CHE211 BASIC PRINCIPLES IN CHEMICAL ENGINEERING
2021- 2022 Fall Semester

Problem Set 4

1. A catalytic reactor is used to produce formaldehyde from methanol in the reaction

$$CH_3OH \rightarrow HCHO + H_2$$

A single-pass conversion of 60.0% is achieved in the reactor. The methanol in the reactor product is separated from the formaldehyde and hydrogen in a multiple-unit process. The production rate of formaldehyde is 900.0kg/h.

a) Calculate the required feed rate of methanol to the process (kmol/h) if there is no recycle.

b) Suppose the recovered methanol is recycled to the reactor and the single-pass conversion remains 60%. Without doing any calculations, prove that you have enough information to determine the required fresh feed rate of methanol (kmol/h) and the rates (kmol/h) at which methanol enters and leaves the reactor. Then perform the calculations.

2. Methanol is synthesized from carbon monoxide and hydrogen in a catalytic reactor. The fresh feed to the process contains 32.0 mole% CO, 64.0% H_2, and 4.0% N_2. This stream is mixed with a recycle stream in a ratio 5 mol recycle/1 mol fresh feed to produce the feed to the reactor, which contains 13.0 mole% N_2. A low single-pass conversion is attained in the reactor. The reactor effluent goes to a condenser from which two streams emerge: a liquid product stream containing essentially all the methanol formed in the reactor, and a gas stream containing all the CO, H_2, and N_2 leaving the reactor. The gas stream is split into two fractions: one is removed from the process as a purge stream, and the other is recycle stream that combines with the fresh feed to the reactor.

a) Calculate the production rate of methanol (mol/h), the molar flow rate and composition of the purge gas, and the overall and single-pass conversions.

b) Briefly explain in your own words the reasons for including (i) the recycle stream and (ii) the purge stream in the process design.

3. Methanol is being produced by reacting CO and H_2. A fresh feed stream containing CO and H_2 joins a recycle stream and the combined stream is fed to a reactor. A portion of methanol leaving the reactor is condensed, and the unconsumed CO and H_2 and uncondensed CH_3OH are recycled. The stream going from reactor to the condenser flows at a rate of 275 mol/min., and contains 10.6 wt%H_2, 64.0 wt%CO, and 25.4wt% CH_3OH. The mol fraction of methanol in recycle stream is 0.004. Calculate the molar flow rates of CO and H_2 in the fresh feed , and the production rate of liquid methanol, flow rate of recycle stream.

4. Ethylene oxide is produced by the catalytic oxidation of ethylene.

$$2\ C_2H_4 + O_2 \rightarrow 2\ C_2H_4O$$

An undesired reaction is the combustion of ethylene

$$C_2H_4 + 3O_2 \rightarrow 2\ CO_2 + 2\ H_2O$$

The feed to the reactor contains 3 moles of ethylene per mole of oxygen. The single-pass conversion is 20%, and for every 100 moles of ethylene consumed in the reactor, 80 moles of ethylene oxide emerge in the reactor products. After separation ethylene and oxygen are recycled back to the reactor, ethylene oxide is sold as a product, and carbon dioxide and water are discarded. Calculate the molar flow rates of ethylene and oxygen in the fresh feed needed to produce 1500 kg C_2H_4O/h, and the overall conversion of ethylene.

5. The fresh feed to an ammonia production process contains 24.75% nitrogen, 74.25% hydrogen, and the balance inerts(I). The feed is combined with a recycle stream containing the same species, and the combined stream is fed to a reactor in which a 25% single pass conversion of nitrogen is achieved. The products pass through a condenser in which essentially all of the ammonia is removed, and the remaining gasses are recycled. However to prevent build up the inerts a purge stream must be taken off. The recycle stream contains 12.5% inerts. Calculate the overall conversion of nitrogen, the ratio (moles purge gas / mole of gas leaving the condenser), and the ratio moles fresh feed / mole fed to the reactor).

6. It is proposed to produce ethylene oxide ($(CH_2)_2O$) by the oxidation of ethane (C_2H_6) in the gas phase.

$$C_2H_6 + O_2 \rightarrow (CH_2)_2O + H_2O$$

The ratio of air to the C_2H_6 in the gross feed into the reactor is 10 to 1 , and conversion of C_2H_6 on one pass through the reactor is 18%. The unreacted ethane is separated from the reactor products and recycled as shown in Figure 6. What is the ratio of recycle stream to the feed stream, and what is the composition of the outlet gas from the reactor?

