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

Course: Material and Energy Balances UCH301

Course Instructor:

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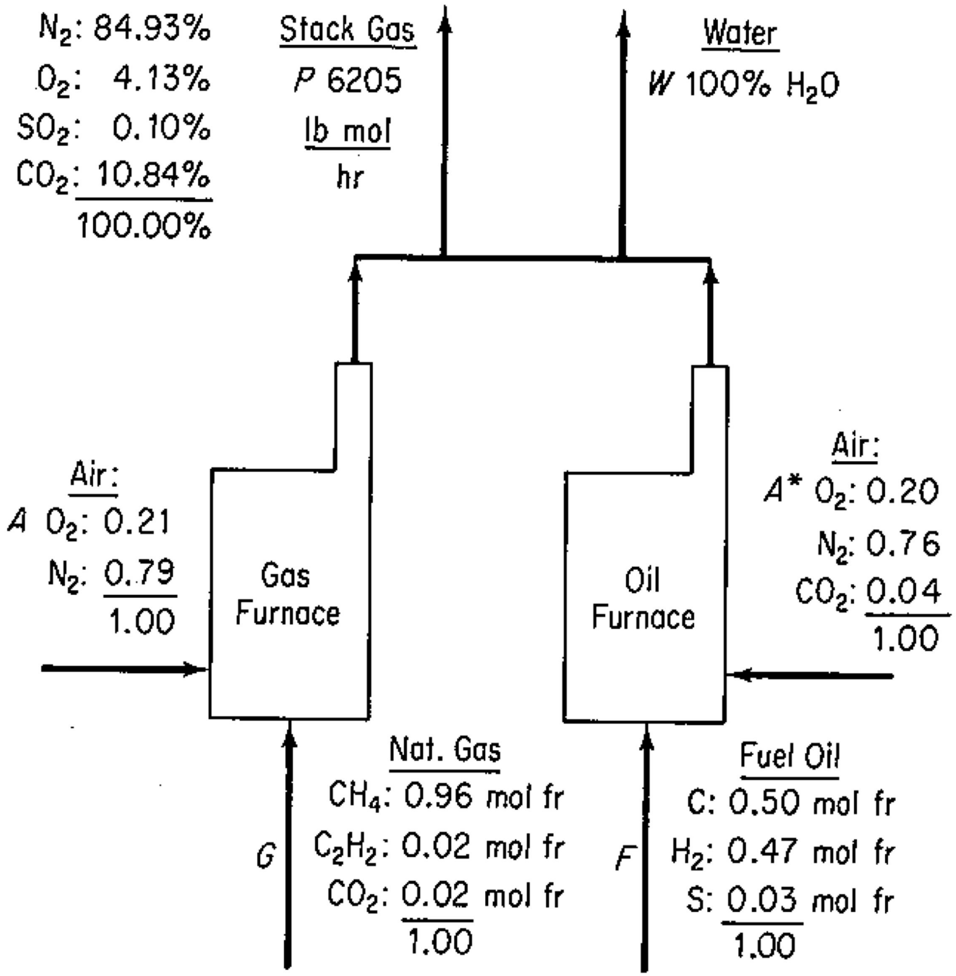
Problem

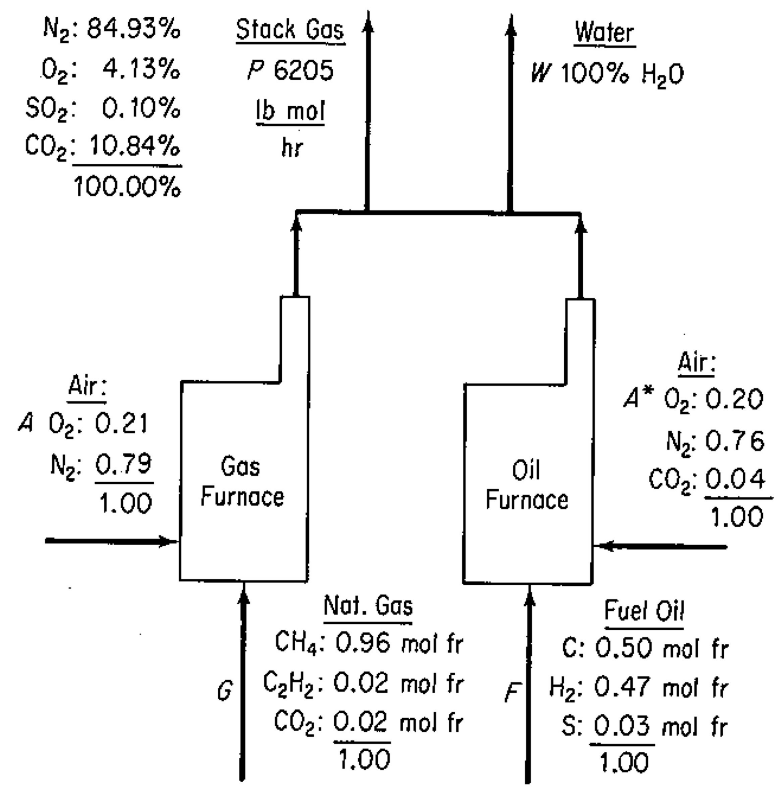
- A company operates two boilers to generate steam. First boiler uses Fuel Oil (C =50mol%, H2 = 47 mol%, S = 3 mol%) and the second one uses Natural gas (CH_4 = 96%, C_2H_2=2%, CO2=2%). Air (O_2=20%,N_2=76%, CO_2 = 4%) is used in the first boiler and Air (O_2=21% and N_2=79%) is used in the second boiler.
- The orsat analysis of the flue gas from the combined stack of the two boilers is (N_2=84.93%, O_2=4.13%, SO_2=0.1%, CO_2=10.84%). The stack gas flow is 6205 lbmol/hr. Calculate the molar rates of Natural Gas and Fuel oil.

