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

# Course: Material and Energy Balances UCH301

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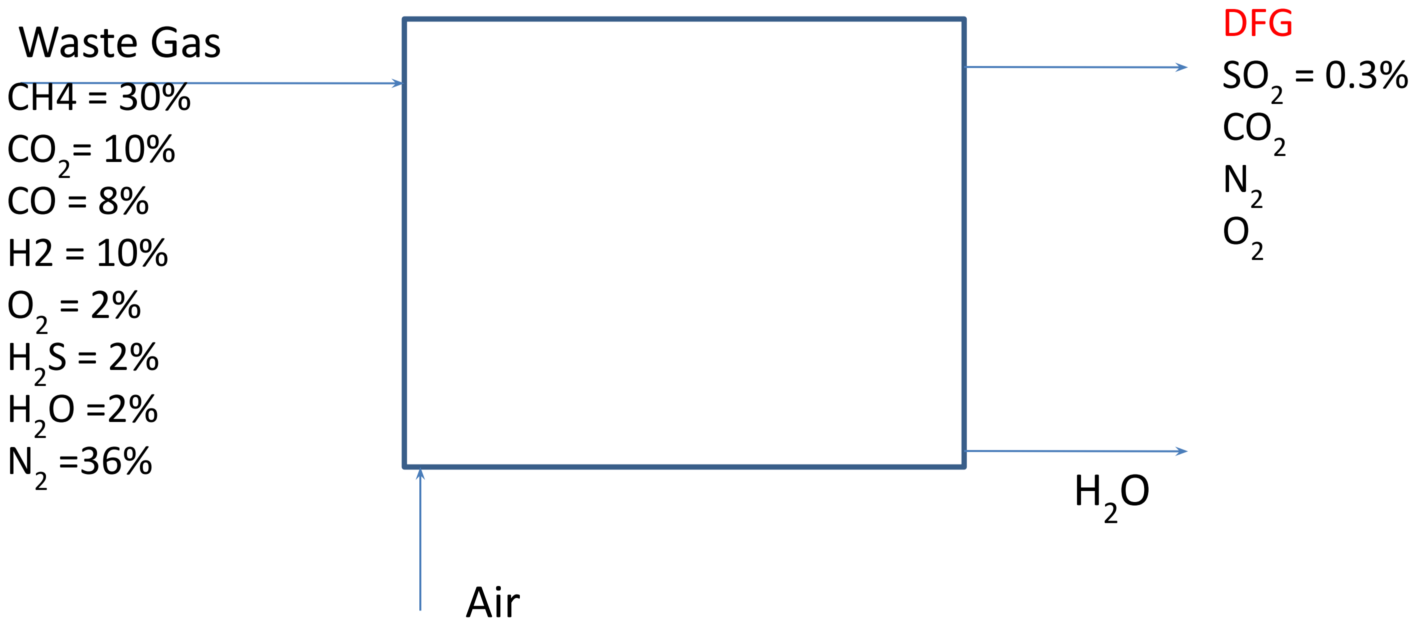
# Exercise

- A waste gas stream from a plant is being disposed off after burning it with air. The composition of the waste gas is:

$CH_4$ = 30%, **$CO_2$ = 10%,** CO=8%, $H_2$ = 10%, **$O_2$ = 2%,** $H_2S$= 2%, $H_2O$ = 2%, $N_2$= 36%

The Orsat analysis of the flue gas shows 0.3% $SO_2$ along with $CO_2$, $O_2$ and $N_2$. Calculate the percentage excess air and the composition of the Dry flue gas.