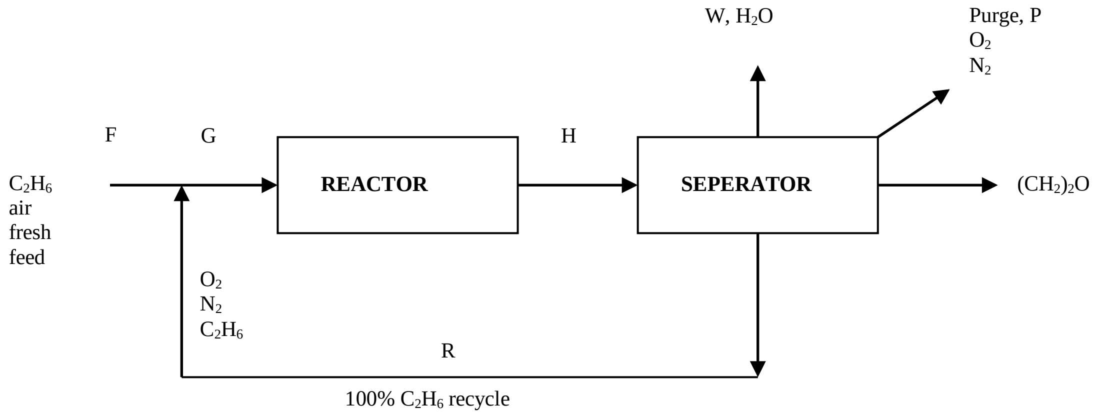


Figure - 6

7. D-Glucose and D-Fructose have the same chemical formula ($C_6H_{12}O_6$) but different properties. Glucose is converted to fructose as shown in Figure 7, but 60% is converted on one pass through the converter vessel so that unconverted material is recycled. Calculate the flow of the recycle stream per kg of 100% glucose fed to the converter. Ignore the solvent water used to carry the glucose and fructose.

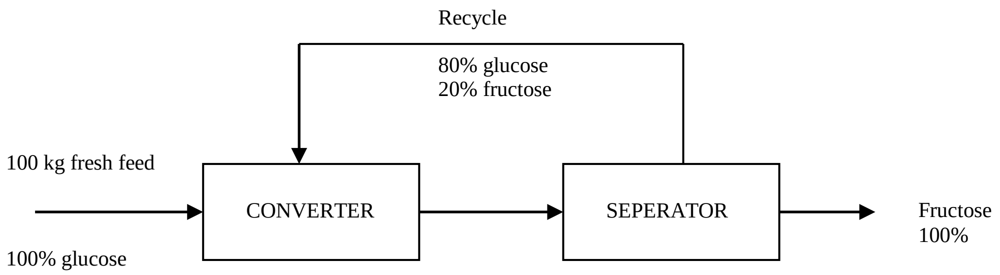


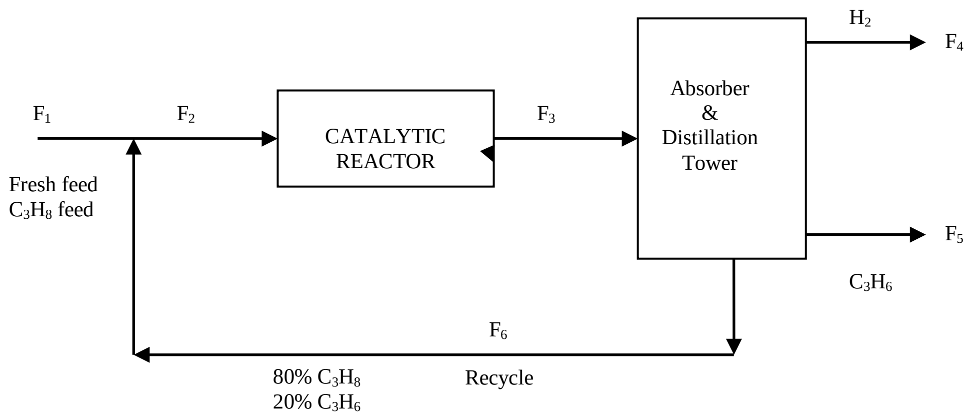
Figure-7

8. The process shown in Fig.8 is the dehydrogenation of propane (C_3H_8) to propylene(C_3H_6)according to the reaction :

$$C_3H_8 \rightarrow C_3H_6 + H_2$$

The conversion of propane to propylene based on the total propane feed into reactor at F_2 is 40%.
The product flow rate F_5 is 50 kg.mol /hr.

a) Calculate all the six flow rates F_1 to F_6 in kg mol/hr.
b) What is the percent conversion of propane in the reactor based on the propane fed to the process(F_1).



9. The fresh feed to a reactor in which methanol is synthesized from CO and H_2 contains 32%CO, 64% H_2, and 4% N_2, and flows at a rate of 100 mol/h. The fresh feed is mixed with a recycle stream flowing at a rate of 400 mol/h to produce a reactor feed containing 13.0% N_2. The product stream leaving the condenser contains only liquid methanol. From the recycle stream purge is taken off. Calculate the production rate of methanol (mol/h), the molar flow rate and the composition of the purge gas, and the overall and single-pass conversions.

10. In the simplified flow diagram shown in Figure 10, we see that each mol of ethanol, formaldehyde, and acetaldehyde are produced per mole of ethane when it is oxidized with air, and equimolar amounts of CO and CO_2 are also produced.
If 1000 lb_m / day of acetaldehyde are desired, determine the weight and weight percent composition of each stream.

