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

Course: Material and Energy Balances UCH301

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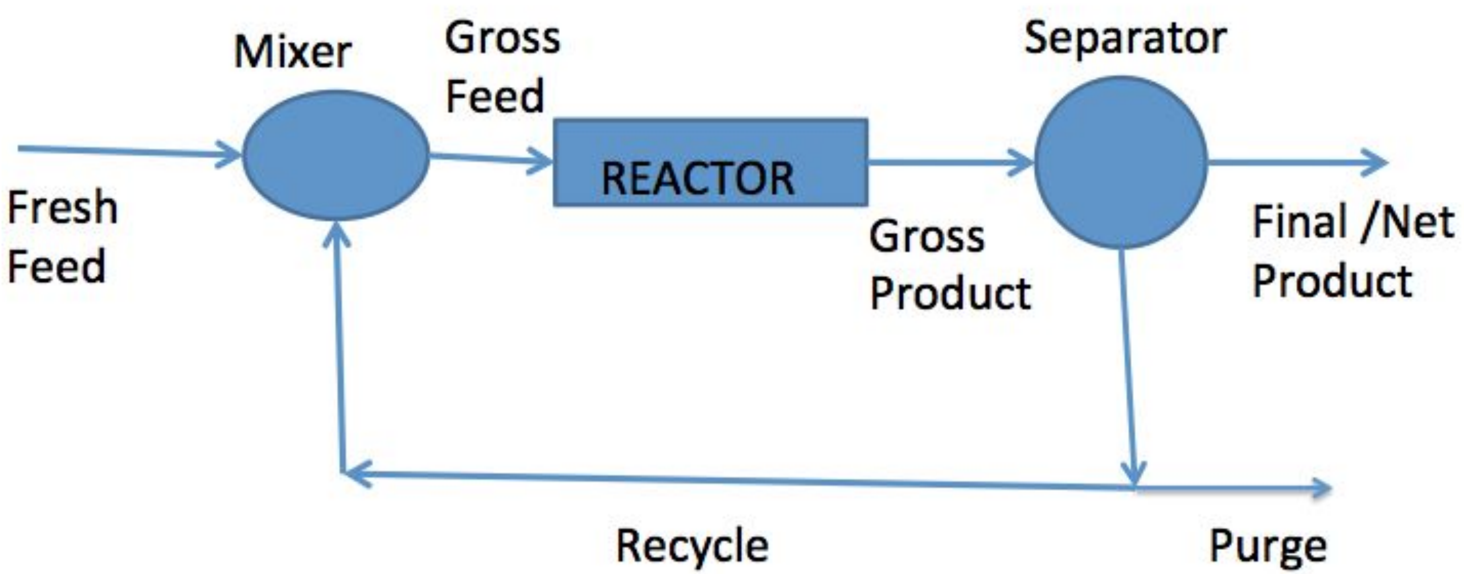
Product separation and recycle

- **In many processes the output from the reactor contains unconverted reactant.**
- **This unconverted reactant is required to be separated from the product and sent back to the process to achieve maximum conversion.**



- ✔ **In a process, where reaction is involved, there are two ways of defining conversion**
- ✔ **When the reactant passes once through the reactor**

  Single pass conversion =

  (reactant in Gross Feed – reactant in Gross Product)/ (reactant in Gross Feed)

- ✔ **When reactant is recycled back to the reactor and the conversion is observed at the outlet of the process**

  Overall conversion =

  (reactant in Fresh Feed – reactant in Final Product)/ (reactant in Fresh Feed)