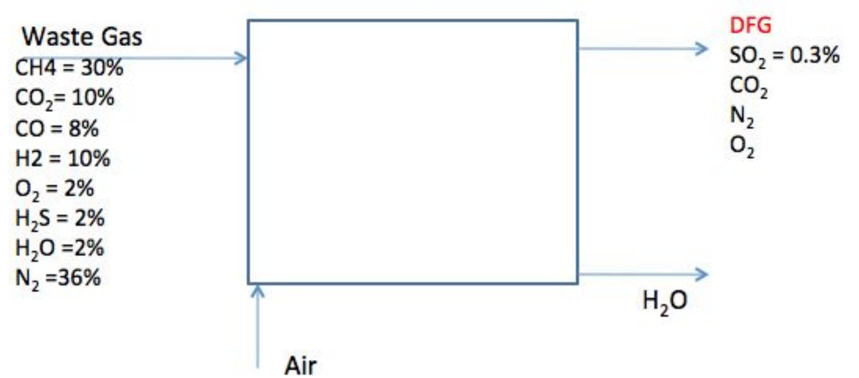
# Solution



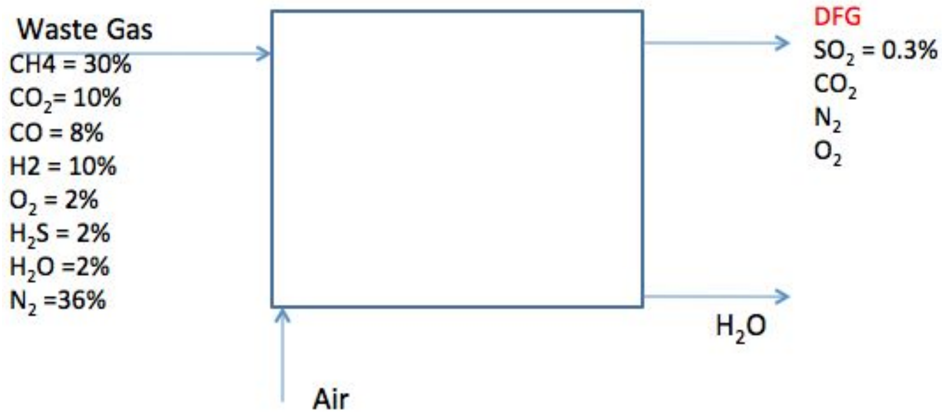

- Basis is not given in the statement, as the complete composition of waste gas is given we may choose
- Basis = 100 mol of Waste Gas

- From the given composition of waste gas we can calculate moles of each component in waste gas:

| $CH_4$ | $CO_2$ | $CO$ | $H_2$ |
|---|---|---|---|
| 30 mol | 10 mol | 8 mol | 10 mol |
| $O_2$ | $H_2S$ | $H_2O$ | $N_2$ |
| 2 mol | 2 mol | 2 mol | 36 mol |



- As moles of air (A), DFG and $H_2O$ (W) are not known we should first calculate the amount of air required from the given composition of waste gas:




Reactions Involved:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$CO + 1/2O_2 \rightarrow CO_2$

$H_2 + 1/2O_2 \rightarrow H_2O$

$H_2S + 3/2O_2 \rightarrow SO_2 + H_2O$

$O_2$ required:

for $CH_4$ : 60 mol;

For CO: 4 mol;

For $H_2$: 5 mol

For $H_2S$ : 3 mol

**Total = 60+4+5+3 = 72 mol**

$O_2$ in waste gas = 2 mol

(since this is available in feed gas, reduce from required amount)

Total $O_2$ required = 60+4+5+3 -2= 70mol

**Air required = 70/0.21=333.33 mol**

Reactions Involved:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$CO + 1/2O_2 \rightarrow CO_2$