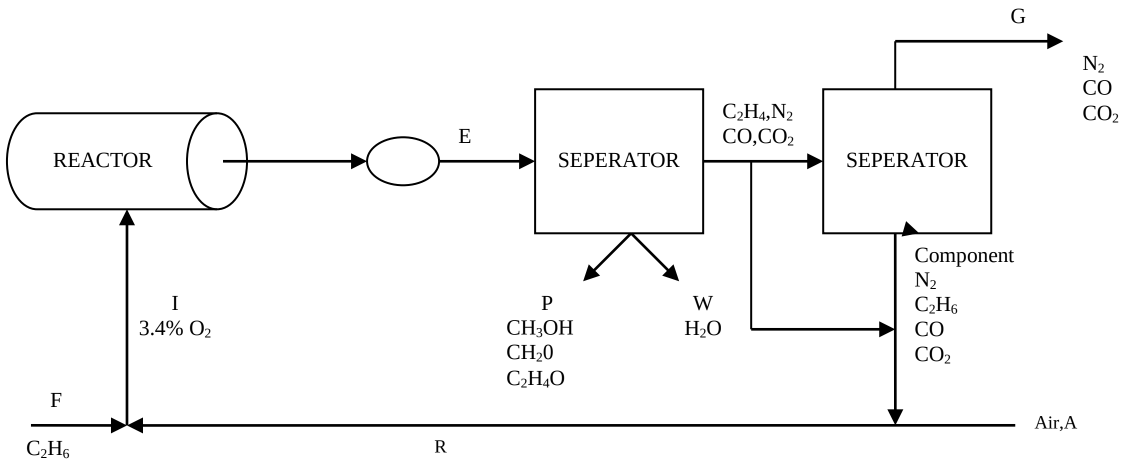


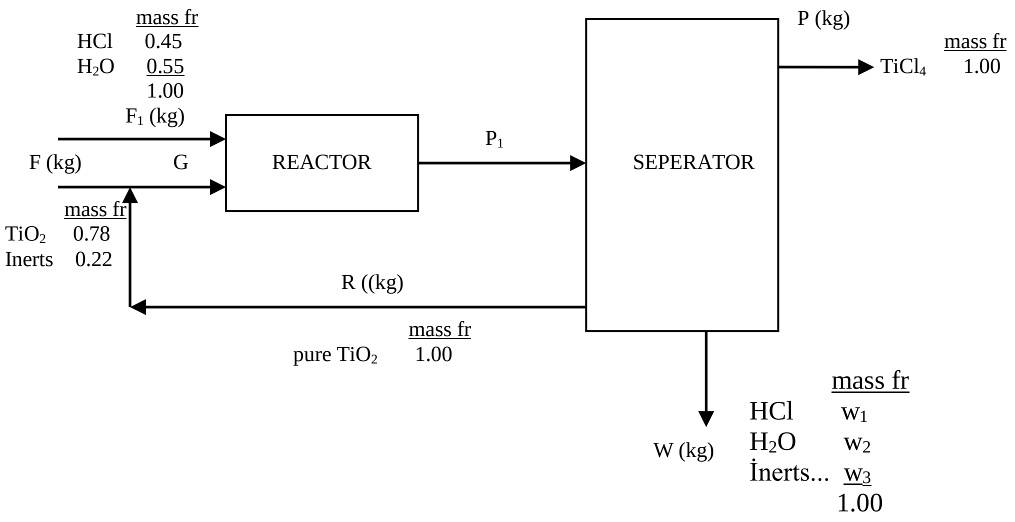
Figure-10

11. $TiCl_4$ can be formed by reacting titanium dioxide (TiO_2) with hydrochloric acid. TiO_2 is available as an ore containing 78% TiO_2 and 22% inerts. The HCl is available as 45 wt% solution (the balance is water). The per pass conversion of TiO_2 is 75%. The HCl is fed into the reactor in 20% excess based on the reaction. Pure unreacted TiO_2 is recycled back to mix with the TiO_2 feed.

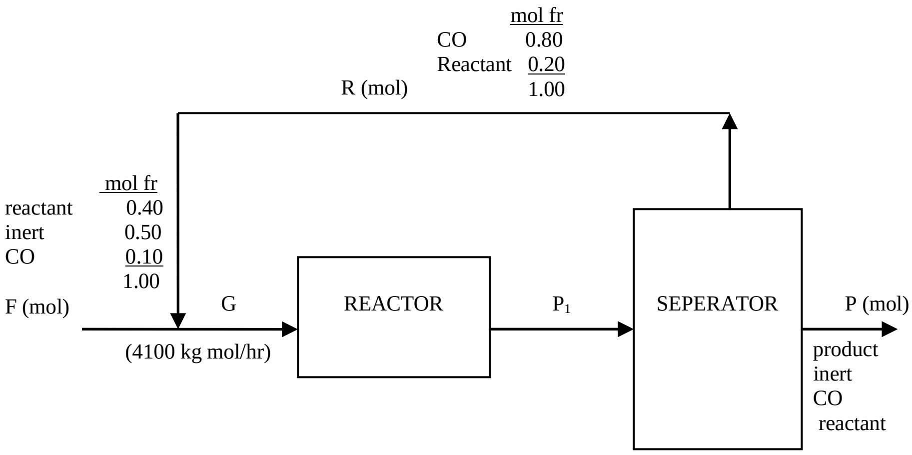
$$TiO_2 + 4HCl \rightarrow TiCl_4 + 2H_2O$$

For 1 kg of $TiCl_4$ produced, determine:

a) the kg of TiO_2 ore fed.
b) the kg of 45 wt % HCl solution fed.
c) the ratio of recycle stream to fresh TiO_2 ore (in kg).
(MW: TiO_2 79.9; HCl 36.47; $TiCl_4$ 189.7)
d) Overall conversion ?