Problem

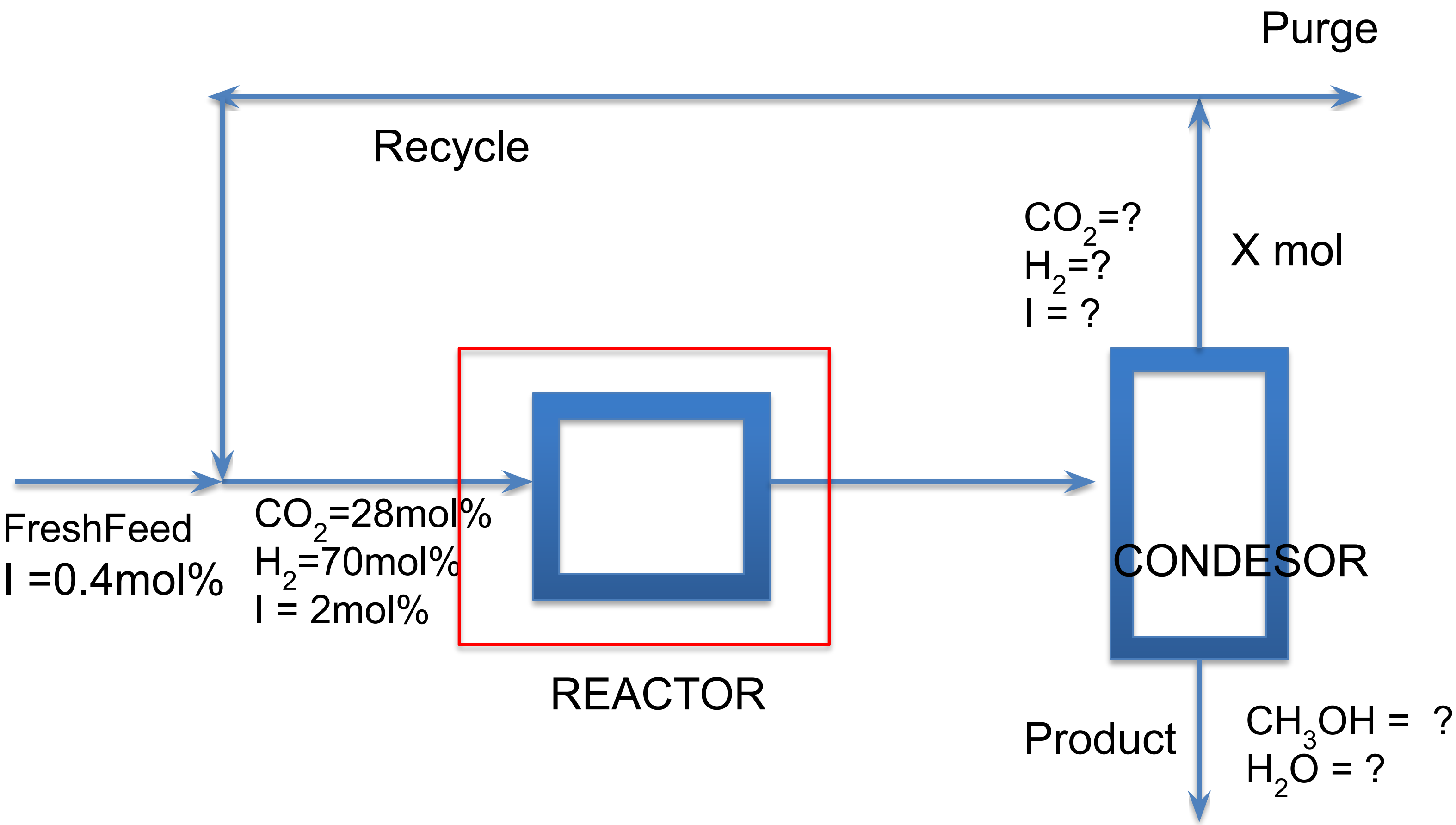
CO_2 reacts with H_2 to produce methanol as per the reaction:

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$$

The fresh feed to the process contains hydrogen, carbon dioxide, and 0.4 mol% inerts (I). The reactor effluent passes through a condenser that removes all of the methanol and water formed and none of the reactants and inerts. The later substances are recycled to the reactor. To avoid the buildup of the inerts in the reactor, a purge stream is withdrawn from the recycle stream.

The feed to the reactor contains 28 mol% CO_2, 70 mol% H_2 and 2 mol% inerts. The single pass conversion of hydrogen is 60%. Calculate the molar flow rates and molar compositions of the fresh feed, the feed to the reactor, the recycle stream, and the purge stream.

SOLUTION



What should be the basis ?
Where to write M.B. first ?

