Department of Chemical Engineering
Thapar Institute of Engineering & Technology, Patiala

Course: Material and Energy Balances UCH301

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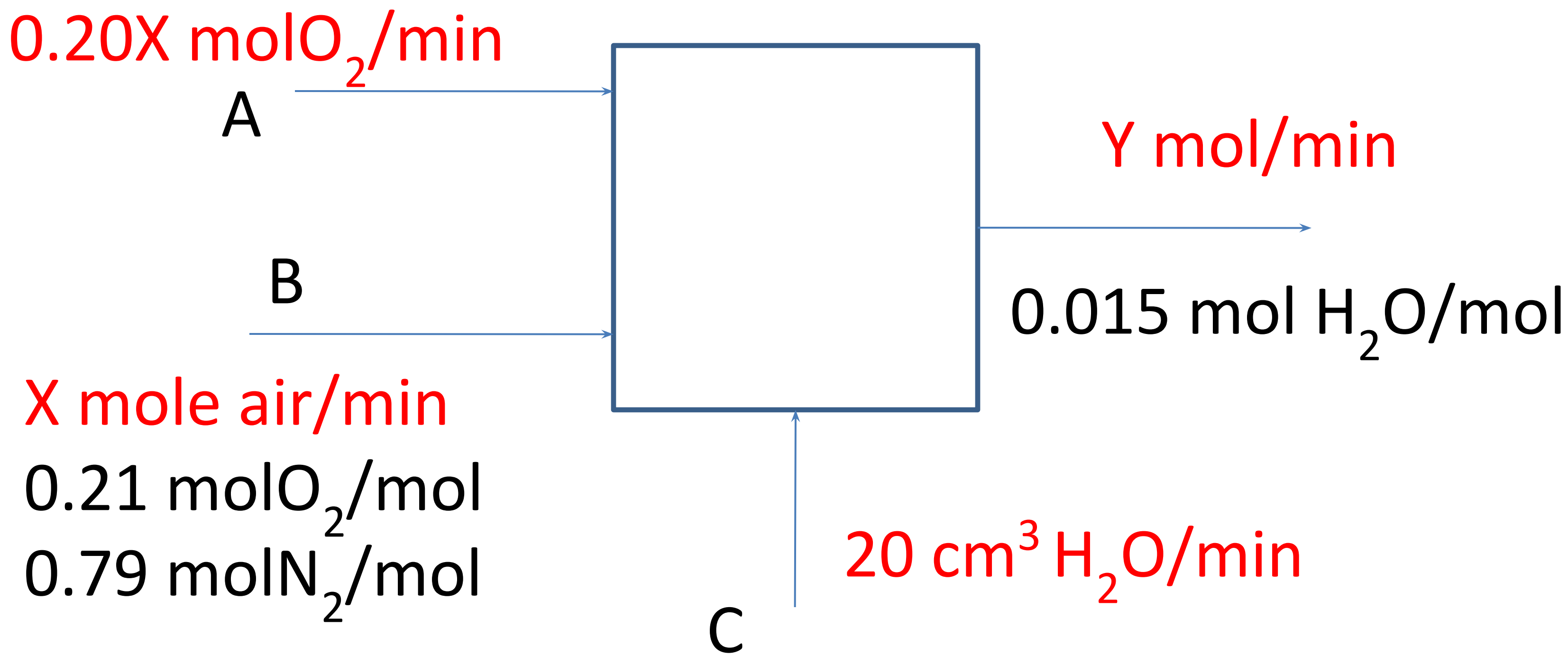
Writing material balances for different types of processes

Problem:

- An experiment on the growth rate of certain organisms requires an environment of humid air enriched in oxygen. Three streams are fed into an evaporation chamber to produce an output stream of air having desired composition.
- STRAEM A: Pure oxygen, with a molar flow rate one fifth of the molar flow rate of stream B.
- STREAM B: Air (21% O_2, 79%N_2)
- STREAM C: Liquid water, fed at a rate of 20 cm^3/min

The output gas stream is analyzed and is found to contain 1.5 mol% water. Calculate all flows and compositions at steady state operation.

