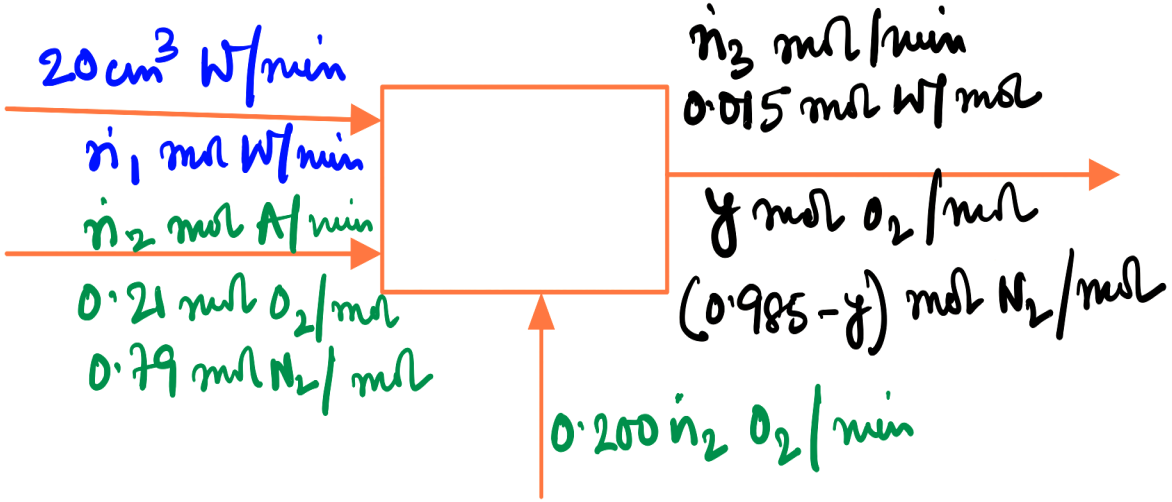
(Material Balance Calculations: Fundamentals & Single Unit)

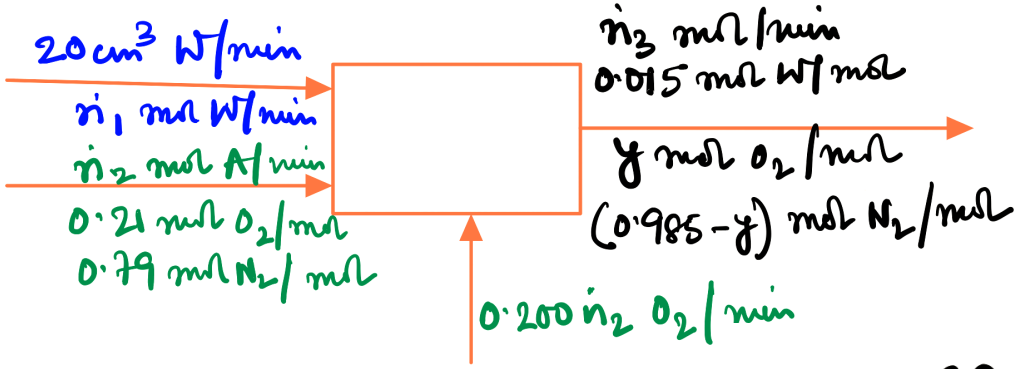
Lecture #5: August 25, 2022

An experiment on the growth rate of certain organisms requires an environment of humid air enriched in oxygen. Three input streams are fed into an evaporation chamber to produce an output stream with the desired composition.

A: Liquid water, fed at a rate of 20.0 cm^3/min
B: Air (21 mole% O_2, the balance N_2)
C: Pure oxygen, with a molar flow rate one-fifth of the molar flow rate of stream B

The output gas is analyzed and is found to contain 1.5 mole% water. Draw and label a flowchart of the process, and calculate all unknown stream variables.





unit consistency

$$\dot{n}_1 = \frac{20.0\ cm^3\ H_2O}{min} \times \frac{1.00\ g\ H_2O}{cm^3} \times \frac{1\ mol}{18\ g}$$