12. Many chemicals generate emissions of volatile compounds that need to be controlled. In the process shown in the accompanying figure, the CO in the exhaust is substantially reduced by separating it from the reactor effluent and recycling the unreacted CO together with the reactant. Although the product is proprietary, information is provided that the fresh feed stream contains 40% reactant, 50% inert and 10% CO, and that on reaction 2 moles of reactant yield 2.5 moles of product. Conversion of the reactant to product is 73% on one pass through the reactor, and 90% for the over all process. The recycle stream contains 80% CO and 20% reactant. Calculate the ratio of moles of the recycle stream to moles of the product stream.



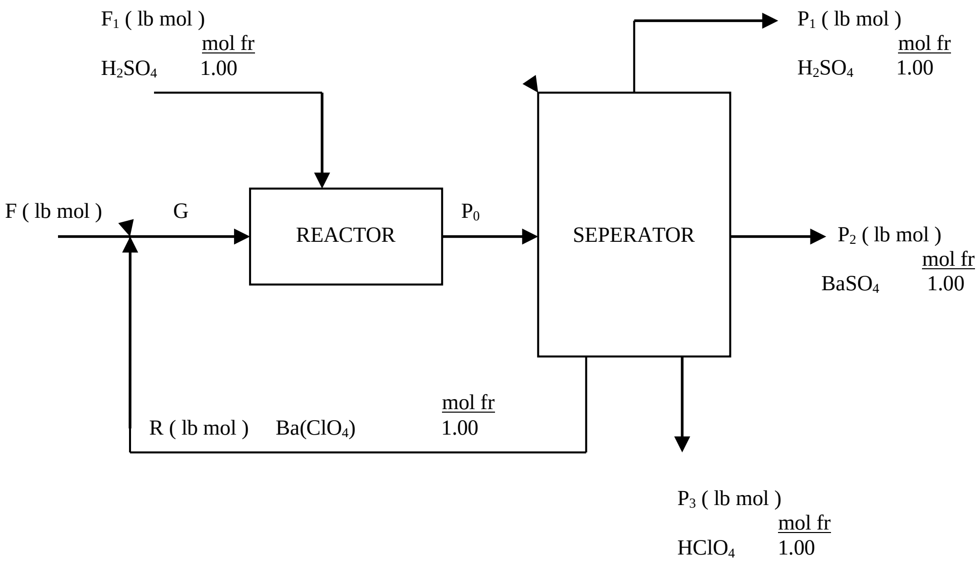
13. Perchloric acid ($HClO_4$) can be prepared as shown in the diagram below from $Ba(ClO_4)_2$ and H_2SO_4. Sulfuric acid is supplied in 20% excess to react with $Ba(ClO_4)_2$. If 17,400 lb $HClO_4$ leave the separator and the recycle is 6125 lb $Ba(ClO_4)_2$ over the time period, calculate:

a) The overall conversion of $Ba(ClO_4)_2$.
b) The lb of $HClO_4$ leaving the separator per lb of feed.
c) The lb of H_2SO_4 entering the reactor
d) The per pass conversion of $Ba(ClO_4)_2$

Note: 20% H_2SO_4 is based on the total $Ba(ClO_4)_2$ entering the reactor.

$Ba(ClO_4)_2 + H_2SO_4 \rightarrow BaSO_4 + 2\ HClO_4$

MW: $Ba(ClO_4)_2$ 336; $BaSO_4$ 233; H_2SO_4 98; $HClO_4$ 100.5



14. In an attempt to provide a means of generating NO cheaply, gaseous NH_3 is burned with 20 per cent excess O_2:

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

The reaction is 70 percent complete. The NO is separated from the unreacted NH_3, and the latter recycled as shown Figure-14. Compute the

a) Moles of NO formed per 100 moles of NH_3 fed.
b) Moles of NH_3 recycled per mole of NO formed.

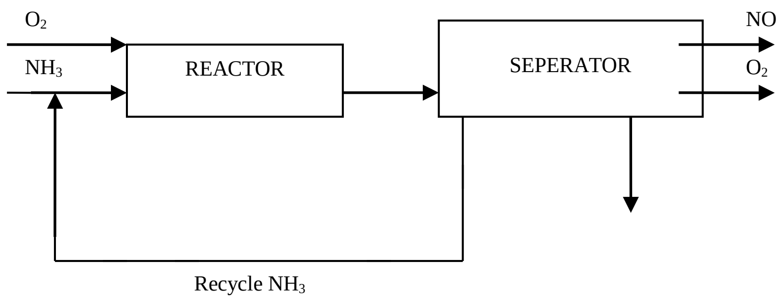


Figure - 14

15. Acetic acid is to be generated by the addition of 10 percent excess sulfuric acid to calcium acetate. The reaction $Ca(Ac)_2 + H_2SO_4 \rightarrow CaSO_4 + 2HAc$ goes on with 90 percent completion. The unused $Ca(Ac)_2$ and the H_2SO_4 are separated from the products of the reaction, and the excess $Ca(Ac)_2$ is recycled. The acetic acid is separated from the products. Find the amount of recycle per hour based on 1000 lb of feed per hour, and also the pounds of acetic acid manufactured per hour. See Figure 15.