The figure below shows the process arrangement



Solution

- Basis: As the amount of stack gas flow is given in the problem statement, we will select this amount as basis of our calculations.
- The composition of all streams are given, but information about the combustion in each boiler is not provided.
- In such case we will need to write elemental species balances, to calculate the flows of the various streams



Writing elemental species balances

- As you can see that sulphur is entering from one stream (Fuel oil) only and leaving from one stream, so, S balance can be solved independently
- Balance for sulphur: Sulphur in = Sulphur out

$$S: \quad F(0.03) = 6205(0.001)$$

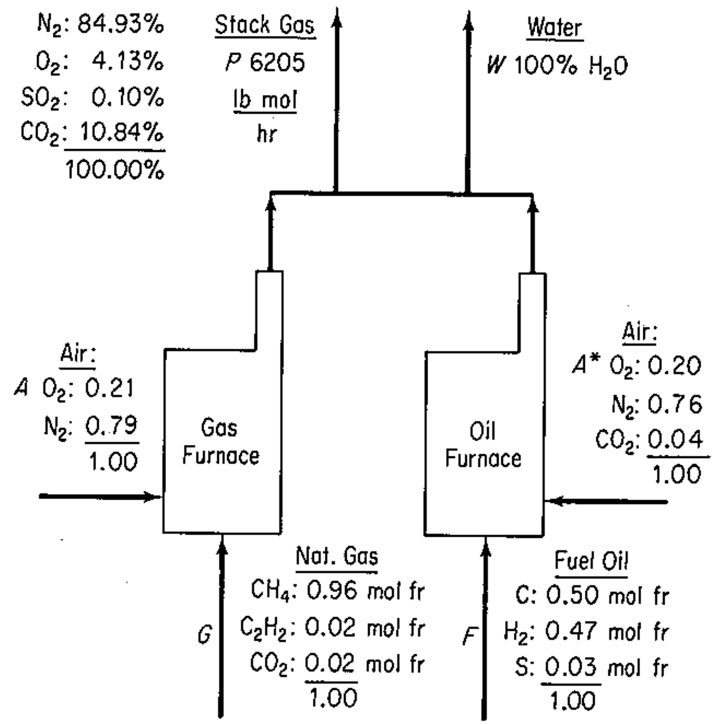
$\rightarrow$ F = 207 lbmol/hr

- The remaining balances will have to be solved simultaneously

Elemental species balances

- Balances for H, N_2, and O & C

In = Out



