Exercise-1

Exercise-2

Exercise-3

Keywords: Combustion, Excess air, Stoichiometric air, Furnace, Blast furnace

Exercise-1

1) A furnace is heated by combusting a gaseous fuel of composition 29% CO, 9% CO₂, 16% H₂ and 46% N₂ with dry air. The Orsat analysis of products of combustion (POC) is 15% CO₂, 7% O₂ and 78% N₂. Calculate the following on the basis of 1 m³ of gaseous fuel

   a) volume of POC at NTP, STP and at 1000°C
   b) Volume of air at NTP
   c) Percent excess air
   d) % H₂O in POC

SOLUTION:

a) Volume of POC (Note that POC and flue gas are the same)

Consider 1 m³ of gaseous fuel at NTP (1 atm. And 273K). Let Y m³ is POC (1 atm, 273 K)

Performing Carbon balance:

Carbon in CO + Carbon in CO₂ = Carbon in POC; it follows that

0.29 + 0.09 = 0.15Y, hence

Y = 2.53 m³ at NTP (1 atm and 273K)

Y = 2.53 × 298/273 = 2.765 m³ at STP (1 atm and 298K)

Y = 2.53 × 1273/273 m³ at (1 atm and 1273K)

Note the increase in volume of POC at 1273 K which is around 5 times than at 273K. This knowledge is important in designing combustion chamber.
b) Volume of air

Let \( Z \) m\(^3\) is the volume of air required at NTP. Performing nitrogen balance we get

Nitrogen from air + Nitrogen in gaseous fuel = Nitrogen in POC, we get

\[
0.79Z + 0.46 = 0.78 \times 2.53, \text{ hence}
\]

\[
Z = 1.916 \text{ m}^3 \text{ at NTP}
\]

c) Percent excess air

In order to calculate percent excess air, first we have to calculate theoretical air. Theoretical air is the air required for complete combustion of the following reactions:

\[
\begin{align*}
\text{CO} & + 0.5 \text{O}_2 = \text{CO}_2 \quad \text{(1)} \\
\text{H}_2 + 0.5\text{O}_2 & = \text{H}_2\text{O} \quad \text{(2)}
\end{align*}
\]

We note that both \( \text{CO} \) and \( \text{H}_2 \) require 0.5 mole of oxygen. Hence

Theoretical amount of air 1.071 m\(^3\) at NTP

Excess air in % = 100 \((\text{Actual} - \text{Theoretical}) / \text{Theoretical}) = 78.89\%.

Alternatively excess air can also be calculated from excess oxygen in POC, since theoretically oxygen in POC will appear only when it is excess than theoretical in this problem

Excess air in % = 100\((0.07 \times 1.916) / (0.21 \times 1.071) = 78.74\%.

The slight difference in excess air may be due to rounding off.

\[\text{d) } \% \text{H}_2\text{O in POC} \]

From the reaction 2 we get straightway that a mole of hydrogen gives 1 mole of water, hence

Percent \( \text{H}_2 \) in POC = \((100 \times 0.16) / (2.53 + 0.16) = 5.95\%\]
2) A furnace heats the billet. The furnace is heated by combusting coal with air. The ultimate analysis of coal is: C 72.5%, H 7.5%, O 6.7%, N 1.3%, S 2.5% and ash 9.5%. The moisture content of coal, when fired is 3%. The air is moist with the relative humidity (RH) of 45%. The barometer shows 735 mm Hg pressure and 20°C temperature. The water vapour at saturation is 17.54 mm Hg. The Orsat analysis of products of combustion (POC) is 10.3% CO_2, 6.2% O_2, 2% CO and 81.5% N_2. Calculate the following on the basis of 1 kg of coal.

- Percent excess air
- Volume of air at NTP
- Total volume of POC

**SOLUTION: i) Percent excess air**

Let V is volume of POC at NTP (1 atm and 273K). Performing carbon balance as done in problem 1 gives the volume of POC. Note that coal contains sulphur. Orsat analysis as explained in lecture 10 reports both CO_2 and SO_2. Therefore carbon balance here is

\[
\text{Carbon from coal} + \text{Sulphur from coal} = \text{Carbon in POC}
\]

The volume of POC is = 11.142 m³

Now we can calculate actual amount of air that is used in the combustion process by performing nitrogen balance; Let \( Z \) kg mole is the amount of nitrogen derived from air.

\[
\text{Nitrogen in coal} + \text{Nitrogen in air} = \text{Nitrogen in POC}
\]

Substituting the values we get \( Z = 0.405 \) kg mole, hence oxygen would be 0.108 kg mole.