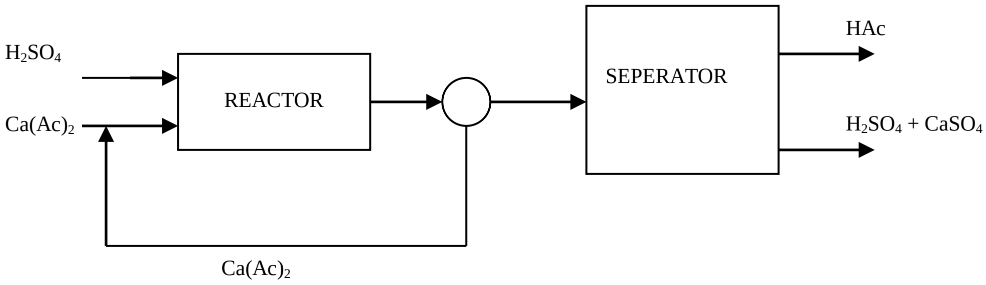
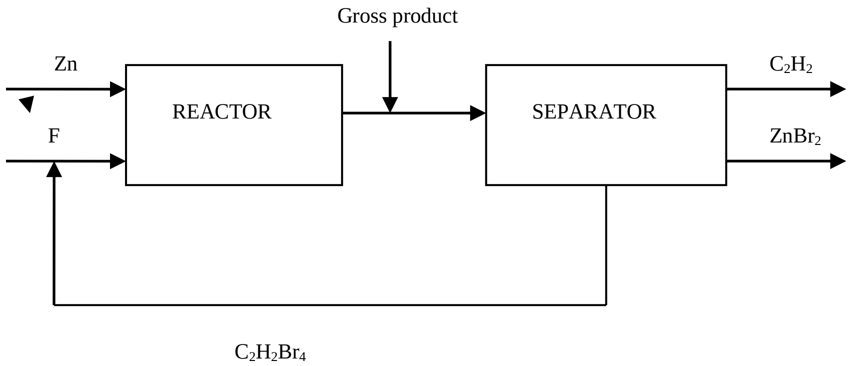


Figure - 15

16. The reaction of ethyl-tetrabromide with zinc dust proceeds as shown in the diagram below. The reaction is :

$C_2H_2Br_4 + 2Zn \rightarrow C_2H_2 + 2ZnBr_2$



Based on the $C_2H_2Br_4$, on one pass through the reactor the conversion is 80%, and the unreacted $C_2H_2Br_4$ is recycled. On the basis of 1000 kg of $C_2H_2Br_4$ fed to the reactor per hour, calculate:

a) how much C_2H_2 is produced per hour (in lb)
b) the rate of recycle in lb / hour
c) the amount of Zn that has to be added per hour if Zn is to be 20% in excess
d) the mole ratio of $ZnBr_2$ to C_2H_2 in the products**.**

17. Fructose is produced from glucose in a reactor with an isomerization reaction:

$C_6H_{12}O_6 \rightarrow C_6H_{12}O_6$
Glucose Fructose

Fresh feed (E) contains 40% by mass glucose and 60% water. Water is used as solvent and it doesn't enter reaction. Fresh feed is mixed with recycle stream (R) to produce process feed (F´) . Process feed contains 4% by mass fructose. Reactor output (M) is separated into two stream. The first is taken as product and the second stream is used as recycle stream. Reactor output, product and recycle stream have the same composition. Product/recycle mass ratio is 8.33. Calculate: (a) composition of the recycle stream, (b) single pass conversion.