H: $G(0.96*4+0.02*2)+ F(0.47*2) = W*2$

N: $A(0.79*2) + A^{*}().76*2) = 6205 (0.8493*2)$

O: $G(0.02*2)+ A(0.21*2)+A*(0.2*2+0.04*2) = 6205*2(0.0413+0.001+0.1084)+W*1$

C: $G(0.96+2*0.02+0.02) + F(0.5) +A^{*}(0.04) = 6205(0.1084)$

ANSWERS

- **FOUR UNKNOWNS A, A*, G, & W CAN BE OBTAINED BY SOLVING THE ABOVE EQUATIONS**

✔ Fuel oil (F) = 207 lbmol/hr

✔ NG (G) = 498 lbmol/hr

✔ A* =1529 lbmol/hr

✔ A = 5200 lbmol/hr

✔ W =1067.6 lbmol/hr

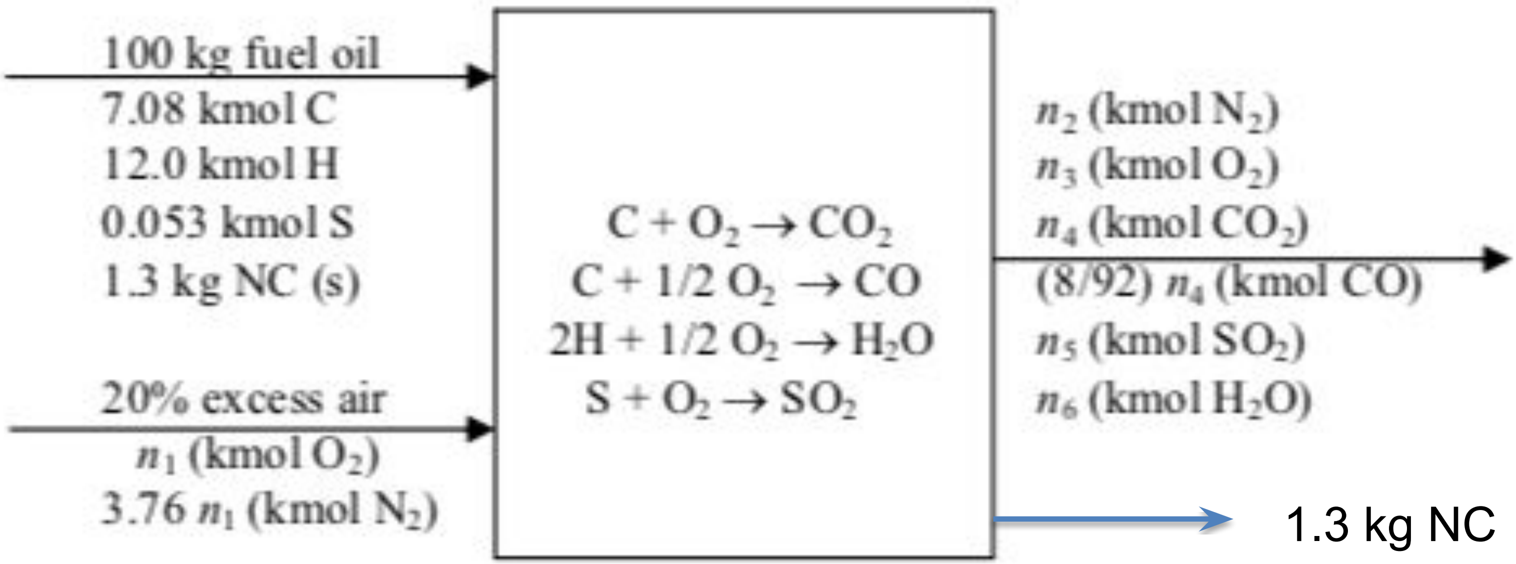
Combustion of Liquid Fuel

Exercise

- A fuel oil is analyzed and found to contain 85.0 wt% carbon, 12.0% elemental hydrogen (H), 1.7% sulfur, and the remainder noncombustible matter. The oil is burned with 20% excess air, based on complete combustion of the carbon to CO_2, the hydrogen to H_2O, and the sulfur to SO_2. The oil is burned completely, but 8% of the carbon forms CO. Calculate the molar composition of the stack gas.

