1. 0.25 g of a sample of coal was analyzed by combustion method. The increase in weights of $CaCl_2$ tube and the potash bulbs at the end of the operation was found to be 0.15 g and 0.55 g, respectively. Calculate the percentage of carbon and hydrogen in the coal.

Solution

Weight of CO_2 (increase in weight of KOH bulb) = 0.55 g.

Weight of H_2O (increase in weight of $CaCl_2$ tubes) = 0.15 g.

$$\underset{12}{C} + O_2 \rightarrow \underset{44}{CO_2}$$

44 g CO_2 contains carbon = 12 g

0.55 g CO_2 contains carbon = $\frac{12}{24} \times 0.55$ g

Percentage of carbon = $\frac{12 \times \text{weight of carbondioxide}}{44 \times \text{weight of coal sample taken}} \times 100$

$$= \frac{12}{44} \times \frac{0.55}{0.25} \times 100 = 60\%$$

Percentage of carbon = 60%.

To calculate % of hydrogen,

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$$

2 g 18 g

18 g H_2O contains hydrogen = 2 g

0.15 g H_2O contains hydrogen = $\frac{2}{18} \times 0.15$

Percentage of hydrogen $= \frac{2}{18} \times \frac{0.15}{0.25} \times 100 = 6.67\%$

Percentage of hydrogen = 6.67 %

2. 1.0 g of a coal sample was used in a bomb calorimeter for the determination of calorific value. Calorific value of coal was found to be 8800 cal/g. The ash formed in the bomb calorimeter was extracted with acid and the acid extract was heated with $BaCl_2$ solution and a precipitate of $BaSO_4$ was obtained. The precipitate was filtered, dried and weighed. The weight of precipitate was found to be 0.08 g. Calculate the percentage of sulphur in the coal sample.

Solution

$$\text{Percentage of sulphur} = \frac{\text{weight of } BaSO_4 \text{ ppt obtained} \times 32 \times 100}{233 \times \text{weight of coal sample taken}}$$

$$= \frac{0.08 \times 32 \times 100}{233 \times 1} = 1.0987\%$$

Percentage of sulphur = 1.0987 %

3. 0.3 g of coal sample on Kjehldahl's analysis gave ammonia to just neutralize 30 ml of 0.1 N H_2SO_4. Calculate the percentage of nitrogen in the coal sample.

Solution

Weight of coal sample = 0.3 g

Volume of H_2SO_4 used = 30 ml

Normality of H_2SO_4 = 0.1 N

$$\text{Percentage of Nitrogen} = \frac{\text{volume of } H_2SO_4 \text{ used} \times \text{normality} \times 1.4}{\text{weight of coal sample taken}}$$

$$= \frac{30 \times 0.1 \times 1.4}{0.3} = 14\%$$

Percentage of nitrogen = 14%

4. 1.56 g of a coal sample was Kjehldahlized and NH_3 gas thus evolved was absorbed in 50 ml of 0.1 N H_2SO_4. After absorption, the excess (residual) acid required 6.25 ml of 0.1 N NaOH for exact neutralization. Calculate the percentage of nitrogen in the coal sample.

Solution

Weight of coal sample taken = 1.56 g

Since, 6.25 ml of 0.1N NaOH is used for neutralization, hence excess acid

= 6.25 ml of 0.1 N H_2SO_4

Therefore, Volume of H_2SO_4 used to neutralize NH_3 evolved

= 50 ml of 0.1N – 6.25 ml of 0.1 N H_2SO_4

= (50–6.25)× 0.1 N H_2SO_4

= 43.75 ml of 0.1 N H_2SO_4

$$\text{Percentage of nitrogen} = \frac{\text{Volume of } H_2SO_4 \text{ used} \times \text{normality of } H_2SO_4 \times 1.4}{1.56} = 3.926\%$$

$$\frac{43.75 \times 0.1 \times 1.4}{1.56} = 3.926$$

Percentage of nitrogen = 3.926%

Practice problems

1. 0.26 g of a sample of coal analyzed by combustion gave 0.039 g of water and 0.245 g of carbon dioxide. Calculate the percentage of carbon and hydrogen in the coal.
(Ans % of carbon = 25.69%: % hydrogen = 1.66%)