18. Product P is produced from reactant A according to the reaction

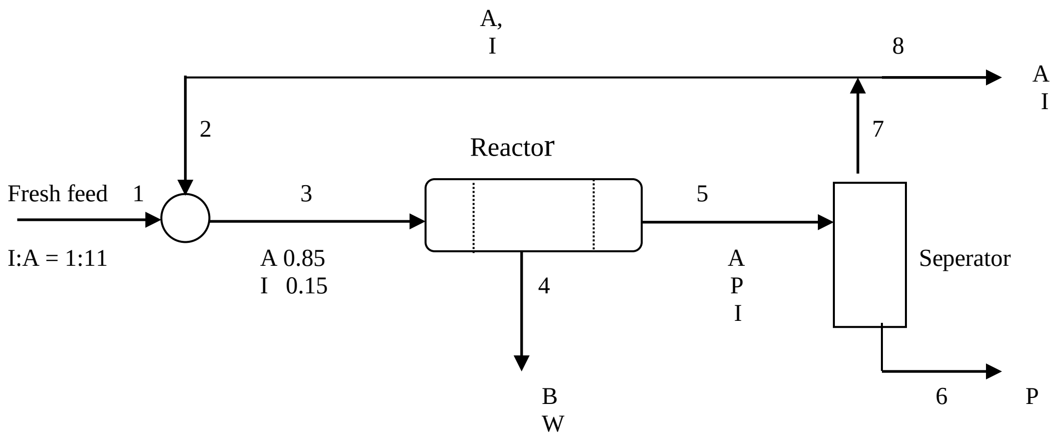
$2A \rightarrow 2P + W$

Unfortunately one side reaction is also observed

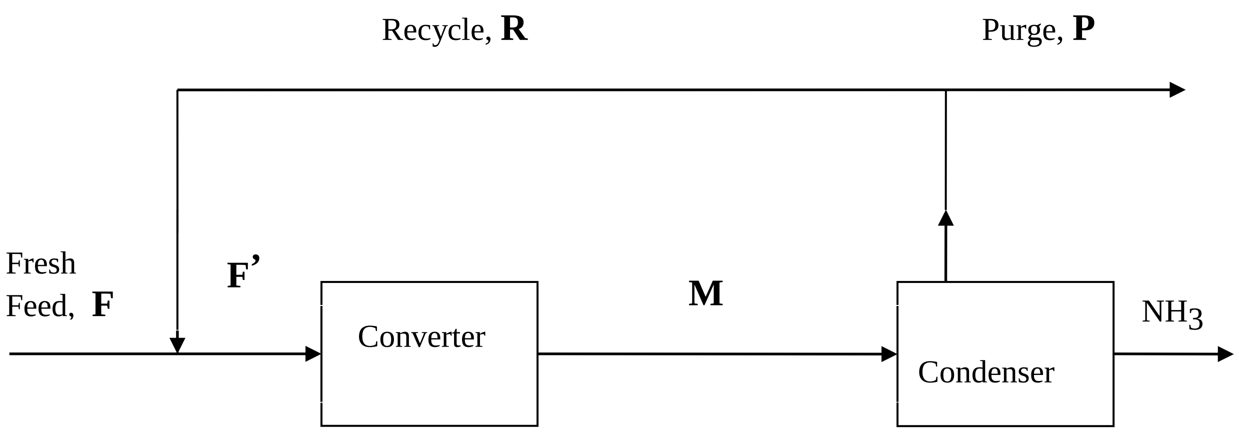
$A \rightarrow B + W$

In the fresh feed mole ratio of inert (I) to reactant A is 1:11. Mole fraction of A in the process feed is 0.85. A 50% single-pass conversion of A was observed in the reactor . For every 100 moles of A consumed in the reactor, 80 moles of P emerge in the reactor products. Take 100 moles of feed to the reactor as basis

(a) Do a degree of freedom analysis and deduce a calculation order which can be used to determine composition and flow rates of all streams.
(b) Solve the problem. Calculate over-all conversion of R.
(c) For a production rate of 1000 mol P/h , calculate the molar flow rates of the fresh feed and recyle.



19. An ammonia (NH_3) converter is fed a stoichiometric mixture of nitrogen and hydrogen (i.e mol ratio of nitrogen to hydrogen is 1:3) and argon. In the converter 10% of the reactants are converted to NH_3. All of the NH_3 formed is removed in a condenser. The unconverted gas is recycled and mixed with the fresh feed before giving the converter. In order to avoid unlimited accumulation of argon, a purge stream is taken of from the recycle stream. Calculate the fraction of recycle gas that is taken as purge stream if the argon entering the converter is to be limited to 0.5%. In fresh feed, N_2 and H_2 are in stoichiometric ratio, and the ratio of the N_2 to argon is (78.0/1.0).



20) Methane (CH_4) reacts with chlorine to produce methyl chloride(CH_3Cl) and hydrogen chloride (HCl). Once formed, methyl chloride may undergo further chlorination to form methylene chloride(CH_2Cl_2).

A methyl chloride production process consists of a reactor, a condenser, and an absorption column. A gas stream containing 80.0 mole% methane and the balance chlorine is fed to the reactor. In the reactor a single-pass chlorine conversion is 100 % ; the mole ratio of methyl chloride to methylene chloride in the product is 5:1. The product stream flows to the condenser. Two streams emerge from the condenser: the liquid condensate, which contains essentially all of the methyl chloride and methylene chloride in the reactor effluent, and a gas containing the methane and hydrogen chloride. The gas leaving the condenser flows to the absorption column where it contacts a solvent The solvent absorbs essentially all of the HCl and none of the CH_4 in the feed. The liquid leaving the absorber is pumped elsewhere in the plant for further processing, and the methane is recycled to join the fresh feed to the process (a mixture of methane and chloride). The combined stream is feed to the reactor.

(a) Choose a quantity of the reactor feed as a basis of calculation, draw and label a flowchart, and determine the degrees of freedom for the overall process and each single unit and stream mixing point. Then write in order the equations you would use to calculate the molar flow rate and molar composition of the fresh feed, the rate at which HCl must be removed in the absorber, the methyl chloride production rate, and the molar flow rate of the recycle stream. Do no calculations.