- Basis: 100 mol of feed to reactor

60% single pass H_2 conversion is given

H2 Balance: H_2 in – H_2 out = H_2 converted

moles of H_2 exiting the reactor = mol H_2 in- mol H_2 converted

70 – 70*0.6 = 28 mol

H_2 consumed = 42 mol

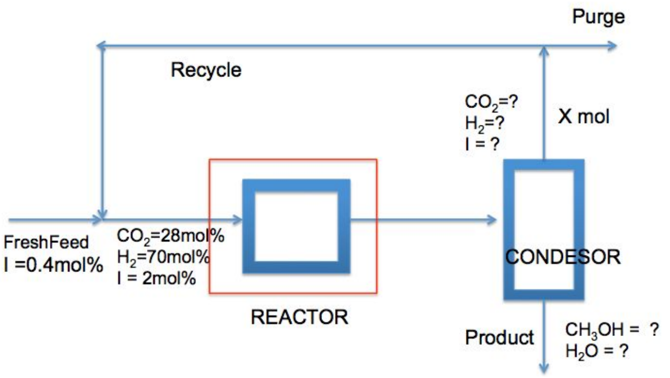
CO_2 Balance: CO_2 out = CO_2 produced

moles of CO_2 exiting the reactor=

28 – 42/3 = 14 mol

moles of CH_3OH exiting the reactor=

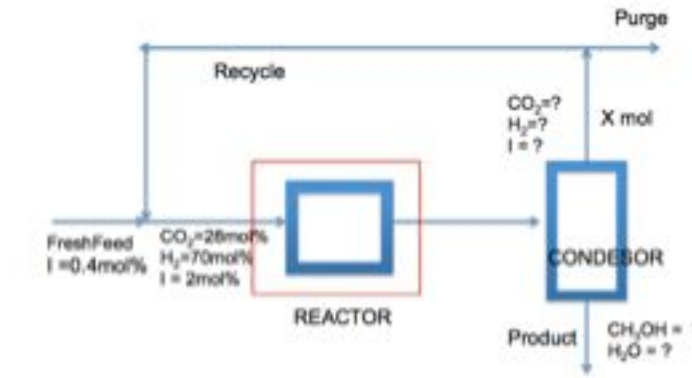
42/3 = 14 mol



$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$

Moles of H_2O exiting the reactor= 42/3 = 14 mol

M. Balance on condenser:



$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$$

Total mol balance:

input moles = output moles

(as there is no reaction in the condenser)

14+28+14+14+2 = Product (=28)+Purge+Recycle

Purge+Recycle = X = 44 mol

- Composition of X:
- CO2= 14 mol; H2 = 28 mol; I = 2 mol

C02 = 14/44 = 0.318 (0r 31.8%)

H2 = 28/44 = 0.636 (or 63.6%)

I= 2/44 = 0.046 (or 4.6%) }

(composition of purge and recycle will be same as that of X ??)

Balance on mixing point:

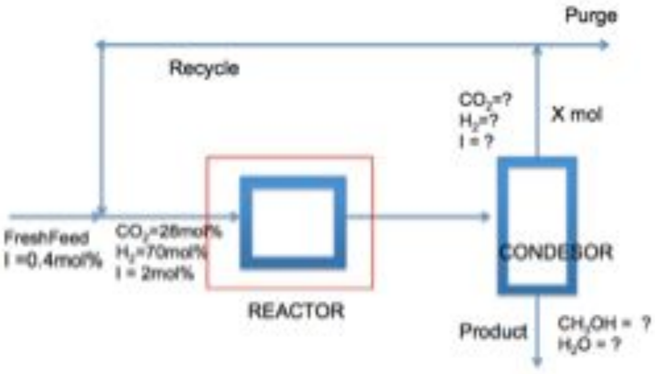
Total mol balance : Fresh Feed + Recycle = 100

Inerts balance: Fresh Feed *(0.004)+ Recycle* (0.046) = 2.0

Solving these two equations:

Fresh Feed = 61.4 mol; Recycle = 38.6 mol

Now, CO_2 balance gives:



$61.4 * x_{co2,FF} + 38.6(0.318) = 100*0.28$

$x_{co2,FF} = 0.256$ mol CO_2/mol

And,

$x_{H2,FF} = 1-0.004-0.256 = 0.74$ molH_2/m

$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$

- Balance on splitting point:

X = Recycle + Purge

Purge = 44 -38.6 = 5.4 mol

Problem

Scale the above process for a methanol production rate of 155 kmol/hr.

Solution

Scaling all streams :

For 100 kmol fed the methanol produced is 14 kmol

A scaling factor of 155/14 = 11.1 is required

- Fresh feed Calculated = 61.4 kmol
- Fresh feed scaled up = 681 kmol/h

(25.6 mol% CO_2, 74 mol% H_2, 0.4 mol% I)

- Feed to reactor Calculated = 100 kmol
- Feed to reactor scaled up = 1110 kmol/h

(28 mol% CO_2, 70 mol% H_2, 2 mol% I)

- Recycle = 38.6 kmol, Scaled up = 428 kmol/h

(31.8 mol% CO_2, 63.6 mol% H_2, 4.6 mol% I)

- Purge = 5.4 kmol, Scaled up = 59.9 kmol/h

(31.8 mol% CO_2, 63.6 mol% H_2, 4.6 mol% I)

TRY Yourself

- Ammonia is burned to form nitric oxide in the following reaction:

  $$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

(i) If ammonia is fed to a continuous reactor at a rate of 100 kmol NH_3/h, what oxy`gen feed rate (kmol/h) would correspond to 40% excess O_2.

(ii) If 50 kg of ammonia and 100 kg of oxygen are fed to a batch reactor, determine the excess reactant and its percentage excess. Also, find the mass of NO produced (kg) if the reaction proceeds to completion.