$H_2 + 1/2O_2 \rightarrow H_2O$

$H_2S + 3/2O_2 \rightarrow SO_2 + H_2O$

## ✔ USE S BALANCE TO GET DFG MOLES

S balance: S input = S output

$2 = 0.003 * \text{mol DFG}$

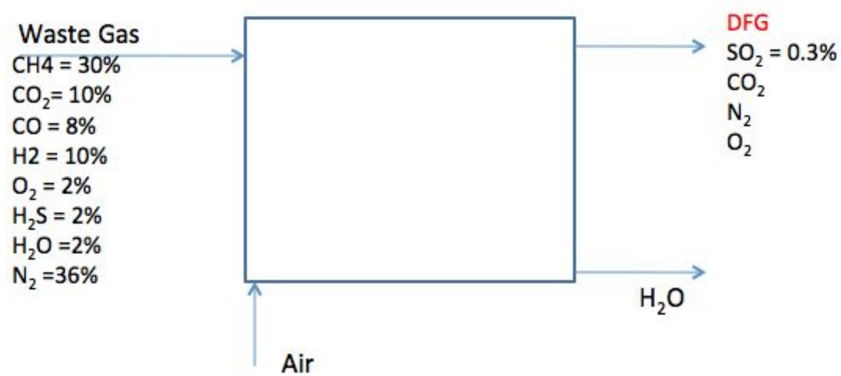
$\rightarrow$ mol DFG = 666.7 mol

## ✔ WRITE C, O, AND N ELEMENTAL BALANCES

C balance: C input = C output

$30+10+8 = Xco_{2,DFG} * 666.7$

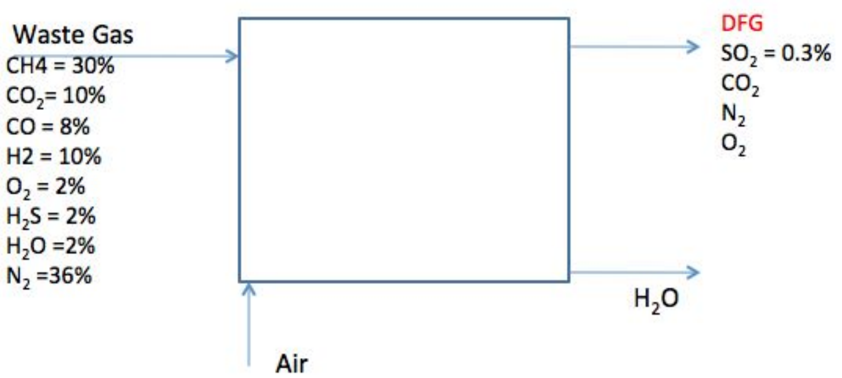
$\rightarrow \quad Xco_{2,DFG} = (48/666.7) = 0.072$



N2 balance :

$N_2$ Balance: $N_2$ in = $N_2$ out

$36 + A*0.79 = 666.7*X_{N2}$




O balance:

O at inlet = O at outlet

$10*2+8+2*2+2 + x_{O2,A}A*2 =$ Mol of $H_2O$ $+ x_{SO2,DFG}*666.7*2 + X_{CO2,DFG}*666.7*2 + X_{O2,DFG}*666.7*2$

Moles of water at outlet = 60 + 10+ 2+2 = 74 mol

$34 + 0.21A*2 = 74 + 0.003*666.7*2 + 0.072*666.7*2[(1-0.003-0.072-X_{N2})*666.7]*2$

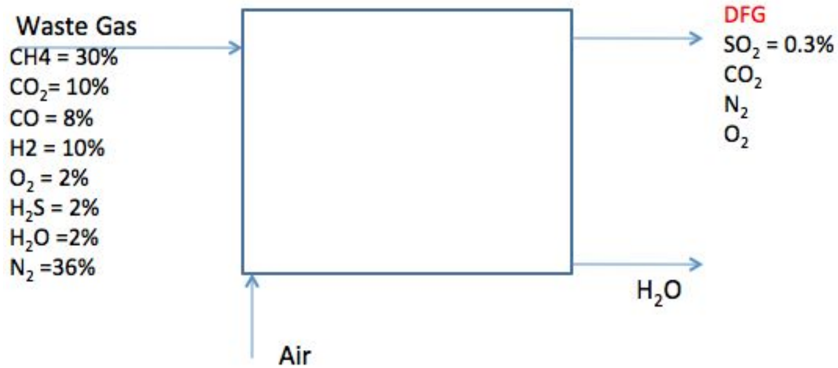
Solving the two equations for A and $X_{N2}$

$A = 650.6$ mol

$X_{N2} = 0.825$

$X_{O2} = 1-0.003-0.072-0.825$

$=0.1$




$N_2$ in exit gas = 550 mol,

36 mol $N_2$ is entering with Waste Gas, hence rest must be entering with Air

$N_2$ entering with Air = 550-36 = 514 mol

Thus $O_2$ entering with air = [(**514**)/0.79]*0.21

= 136.63 mol

$O_2$ reqiured = 70 mol

% excess $O_2$ = {(136.63-70)/70} * 100 = 95.18%

Moles of each component in DFG:

$O_2$ in DFG = 66.63 mol

$CO_2$ in DFG = 48 mol

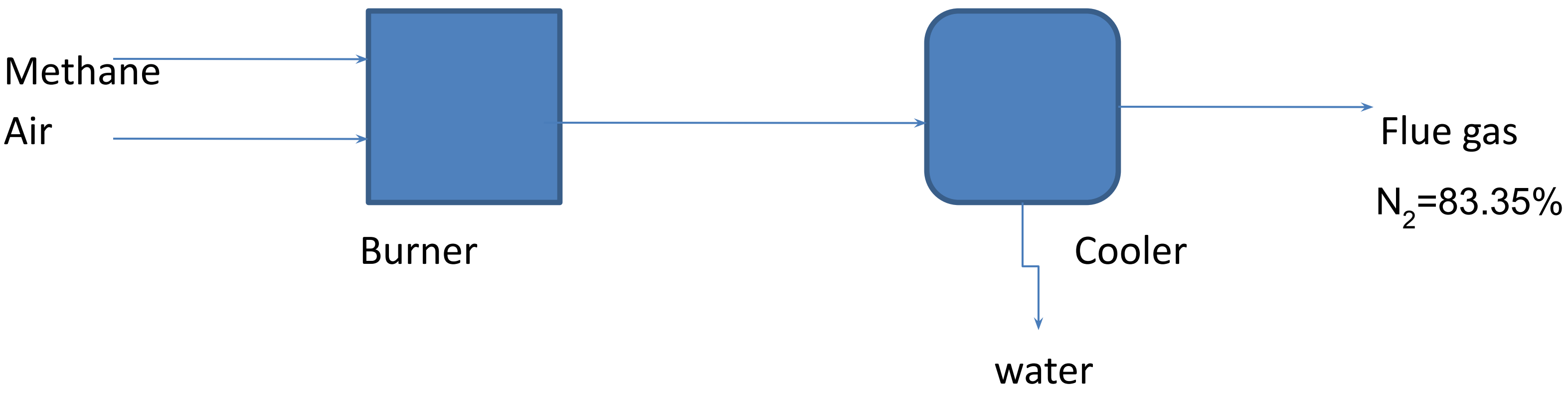
$SO_2$ in DFG = 2 mol

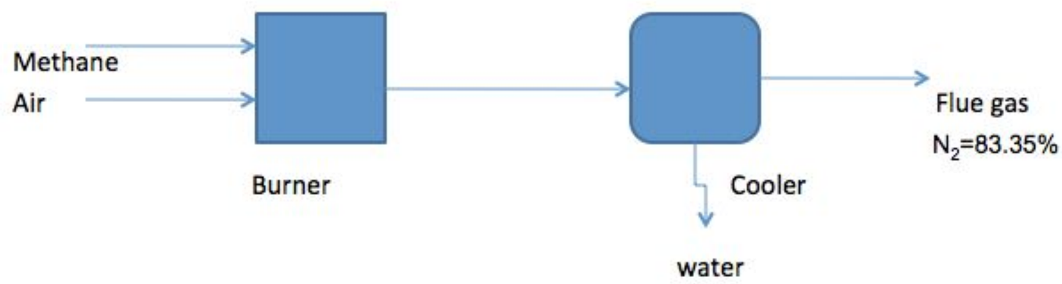
Total mol DFG = 550+66.63+48+2 = 666.63 mol

# Problem

- Pure methane is burned completely with air. The outlet gases from the burner, containing no oxygen, are passed through a cooler, where some of the water formed is removed by condensation. The gases leaving the cooler have a nitrogen mole fraction of 0.8335. Calculate: (a) composition of the flue gas leaving the cooler (b) Moles of $H_2O$ condensed per mole of methane burned

# SOLUTION






Basis = 1 mol of methane

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

$O_2$ required = 2 mol

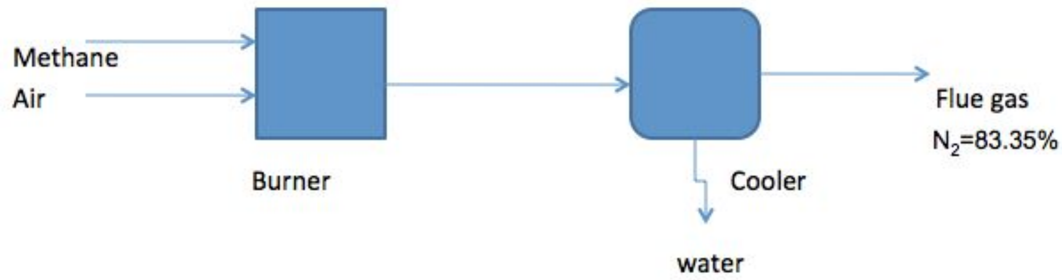
$O_2$ supplied = 2mol

$N_2$ supplied =(2/0.21)*0.79= 7.524 mol

$N_2$ in = $N_2$ out

Therefore

7.524 = Mol of gas leaving the cooler*0.8335




Mol of gas leaving the cooler=7.524/(0.8335)

=9.03 mol

Moles of $CO_2$ formed = 1 mol

Moles of $H_2O$ formed = 2 mol

Total moles coming out of burner=7.524+1+2

=10.524 mol

Moles of water condensed = 10.524-9.03

=1.494 mol

- Composition of gas exiting the cooler

$N_2$= 83.35%

$CO_2$= (1/9.03)*100 = 11.05%

$H_2O$ = {(2-1.494)/9.03}*100 =5.60%