(b) Calculate the quantities specified in part (a), and the composition of the fresh feed.

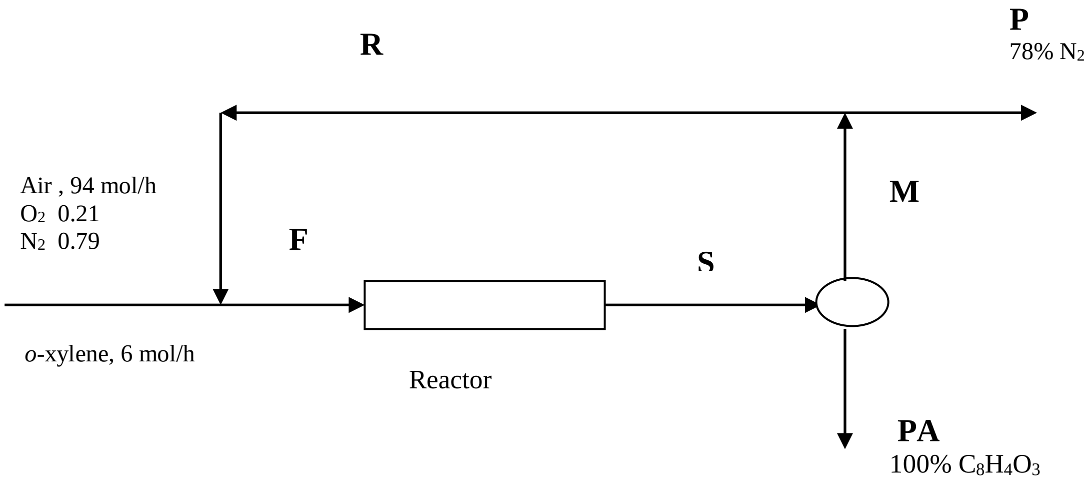
(c) What molar flow rates and the recycle stream are required for a methyl chloride production rate of 1000 kg/h?

Molecular weight of CH_3Cl is 50.5.

21. Phthalic anyhride (PA) is produced by the oxidation of *o*-xylene (C_8H_{10}) in a fixed bed reactor according to the reaction.

$C_8H_{10} + 3O_2 \rightarrow C_8H_4O_3 + 3H_2O$

All of the $C_8H_4O_3$ (PA) is removed in condenser. Purge gas is 78% N_2 and 60% single pass conversion of *o*-xylene takes place in reactor. Fresh feed is the mixture of air and o-xylene. Calculate: (a) the molar flow rate and composition of the purge stream , (b) the molar flow rate of recycle stream and molar flow rate of each chemical compound in stream F



22. Toluene reacts with H_2 to form benzene (B) , but a side reaction occurs in which a by product diphenyl (D) is formed . The process is shown in the figure below

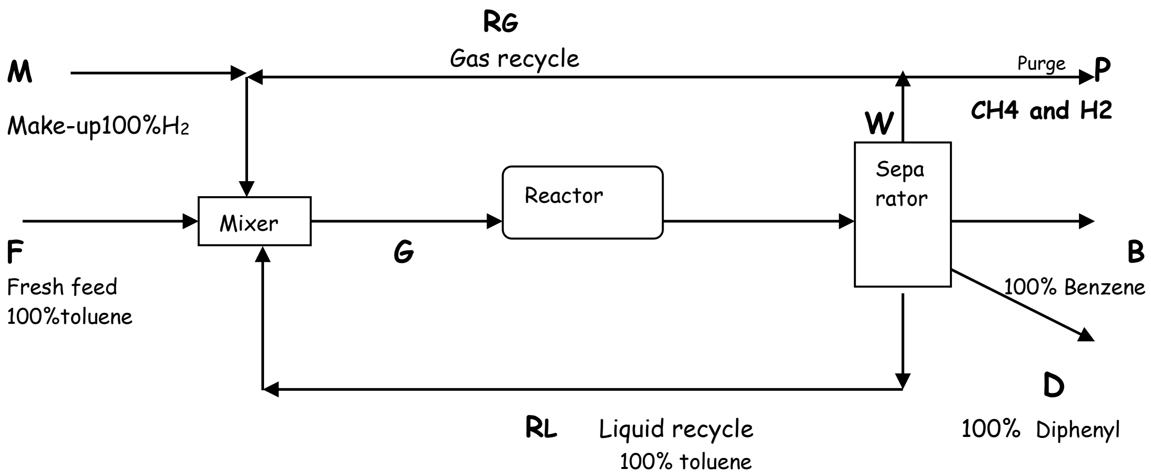
$C_7H_8 + H_2 \rightarrow C_6H_6 + CH_4$ (1)
(toluene) (hydrogen) (benzene) (methane)

$2C_7H_8 + H_2 \rightarrow C_{12}H_{10} + 2CH_4$ (2)
(diphenyl)

H_2 gas is added to the gas recycle stream to make the ratio of H_2 to CH_4 1 to 1 before the gas enters the mixer .The ratio of H_2 to toluene entering the reactor in G is 4 H_2 to 1 toluene(the ratio of H_2 to CH_4 is still 1 to 1 in G).