$$\Rightarrow \dot{n}_1 = 1.11\ \frac{mol\ H_2O}{min}$$

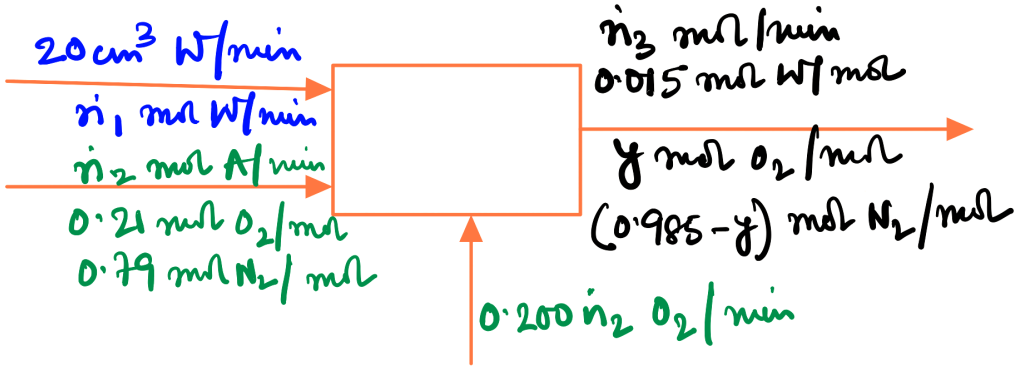
Nonreactive Steady State process

$$Input = Output$$

H_2O (W) balance:

$$\dot{n}_1 = \dot{n}_3 \times 0.015$$

$$\Rightarrow \dot{n}_3 = 1.11/0.015 = 74\ \frac{mol}{min}$$



Total mole balance:

$$\dot{n}_1 + \dot{n}_2 + 0.200\dot{n}_2 = \dot{n}_3$$

$$\Rightarrow \quad \dot{n}_2 = (74 - 1.11)/1.200 \text{ mol/min}$$

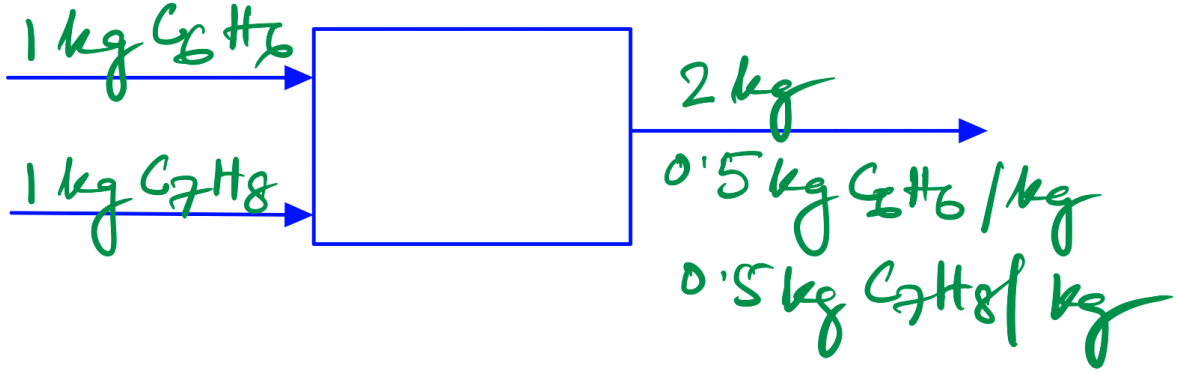
$$= 61 \frac{\text{mol}}{\text{min}}$$

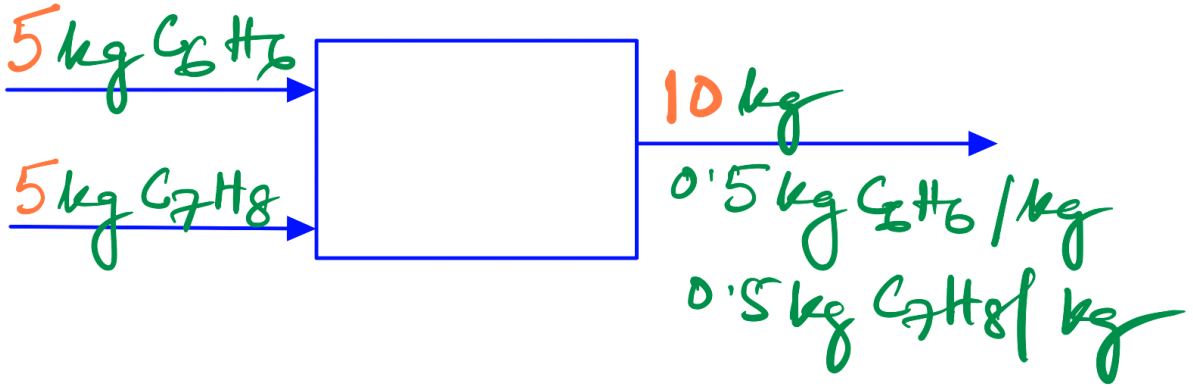
N_2 balance:

$$\dot{n}_2 \times 0.79 = \dot{n}_3 \times (0.985 - y)$$

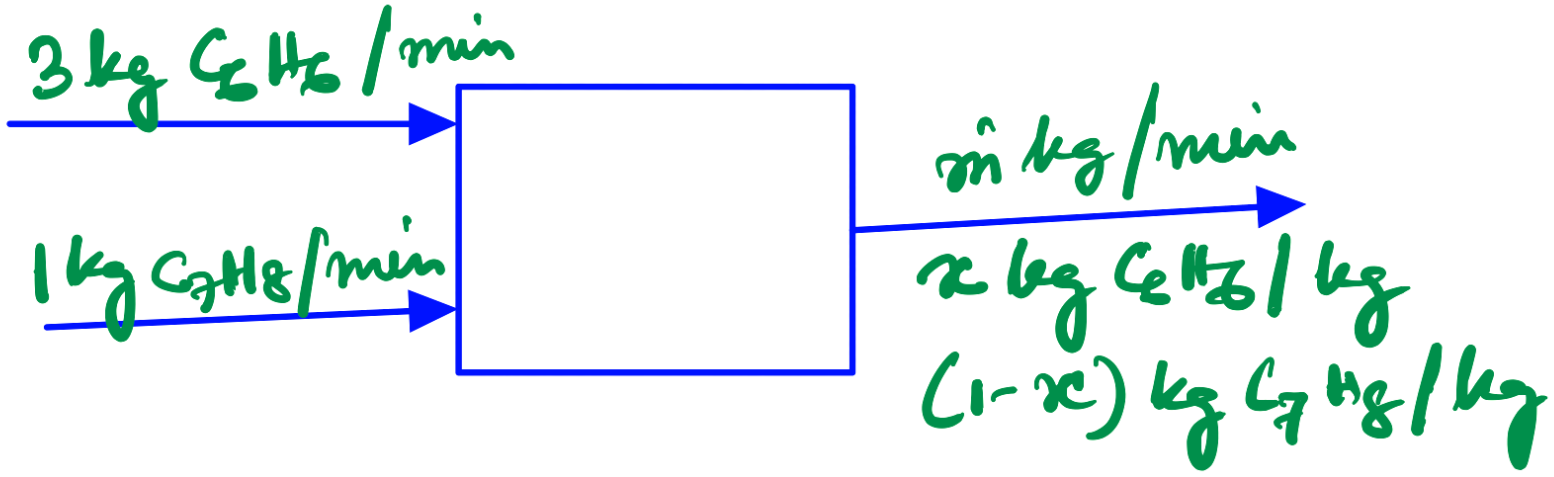
$$\Rightarrow \quad y = 0.33 \text{ mol } O_2/\text{mol}$$

Flowchart scaling





Writing balance equations



Total Mass Balance

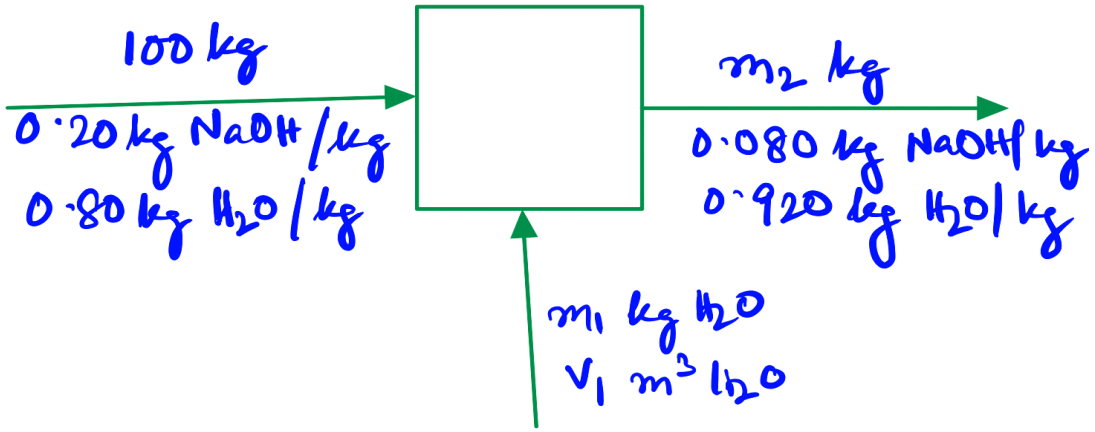
$$3 + 1 = \dot{m} \Rightarrow \dot{m} = 4 \text{ kg/min}$$