2. 0.1 g of a sample of coal was used in a bomb calorimeter for the determination of calorific value. The ash formed was extracted with acid and the acid extract was heated with $BaCl_2$ solution and a precipitate of $BaSO_4$ was obtained. The precipitate was filtered, dried and weighed. The weight of precipitate was found to be 0.01 g. Calculate the percentage of sulphur in the coal sample.
(Ans % sulphur = 1.3734%)

3. 3.12 g of the coal sample was Kjehldahlized and NH_3 gas was absorbed in 50 ml of. 0.1N H_2SO_4. After absorption, the excess (residual) acid required 12.5 ml of 0.1 N NaOH for exact neutralization. Determine the percentage of nitrogen in the coal sample.
(Ans % nitrogen = 1.683%)

4. 3.0 g of the coal sample was Kjehldahlized and NH_3 gas was absorbed in 45 ml of 0.1N H_2SO_4. After absorption, the excess (residual) acid required 8.5 ml of 0.1 N NaOH for exact neutralization. Determine the percentage of nitrogen in the coal sample.
(Ans % nitrogen = 1.7033%)

Calculation of air required for the combustion of solid and liquid fuels

The elements generally present in the fuel are carbon, hydrogen, oxygen, nitrogen and sulph… During combustion of the fuel these elements combine with oxygen. If the percentage compo… of fuel is known, the amount of oxygen required for combustion can be calculated. The metho… calculation of air is summarized below

(i) Weight of each constituent present per kilogram of the fuel is calculated from the percen… composition of the fuel. Let the weight of carbon, hydrogen, oxygen, and sulphur in on… of the fuel be C kg, H kg, O kg and S kg respectively.

(ii) The quantity of oxygen required for the combustion of C kg of carbon, H kg of hydrogen… S kg of sulphur can be calculated with the help of the equations given below

Combustion of carbon

$$\underset{12\,kg}{C} + \underset{32\,kg}{O_2} \rightarrow CO_2$$

12 kg of carbon requires 32 kg of oxygen.

C kg of carbon requires $\frac{32}{12} \times$ C kg or 2.67 C kg of oxygen.

Combustion of hydrogen

$$\underset{2kg}{H_2} + \underset{16kg}{\frac{1}{2} O_2} \rightarrow H_2O$$

2 kg of hydrogen requires 16 kg of oxygen.

H kg of hydrogen requires $\frac{32}{02} \times$ H kg or 8H kg of oxygen

Combustion of sulphur

$$S + O_2 \rightarrow SO_2$$

32 kg of sulphur requires 32 kg of oxygen.

S kg of sulphur requires $\frac{32}{32} \times$ S kg or 1 S kg of oxygen.

The other constituents present in fuel do not require oxygen.

Thus, total quantity of oxygen required for the combustion of 1 kg of fuel will be

(2.67C + 8 H + S) kg.

If oxygen is already present in the fuel, the quantity of oxygen to be supplied from air (Total oxygen required–O_2 present in fuel)

$$(2.67C + 8H + S - O) \text{ kg}$$

So, minimum quantity of O_2 or the theoretical amount of O_2 required for the complete combustion of 1 kg of a fuel

$$= (2.67C + 8H + S - O) \text{ kg}$$

As air contains 23% oxygen by weight; hence, minimum weight of air required for combustion

$$= (2.67C + 8H + S - O) \frac{100}{23} \text{ kg.}$$

Calculation of volume of oxygen or air required

At certain temperature and pressure, the mass of any gas can be converted into its volume and vice versa by using the gas equation. The volume of oxygen or air required for the combustion of fuel is calculated

$$PV = \frac{W}{M} \times RT$$

Where,

P = pressure of gas in atmosphere; V = Volume of gas

R = gas constant; T = temperature in K

W = mass of gas; M = Molecular mass of the gas.