The single pass conversion of toluene in the reactor is 88%. For every 100 moles of toluene consumed in the reactor, 91 moles toluene were used in first reaction and the remaining were consumed in the second reaction.

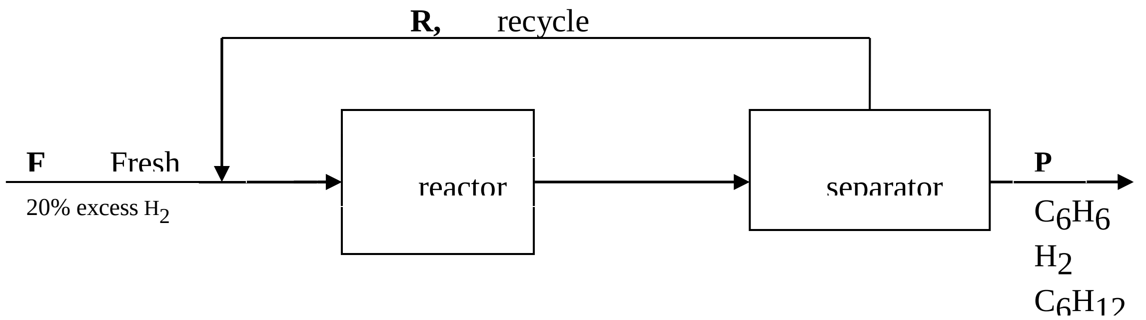
i) Take as a basis of 100 moles of toluene entering reactor in G, do a degree of freedom analysis based on *molecular species balances* to prove that the system has zero degrees of freedom.
ii) Calculate the moles of R_G and R_L and fresh feed per hour for a benzene production rate of 7800 kg/hr with the use of same basis as in part i. C:12, H:1



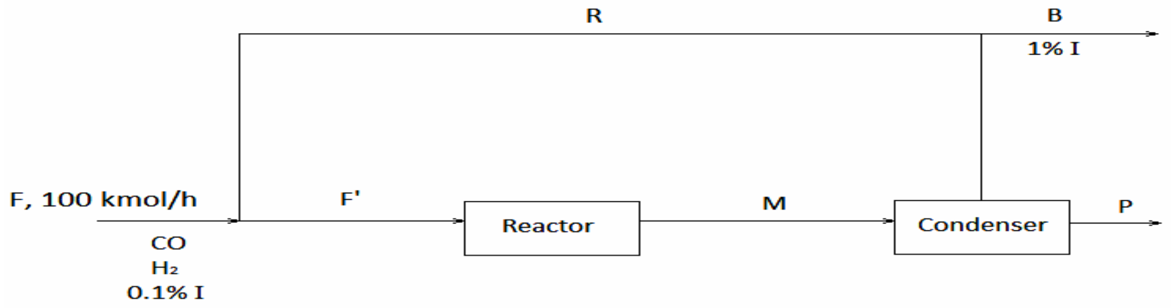
23. Cyclohexane (C_6H_{12}) can be made by the reaction of benzene (Bz) (C_6H_6) with hydrogen according to the following reaction:

$$C_6H_6 + 3H_2 \rightarrow C_6H_{12}$$

For the process shown in Figure, the overall conversion of benzene is 95%, and the single pass conversion is 20%.Assume that 20% excess hydrogen is used in the fresh feed, and that the composition of the recycle stream is 22.74 mol % benzene and 77.26 mol % hydrogen, (a) determine the ratio of the recycle stream to the fresh feed stream (b) average molecular weight of the product.



24. Methyl alcohol (CH_3OH) is obtained from the reaction of CO and hydrogen: $CO + 2H_2 \rightarrow CH_3OH$. Fresh feed is composed of stoichiometric mixture of CO and H_2 and 0.1% inert (I). Single pass conversion of CO is 15%. All of the methanol(CH_3OH) formed is condensed and obtained as a pure liquid alcohol. A fraction of the recycle gas stream is taken as purge. Purge stream contains 1% inert. For 100 kmol /h of fresh feed, calculate : (a) the flow rates of methanol produced, recycle and purge stream, (b) Overall conversion of CO, (c) The fresh feed and recycle stream required to produce 3000 kg CH_3OH/h.



25. Hydrogen gas is used to reduce Fe_2O_3(s) completely to metallic iron Fe(s) according to the reaction :

$$Fe_2O_3 (s) + 3H_2 (g) \rightarrow 2Fe (s) + 3 H_2O(g)$$

After the reactor, solid Fe(s) is taken away and all of the water content of reactor gas effluent is condensed and the unreacted hydrogen and inert is recycled. Fresh feed contains 1 mole % impurity I and balance is H_2. The stream entering the reactor contains 3.5 % I in moles. If the ratio of recycle to fresh feed is 5:1 on molar basis

(a) Calculate the flow rate and composition of purge stream by taking 100 k-mol fresh feed (b)Calculate single- pass conversion of H_2 (c) Calculate over-all conversion of H_2 (d) Calculate the amount of fresh feed to reduce 6.25 k-mol /h Fe_2O_3(s) completely.