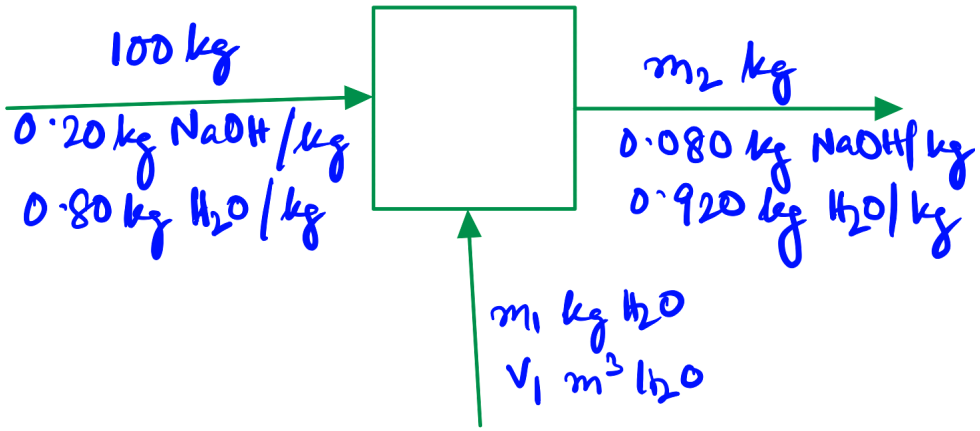
Benzene Balance

$$3 = \dot{m} \times x \Rightarrow x = 0.75 \text{ kg } C_6H_6/\text{kg}$$

Writing balance equations

- For a nonreactive system:
  - maximum number of independent equations = the number of chemical species in the input and output streams
- Priority for the balance which has the fewest unknown variables





