# Design

Material Balance

|  |  |
| --- | --- |
| Component | Molecular weight  (kg/kmol) |
| Methanol | 32 |
| Formaldehyde | 30 |
| Water | 18 |
| Oxygen | 32 |
| Nitrogen | 28 |

60000 tone/yr of 37% (w/w) formaldehyde solution. The plant runs for 8000 hours per year.

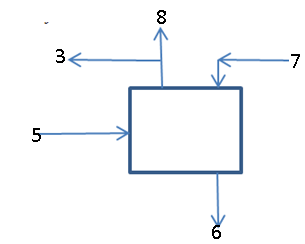
Conversion-

Stream 6(product stream)

Moles of 37% Formaldehyde in outlet stream MF,6=0.37(7500)= 2775 kg/hr   
Therefore moles produced,   
NF6 = NF5 = 92.5

Stream 4(inlet + recycle)

Inlet + generation = output + accumulation + consumption



Material balance around the absorber

Assume the absorber operates at 100% efficiency this mass corresponds to the amount of pure formaldehyde in stream 6. i.e. NF5 = NF6

1mole CH3OH=1mole HCHO  
92.5kmol/hr CH3OH=92.5kmol/hr HCHO

α is the extent of reaction, i.e. the number of moles of methanol reacted.  
α = 92.5As the methanol only undergoes 75% conversion in the reactor.

Moles of Methanol in stream 4, NM,4,

Assuming that methanol and air are equal in stoichiometric quantities on entering the reactor, the ratio of methanol to oxygen is as follows;

Methanol : Oxygen  
 2: 1

NO,4 = 0.5NM4  
NO,4 =0.5(123.3)=61.65

Equation- CH3OH + O2 = HCHO + H2O  
  
61.65kmol/hr of O2. As oxygen is 21% (wt/wt), NA4=293.57kmol/hr.   
therefore, NN4=231.92kmol/hr.

The methanol entering the reactor must be kept at approximately 10% concentration by volume. Assuming a perfect gas, % by volume is the same as % mole.

Total moles in stream 4, Ntotal,4

Ntotal,4= Therefore number of moles of nitrogen remaining-  
NN,4=1233-92.5-92.5= 1048

Mw=MT – MM -MF  
Mw,6 = 7500-986.56-2775 = 3738.44  
Nw,6=

Stream 5(Reactor output)

The remaining methanol which was not reacted, NM5:   
NM,5=NM,4 – α = 30.8   
Can assume that no methanol is recycled in stream 3.

The amount of oxygen remaining which is unreacted:   
NO,5= NO,4 – 0.5α = 15.4

The amount of formaldehyde produced in the reaction:   
NF,5 = 𝛼 = 92.5 The amount of water produced in the reaction:   
NW,5 = 𝛼 = 92.5

Stream 7 (Water input)

Nw,5=92.5  
Nw,6=207.69

Nw,7 =Nw,6 – Nw,5   
N­w,7 = 207.69- 92.5=115.19

Stream 2 & 3

Composition of 3, 5 and 8 are assumed to be equal as no nitrogen is absorbed in the absorber and 8 is the off gasses.

NT,4=NT,2 + NT,3  
  
Oxygen balance-   
NO,4 = 0.21NT,2 + xO,3NT,3  
  
Nitrogen balance-  
NN,4 = 0.79NT2 + xN,3NT3

From stream 5,  
xO,3= xN,3=9855

Rearrange these equations to form two simultaneous equations-

NO,4= 0.21NT,2 + 0.0145NT,3  
NN,4 = 0.79NT,2 + 0.9855NT,3  
  
61.65=0.21NT,2 + 0.0145NT,3 (1)  
1048=0.79NT,2 + 0.9855NT,3 (2)

Multiply equation (1) by 0.79 and equation (2) by 0.21

48.70=0.166NT,2 + 0.011NT,3 (3)  
220.08=0.166NT,2 + 0.207NT,3 (4)

To solve, (4)-(3)

171.38=0.196NT,3  
NT,3=874.37  
  
Substitute this value back into equation (3),  
48.70=0.166NT,2 + 0.011(874.37)  
NT,2=235.43