Alternatively the weight of oxygen required can be converted into its volume at normal temperature and pressure. 22.4 litres of any gas at NTP has a mass equal to its gram molecular weight and air contains 21 % oxygen by volume. Hence, the volume of air required can also be calculated.

Calculation of quantity of flue gases

The gases coming out after combustion CO_2, SO_2, CO, O_2, N_2 are called flue gases. The water vapours formed condense as the gases cool down while the ash is excluded as it does not take part in combustion. Therefore, water vapours and ash are not included while calculating the percentage of dry combustion products.

Calculation of the flue gases when minimum amount of air is supplied

All the O_2 of air will be used in combustion of carbon and sulphur while N_2 in air remains unreacted. Let 1 kg of fuel contain C kg of carbon and S kg of sulphur. The weight of CO_2 and SO_2 thus formed in the combustion of fuel is calculated as follows

Problems Based on Weight Calculations

Solved Examples

1. Calculate the weight and volume of air required for the combustion of 3 Kg of carbon.

Solution

Combustion reaction

$$\underset{12\,g}{C} + \underset{32\,g}{O_2} \rightarrow CO_2$$

Weight of oxygen required to burn 12 kg C = 32 kg

Weight of oxygen required to burn 3 kg $C = \frac{32}{12} \times 3 = 8$ kg

As, air contains 23 % oxygen by weight

Therefore, weight of air required $= 8 \times \frac{100}{23} = 34.783$ kg = 34783 g

Volume of air required

as, 1 mole of any gas at NTP occupies 22.4 L

Therefore, volume occupied by 1 mole air = 28.94 g air = 22.4 L

(molecular weight of air = 28.94 g)

Volume occupied by 34783 g of air $= \frac{22.4}{28.94} \times 34783$

$= 26.92 \times 10^3$ L $= 26.92$ m^3

(Since 1L = 10^3 m^3)

2. Calculate the mass of air needed for the complete combustion of 5 Kg of coal containing C = 80%; H = 15%, O = rest

Solution

Constituent	Amount per kg of the coal sample	Combustion reaction	Weight of O_2 required
C	0.80 kg	$C + O_2 \rightarrow CO_2$	$0.80 \times \frac{32}{12} = 2.133$ kg

H	0.15 kg	$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	$0.15 \times \frac{16}{2} = 1.20$ kg
O	1.00-(0.80 + 0.15) = 0.05 kg		Total O_2 required = 2.133 + 1.20=3.333 kg

Oxygen required from air = Total O_2 required – O_2 in fuel

$$= 3.333 - 0.05 = 3.283 \text{ Kg}$$

Weight of air required for combustion of 1 Kg of fuel $= 3.283 \times \frac{100}{23} = 14.27$ Kg

Therefore, Weight of air required for combustion of 5 Kg of fuel $= 14.27 \times 5 = 71.369$ kg

[Ans = 71.369 Kg]

3. A sample of coal was found to have the following composition by weight

C = 75%; H = 5.2%; O = 12.1%; N = 3.2% and ash = 4.5%

Calculate (i) minimum amount of O_2 and air necessary for complete combustion of 1 kg of coal; (ii) weight of air required if 40% excess air is supplied.

Solution

Constituent	Amount per kg of the coal sample	Combustion reaction	Weight of O_2 required
C	0.75 kg	$C + O_2 \rightarrow CO_2$	$0.75 \times \frac{32}{12} = 2$ kg
H	0.052 kg	$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	$0.052 \times \frac{16}{2} = 0.416$ kg
O	0.121 kg	–	–
N	0.032 kg	–	–
Ash	0.045 kg	–	–
		–	Total O_2 required = 2.416 kg

O_2 required from air = Total O_2 required – O_2 in fuel

$$= 2.416 \text{ kg} - 0.121 \text{ kg} = 2.295 \text{ kg}$$

Minimum weight of air required $= 2.295 \times \frac{100}{23} = 9.978$ kg.