Now calculate theoretical (stoichiometric) amount of air. Remember theoretical amount of air is calculated on the basis of complete combustion; for the following combustion reactions:

- \( C + 0.5 O_2 = CO_2 \) and
- \( 2H + 0.5 O_2 = H_2O \)
- \( S + O_2 = SO_2 \)

Theoretical amount of oxygen = 0.07785 kg moles

Percent excess air = \( 100(\text{Actual oxygen} - \text{theoretical oxygen})/\text{theoretical oxygen} \)
Substituting the values we get

**Percent excess air 38.33%**.

ii) **Volume of air at NTP:**

Note that the air is moist so we have to find the composition of moist air by using Dalton’s law which is

\[ P_{\text{N}_2} + P_{\text{O}_2} + P_{\text{H}_2\text{O}} = 735 \text{ but} \]

\[ P_{\text{H}_2\text{O}} = \text{RH} \times \text{vapour pressure of water vapour at saturation, we get} \]

\[ P_{\text{N}_2} + P_{\text{O}_2} = 574.41 \]

Volume of air = \( \frac{0.405 \times 760}{574.41} = 0.536 \text{ kg mole} \)

**Volume of air = 13.315 at 20°C and 735 mm Hg or 11.998 at 0°C and 760 mm Hg**

iii) **Total volume of POC**

Total volume of POC = Dry volume of POC + \( \text{H}_2\text{O} \) formed by reaction 2 + Moisture of coal + Moisture in air

On substituting the values we get

**Total volume of POC = 12.148 m}^3 \text{ at 0°C and 760 mm Hg and 13.482 m}^3 \text{ at 20°C and 735 mm Hg}**

**Exercise-3**

3) In a continuous heating furnace 750 kg/hr coal is burnt with 3% moisture and the following ultimate analysis (dry basis); C 77, H 7%, O 4%, N 1%, S 2% and ash 9%. In normal operation, the Orsat analysis of products of combustion (POC) is 13% CO\(_2\), 6% O\(_2\), 0.5% CO and 80.5% N\(_2\). The operator has opened the furnace door for charging. He closes the door and operates the furnace with the same firing rate and burner adjustment as was in the normal operation. He does again Orsat analysis of POC. The Orsat analysis now is 11.5% CO\(_2\), 8.2% O\(_2\), and 80.3% N\(_2\). He is surprised to see change in Orsat analysis.

**The operator wants an explanation both qualitatively and quantitatively.**
SOLUTION:

Explanation: The operator has neither changed the firing rate nor adjusted the burner. When the door was opened, atmospheric air is leaked into the combustion chamber and CO of POC was combusted. This has resulted in change in POC. We have to calculate excess air.

Basis of calculation is 1 kg / hr.

Performing Carbon balance we get amount of POC = 0.4802 moles for normal operation.

Again we perform carbon balance when the door was opened. Now we get amount of POC = 0.564 moles.

Air leakage = \( (0.564 \times 0.803) - (0.4802 \times 0.805) \) \times 4.76 / 3.76 = 0.084 kg mols

Amount of air leakage for combustion of 750 kg / hr coal = 23m3/min

Calculations on excess air has been done in problem 1 and 2.

Percent excess air = 21.46%

For further problems refer

A. Butts: Metallurgical problems

Assignments:

1) In a continuous heating furnace 750kg/hr coal is burnt with 3% moisture and the following ultimate analysis (dry basis); 77, H 7%, O 4%, N 1%, S 2% and ash 9%. In normal operation, the Orsat analysis of products of combustion (POC) is 13% CO₂, 6% O₂, 0.5% CO and 80.5% N₂. The operator has opened the furnace door for charging. He closes the door and operates the furnace with same firing rate and burner adjustment as was in the normal operation He does again Orsat analysis of POC. The Orsat analysis now is 11.5% CO₂, 8.2% O₂ and 80.3% N₂. He is surprised to see change in Orsat analysis.
2) A natural gas analyzing 85% CH₄, 5% C₂H₆ and 10% N₂ is burned with air such that percent oxygen in POC remains at 2% on dry basis. Assume complete combustion, calculate (a) analysis of POC (dry basis), and (b) % excess air.

3) A furnace is heated by combusting a gaseous fuel of composition 29% CO, 9% CO₂, 16% H₂ and 46% N₂ with dry air. The Orsat analysis of products of combustion (POC) is 15% CO₂, 7% O₂ and 78% N₂. Calculate the following on the basis of 1 m³ of gaseous fuel

   e) Volume of POC at NTP, STP and at 1000°C
   f) Volume of air at NTP
   g) Percent excess air
   h) % H₂O in POC

4) A furnace heats the billet. The furnace is heated by combusting coal with air. The ultimate analysis of coal is; C 72.5%, H 7.5%, O 6.7 %, N 1.3%, S 2.5% and 9.5%. The moisture content analysis of coal, when fired is 3%. The air is moist with the relative humidity (RH) of 45% the barometer shows 735mm Hg pressure and 20°C temperature. The water vapour at saturation is 17.54 mm Hg. The Orsat analysis of products of combustion (POC) is 10.3% CO₂, 6.2% O₂, 2% CO and 81.5% N₂. Calculate the following on the basis of 1 kg of coal

   iv) Percent excess air
   v) Volume of air at NTP
   vi) Total volume of POC