Solution

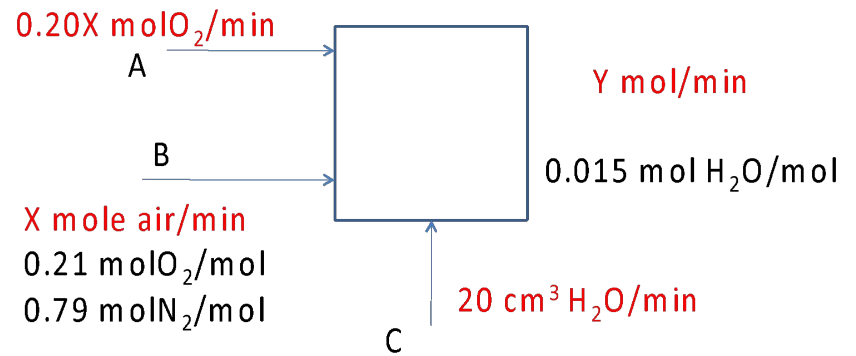


0.20X molO_2/min
A
B
X mole air/min
0.21 molO_2/mol
0.79 molN_2/mol
C
20 cm^3 H_2O/min
Y mol/min
0.015 mol H_2O/mol

BASIS : 20 cm^3/min H_2O (stream C)

As all units are in mol/time except for stream C, first we will convert the units of stream C to mol/min

- Moles of H_2O fed = (20 cc/min * 1 g/cc)/18
  =1.11 moles/min



- ***M. Balance on H_2O:***

H_2O In = H_2O Out

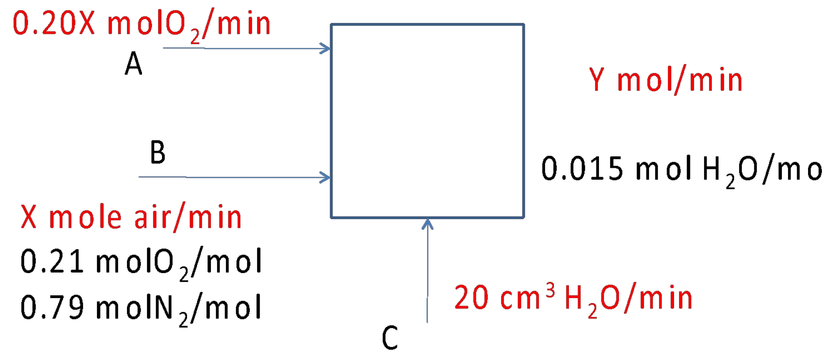
1.11 = Y*0.015

Y = 74 mol/min

- Total mole balance for calculating X (mol/min of Air fed)

$$X + 0.2*X + 1.11 = 74$$

$$X = 60.74 \text{ mol/min}$$



N_2 balance:

$$N_2 \text{ in } = N_2 \text{ Out}$$

$$0.79*60.74 = 74* Y_{N2}$$ (where Y_{N2} is mol fraction of N_2 in Y)

$$Y_{N2} = 0.648$$

$$Y_{O2} = 1-0.648 -0.015= 0.337$$

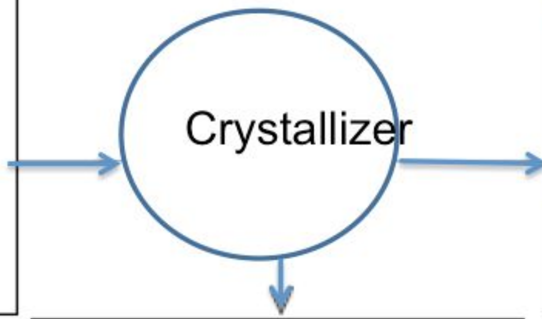
Excercise

- A crystallizer is fed with 6420 lb of aqueous solution of anhydrous sodium sulfate, Na_2SO_4 (concentration 29.6 wt %) at 104 °C. The solution is cooled to 20 °C to crystallize out the desired $Na_2SO_4 . 10\ H_2O$ crystals. The remaining solution (the mother liquor) is found to contain 16.1 % anhydrous sodium sulfate. Calculate the mass of the mother liquor and crystals obtained after crystallization.

SKETCH

Initial F = 6420 lb

	mass fr.
Na_2SO_4	0.296
H_2O	0.704
	1.000



Final P (lb) $Na_2SO_4 \cdot 10H_2O$

	lb mol	*MW*	*lb*	*mass fr*
Na_2SO_4	1	142	142	0.441
water	10	18	180	0.559
			322	1.000

Mother liquor M (lb)

	mass fr.
Na_2SO_4	0.161
H_2O	0.839
	1.000

- Overall material balance:

Mass In = Mass out

$$6420 = P + M$$

- Material balance for Na_2SO_4:

Na_2SO_4 in = Na_2SO_4 Out

$$0.296 \times 6420 = 0.441 \times P + 0.161M$$

Solving the above two equations, we get:

$P = 3100$ lb/hr and $M = 3320$ lb

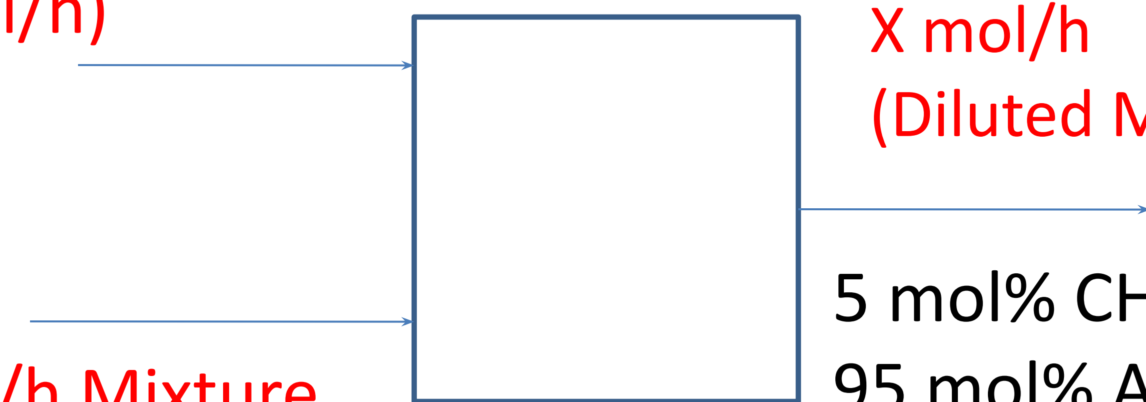
Problem

- A mixture of methane and air is capable of being ignited only if the mol% of methane is between 5% to 15%.

A mixture containing 9 mol% methane in air flowing at a rate of 700 kg/h is to be diluted with air to reduce the methane concentration to lower flammability limit. Calculate the required flow of air in mol/hr, and % of O_2 in the diluted mixture.

(Use Molecular Weight of air = 29)

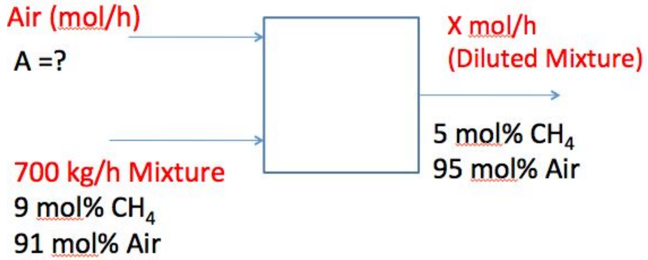
Solution


Air (mol/h)
A =?
700 kg/h Mixture
9 mol% CH_4
91 mol% Air
X mol/h
(Diluted Mixture)
5 mol% CH_4
95 mol% Air

- Let A be the mol/h air used for dilution & X be the mol/h of diluted mixture
- As the composition of the streams are given in mol% we will convert the mass flow rate to mol flow rate
- Mol flow rate of mixture In

  = (700 kg/h)/(29kg/kmol)

  = 24.14 kmol/h



This gas mixture at inlet contains:

CH_4 = 24.14*0.09 = 2.17 kmol/h

O_2 = 24.14*0.91*0.21 = 4.61 kmol/h

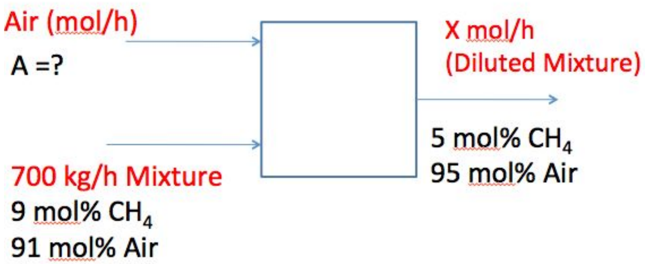
N_2 = 24.14*0.91*0.79 = 17.36 kmol/h

- As methane (CH_4) is entering from one stream and leaving from one stream, we can write balance for CH_4 to calculate the amount of Diluted Mixture (X):

CH_4 in = CH_4 out

$$2.17 = 0.05 * X$$

$$X = 43.4 \text{ kmol/h}$$



From total Mass balance:

$$A + 24.14 = 43.4$$

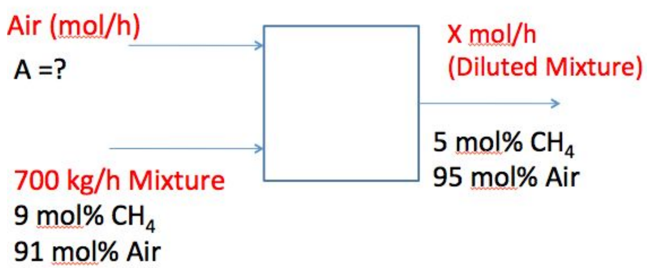
$A = 19.26$ kmol/h Air required for dilution

Mol % of O_2 in X = 100*(Moles of O_2 in X /Total moles of X)

Mol of O_2 in X

$$= 43.4*0.95*0.21$$

$$= 8.66 \text{ kmol/h}$$



Thus, Mol% O_2 in X = 100*(8.66/43.4) = 19.95%