Weight of excess air $= 9.978 \times \frac{40}{100} = 3.9912$ kg

Total air supplied $= 9.978 + 3.9912 = 13.969$ kg.

[Ans = 13.969 kg]

4. A fuel is found to contain C = 90%; H = 6.0%; S = 2.5%; O = 1.0% and ash = 0.5 %. Calculate the amount of air required for complete combustion of 1 kg of fuel. If 25% excess air is used for combustion, calculate the percentage composition of the dry products of combustion.

Solution

Constituent	Amount per kg of the coal sample	Combustion reaction	Weight of O_2 required	Weight of dry flue gas
C	0.90 kg	$C + O_2 \rightarrow CO_2$	$0.90 \times \frac{32}{12} = 2.4$ kg	$0.90 \times \frac{44}{12} = 3.3$ kg
H	0.06 kg	$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	$0.06 \times \frac{16}{2} = 0.48$ kg	H_2O does not constitute dry flue gas
S	0.025 kg	$S + O_2 \rightarrow SO_2$	$0.025 \times \frac{32}{32} = 0.025$ kg	$0.025 \times \frac{64}{32} = 0.05$ kg
O	0.01 kg	–	–	–
Ash	0.005 kg	–	–	–
		–	Total O_2 required = 2.4 + 0.48 + 0.025 kg = 2.905 kg	

O_2 required from air = Total O_2 required – O_2 in fuel

$$= 2.905 - 0.01 = 2.895 \text{ Kg}$$

Minimum weight of air required for combustion $\quad 2.895 \times \frac{100}{23} = 12.587$ kg

According to the question 25 % excess air is supplied

$$\text{Excess air} = 12.587 \times \frac{25}{100} = 3.147 \text{ kg}$$

Total air supplied = 12.587 Kg + 3.147 kg

= 15.734 kg

(i) Calculation of dry products in the flue gases

The flue gases contains CO_2, SO_2, O_2 from excess air and N_2 from the total air supplied.

Weight of CO_2 = 3.3 kg

Weight of SO_2 = 0.05 kg

$$\text{Weight of } O_2 = 3.147 \times \frac{23}{100} = 0.724 \text{ kg}$$

$$\text{Weight of } N_2 = 15.734 \times \frac{77}{100} = 12.115 \text{ kg}$$

Total weight of flue gases = 3.3+0.05+0.724+12.115 = 16.189kg

Percentage composition of dry flue gases

$$\% CO_2 = \frac{3.3}{16.189} \times 100 = 20.38 \%$$

$$\% SO_2 = \frac{0.05}{16.189} \times 100 = 0.309\%$$

$$\% O_2 = \frac{0.724}{16.189} \times 100 = 4.47 \%$$

$$\% N_2 = \frac{12.115}{16.189} \times 100 = 74.835 \%$$

Practice problems

1. A fuel is found to contain C = 90%; H = 3.5 %; S = 0.5 %; H_2O = 1.0 %; N = 0.5 % and ash = rest. Calculate the minimum amount of air required for complete combustion of 1 Kg of fuel.

[Ans = 11.6739 Kg

A sample of coal is found to contain : C = 81%; H = 5.0 %; S = 1 %; O = 8.0 %; N=1% and ash = 4 %.Calculate the amount of air required for complete combustion of 1 Kg of fuel. Also calculate the percentage composition by weight of the dry products of combustion. Oxygen in air is 23% by weight.

[Ans (i)10.826 kg; (ii) CO_2 = 26.22%; N_2 = 73.005%; SO_2 = 0.1765%]

3. A sample of coal was found to contain: C = 80%; H = 5.0 %; N = 2%; O = 1.0 % and remaining ash.

   i. Calculate the amount of air required for complete combustion of 1 Kg of coal sample.

   ii. If 45 % excess air is supplied, estimate the percentage composition of the dry products of combustion.