Stream 2(Air input)  
  
NN,2=NT,2 (0.79)  
 =235.43(0.79)  
 =186.0

NO,2=NT,2 (0.21)  
 =235.43(0.21)  
 =49.44

Stream 3(Recycle)

For the oxygen and nitrogen compositions in stream 3 use the fractions calculated in stream 5.

xO,3= xN,3=9855

NN,3=NT,3 (xN,3)  
 =874.37 (0.9855)  
 =861.69

NO,2=NT,3 (xO,3)  
 =874.37 (0.0145)  
 =12.68

Stream 8(Off gases)

We assume that only nitrogen and oxygen gasses are present in the off gases stream.

NO,8=NO,5 – NO,3  
NO,8=15.4-12.68  
NO,8=2.72

NN,8=NN,5-N­N,3  
NN,8=1048-861.69  
NN,8=186.31

Mass balance over reactor

To check, carry out a mass balance over the reactor to observe whether the law of conservation of mass has been obeyed-

MT,4 = MT,5

MT,4 = MM,4+MN,4+MO,4MT,4 = NM,4(MWM)+MN,4(MWN)+MO,4(MWO)

MT,4=123.33(32) + 1048(28) + 61.65(32)  
MT,4=35260

MT,5 = MM,5+MN,5+MO,5+MF,5+MW,5MT,5 = NM,5(MWM)+NN,5(MWN)+NO,5(MWO)+NF,5(MWF)+NW,5(MWW)  
MT,5 = 30.8(32)+1048(28)+15.40(32)+92.5(30)+92.5(18)  
MT,5 =35260

It is clear that all of the mass has been conserved in the reactor.

Mass balance over whole system

A final check can be carried out using a mass balance over the whole system,  
Min=Mout

Min=MT,1+MT,2+MT,7  
Min=3950+6790+2070  
Min=12810

Mout=MT,6+MT,8  
Mout=7500+5300  
Mout=12800

Two different checks were carried out in order to determine the accuracy of the hand-calculated streams, mass balance over the rector and mass balance over the total system. The mass balance over the reactor showed that the law of conservation of mass was obeyed as the total mass in stream 4 (input to the reactor) was equal to the total mass in stream 5 (reactor ouput). The mass balance over the whole system was expected to show that total mass into the system was equal to the toal mass leaving the system. This was not exactly the same as here was a slight discrepancy of 10kg/hr. This could be down to rounding in Mathcad.

A final check could be carried out using Aspen Plus user interface…

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| STREAM TABLE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|  |  |  |  |  |  |  |  |  |
| Temperature (C) | 20 | 20 | 55 | 120 | 300 | 55 | 20 | 55 |
| Pressure (Bar) | 1 | 1 | 1 | 2 | 1.5 | 1 | 1 | 1 |
| Vapour Fraction | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| Mass Flow (tonne/hr) | 3.95 | 6.79 | 24.53 | 35.26 | 35.26 | 7.50 | 2.07 | 5.30 |
| Mole Flow (kmol/hr) | 123.33 | 235.44 | 874.37 | 1232.98 | 1279.20 | 331.03 | 115.20 | 189.02 |
|  |  |  |  |  |  |  |  |  |
| Component mole flow (kmol/hr) |  |  |  |  |  |  |  |  |
| Methanol | 123.33 | 0.00 | 0.00 | 123.33 | 30.80 | 30.83 | 0.00 | 0.00 |
| Oxygen | 0.00 | 49.44 | 12.68 | 61.65 | 15.40 | 0.00 | 0.00 | 2.72 |
| Nitrogen | 0.00 | 186.00 | 861.69 | 1048.00 | 1048.00 | 0.00 | 0.00 | 186.30 |
| Formaldehyde | 0.00 | 0.00 | 0.00 | 0.00 | 92.50 | 92.50 | 0.00 | 0.00 |
| Water | 0.00 | 0.00 | 0.00 | 0.00 | 92.50 | 207.70 | 115.20 | 0.00 |