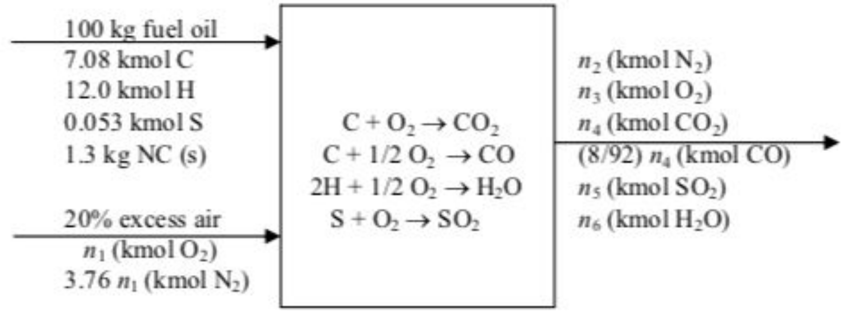
Solution

- Basis: 100 kg fuel oil



- If n1 are moles of O_2, then moles of N_2

  = 0.79/0.21 = 3.76 n1

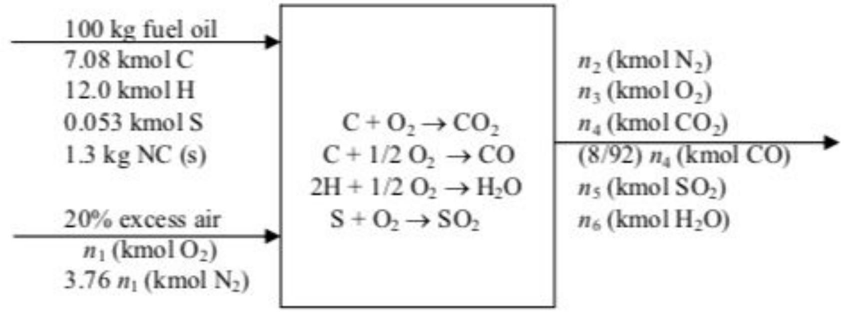


Before applying balance we will convert the mass units to mole units

- Moles of C in fuel = 100*0.85/12 = 7.08 kmol C
- Moles of H in fuel = 100*0.12/1 = 12 kmol H
- Moles of S in fuel = 100*0.017/32 = 0.053 kmol S

✔ Non combustible material in fuel is 1.3 kg, we can not convert this amount into moles as mol.wt. is not known so we will leave this amount in kg.

✔ Also, since the non combustible material will come out as such so keeping this amount in kg is ok.



Theoretical amount of O2 required for combustion

mol O_2 required for C = moles of C = 7.08 kmol

mol O_2 required for H = moles of H/4 = 12/4 = 3 kmol

mol O_2 required for S = moles of S = 0.053 mol

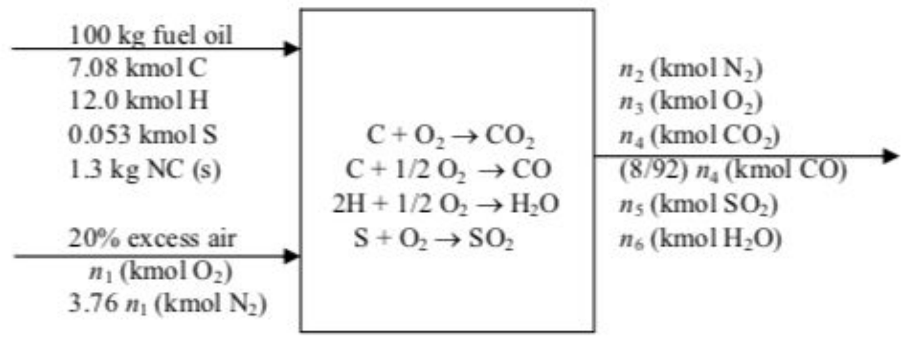
Mol O_2 required for combustion = 7.08+3+0.053=10.133 kmol

Therefore Air required = 10.133/0.21 =48.25 kmol

Air Supplied = 48.25*1.2 = 57.9 kmol

O_2 supplied = 57.9/0.21 = 12.16 kmol

N_2 supplied = 3.76*12.16 = 45.72 kmol



Here, the relation between amounts of CO and CO_2 formed is given:

- Moles of C burned = 7.08 kmol

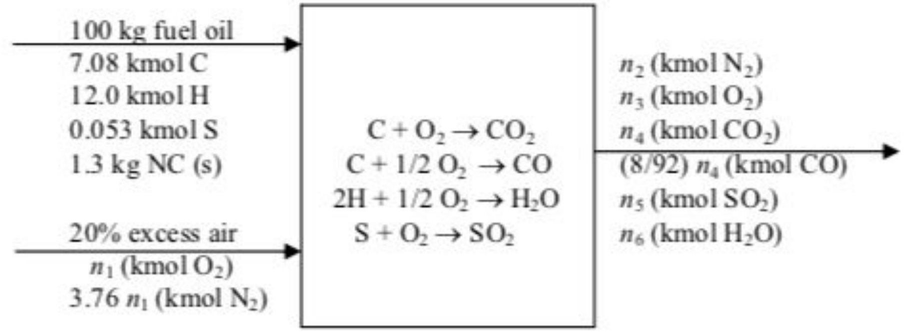
Therefore, 7.08 = n4 + (8/92)*n_4 → n_4 = 6.514 mol CO_2

Mol of CO formed = (8/92)*6.514 = 0.566 mol

The amount of O_2 reacted = O_2 required- (CO formed/2)

= 10.133-0.566/2 =9.853 kmol

O_2 out = O_2 supplied- O_2 reacted =12.16-9.853 = 2.31 kmol = n_3



SO_2 formed = moles of S burned = 0.053 kmol = n5

H_2O out = n6 = moles of H in/2 = 6 kmol

N_2 out = N_2 in = 45.72 kmol =n2

O_2 out = O_2 supplied-O_2 reacted =12.16-9.853= 2.31 kmol=n3

Total moles of flue gas = 45.72+2.31+6.514+CO mol+0.053+6

= 61.16 kmol

Mol% composition of flue gas:

CO_2 = 10.7%, CO=0.92%, SO_2 =0.087%

H_2O =9.8%, O2 3.8%,N_2= 74.8%