Basis of calculation
Desired variables
unknowns
equations
solution procedure

Total mass balance

$100 + m_1 = m_2 \Rightarrow m_1 = 150 \text{ kg } H_2O$

$\rho_{H_2O} = 1000 \text{ kg/m}^3$

$\Rightarrow V_1 = 150/1000 \text{ m}^3 = 0.15 \text{ m}^3$

NaOH Balance

Input = Output

$0.20 \times 100 = 0.080 \times m_2$

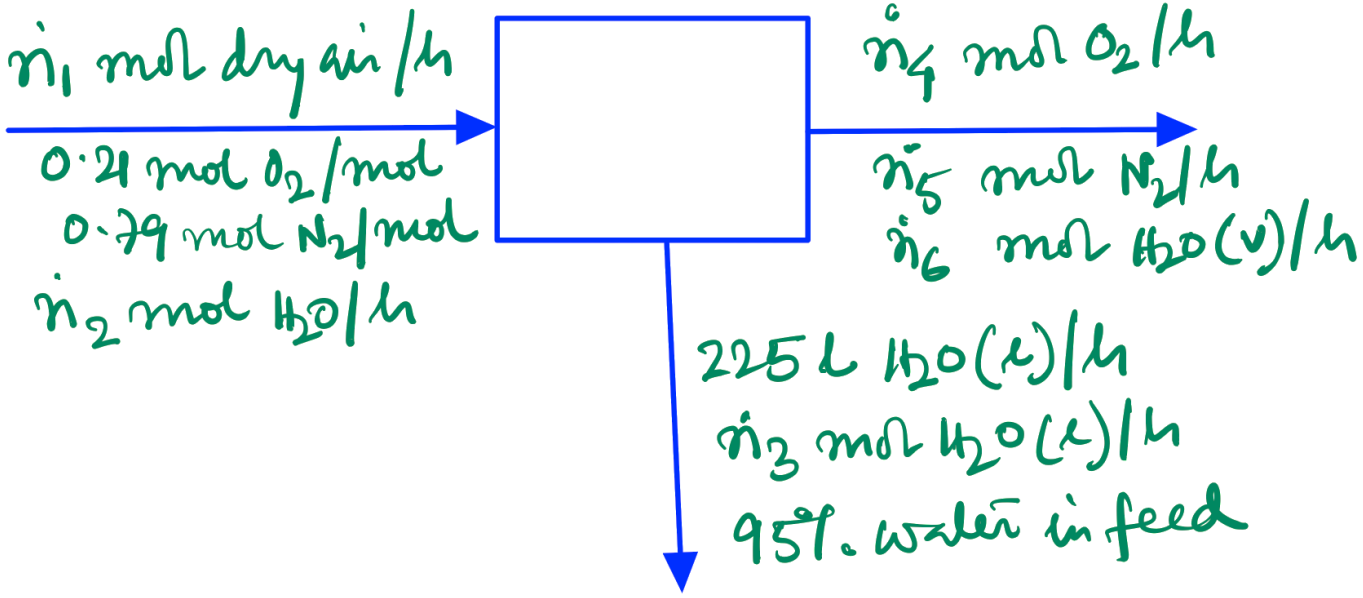
$\Rightarrow m_2 = 250 \text{ kg NaOH}$

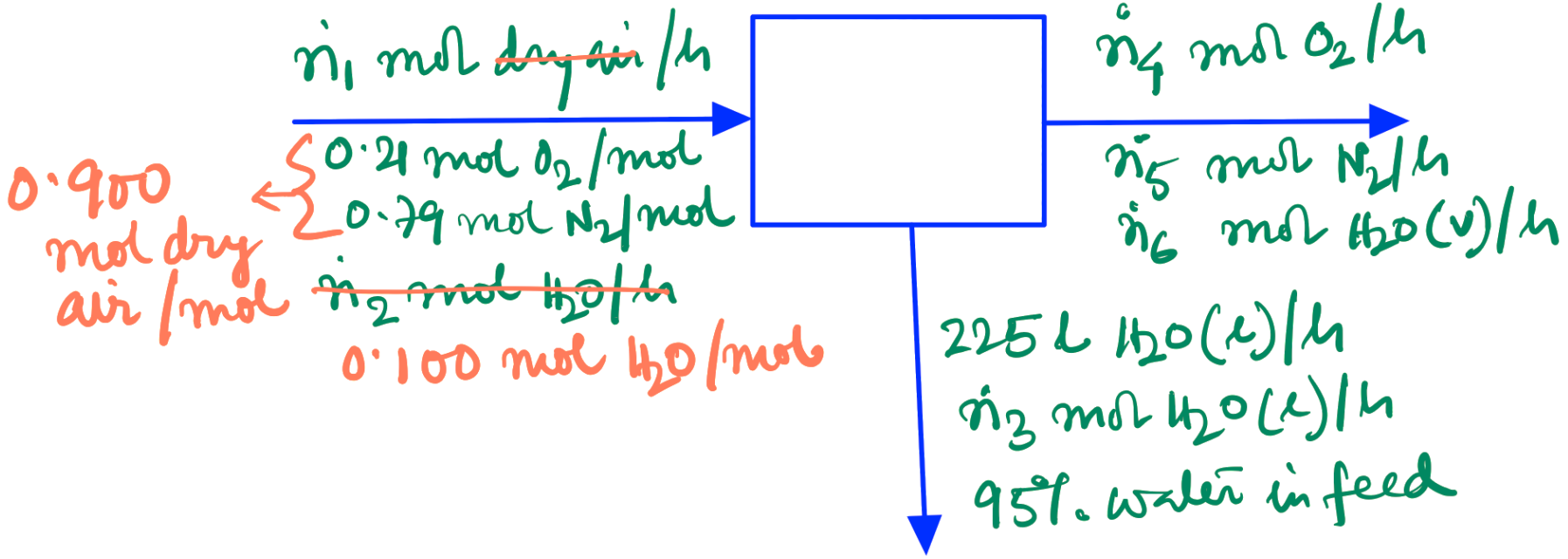
Degree-of-Freedom Analysis

- Draw and completely label the flowchart
- Count the unknown variables
- Count the independent equations relating them
- Subtract the second number from the first

Degree-of-Freedom Analysis

A stream of humid air enters a condenser in which 95% of the water vapor in the air is condensed. The flow rate of the condensate (the liquid leaving the condenser) is measured and found to be 225 L/h. Dry air may be taken to contain 21 mole% oxygen, with the balance nitrogen. Calculate the flow rate of the gas stream leaving the condenser and the mole fractions of oxygen, nitrogen, and water in this stream.




$\dot{n}_1$ mol ~~dry air~~ /h
0.21 mol O_2/mol
0.79 mol N_2/mol
$\dot{n}_2$ mol H_2O/h
0.900 mol dry air/mol
0.100 mol H_2O/mol
$\dot{n}_4$ mol O_2/h
$\dot{n}_5$ mol N_2/h
$\dot{n}_6$ mol $H_2O(v)$/h
225 L $H_2O(\ell)$/h
$\dot{n}_3$ mol $H_2O(\ell)$/h
95% water in feed

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