[Ans Air = 10.9708 kg; % CO_2 = 17.976%; N_2 = 75.067%; O_2 = 6.956%]

Problems based on volume calculations

Solved Problems

1. A gas used in internal combustion engine had the following composition by volume : H_2 = 45%; CH_4 = 36%; CO = 15%; N_2 = 4%. Find the volume of air required for the combustion of 1 m^3 of the gas.

Solution

Constituent	Amount in 1m^3 of the fuel	Combustion reaction	Volume of O_2 required(m^3)
H_2	0.45 m^3	$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	45 ×0.5 =0.225
CH_4	0.36 m^3	$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$	0.36 × 2 = 0.72
CO	0.15 m^3	$CO + \frac{1}{2} O_2 \rightarrow CO_2$	0.15 × 0.5 = 0.075
N_2	0.04 m^3		
			Total = 1.020

Therefore volume of air required per m^3 of the gas = 1.020 m^3 × $\frac{100}{21}$ = 4.857m^3

2. A given sample of petrol contains H = 15.4% and C = 84.6%. Calculate the minimum volume of O_2 required for the combustion of this sample.

Solution

Constituent	Amount in 1 kg of petrol	Combustion reaction	Weight of O_2 required(kg)
H	0.154 kg	$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	0.154 × $\frac{16}{2}$ = 1.232 kg
C	0.846 kg	$C + O_2 \rightarrow CO_2$	0.846 × $\frac{32}{12}$ = 2.256 kg
			Total O_2 reqd = 3.488 kg

Weight of O_2 required for combustion of 1 kg fuel = 3.488 kg = 3488 g.

Since 1 mole = 32 g of O_2 at NTP occupies 22.4 L

Therefore 3488 g of O_2 at NTP occupies = $\frac{22.4}{32} \times 3488 = 2441.6\ L = 2.441\ m^3$

(Since 1000L = $1 m^3$)

3. A gaseous fuel has the following composition by volume – CH_4 = 20 %; CO = 10%; CO_2 = 5%; O_2 = 2%; C_2H_4 = 5%; C_3H_8 = 8%, rest N_2. Calculate the volume of air supplied per m^3 of fuel and the % composition of dry flue gases.

Solution

Constituents	Volume in 1 m^3 of gas	Combustion Reaction	O_2 required (in m^3)	Volume of dry flue gases(m^3)
CH_4	0.20 m^3	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	$0.20 \times 2 = 0.40\ m^3$	$CO_2 = 0.20 \times 1 = 0.20\ m^3$
CO	0.10 m^3	$CO + \frac{1}{2}O_2 \rightarrow CO_2$	$0.10 \times \frac{1}{2} = 0.05\ m^3$	$CO_2 = 0.10 \times 1 = 0.10\ m^3$
CO_2	0.05 m^3	–	–	$CO_2 = 0.05\ m^3$
O_2	0.02 m^3	–	–	
C_2H_4	0.05 m^3	$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$	$0.05 \times 3 = 0.15\ m^3$	$CO_2 = 0.05 \times 2 = 0.10\ m^3$
C_3H_8	0.08 m^3	$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	$0.08 \times 5 = 0.40\ m^3$	$CO_2 = 0.08 \times 3 = 0.24\ m^3$
N_2	0.50	–	–	$N_2 = 0.50 + \frac{79}{100} \times 4.67 = 4.19\ m^3$
			Total O_2 reqd = 1.0 m^3 O_2 in fuel = 0.020 m^3 Net O_2 reqd. = 0.98 m^3	

Volume of air required for the combustion of 1 m^3 of fuel = $0.98 \times \frac{100}{21} = 4.67\ m^3$

Calculation of dry flue gases

$CO_2 = (0.20+0.10+0.05+0.10+0.24)\ m^3 = 0.69\ m^3$

$N_2 = N_2\ (fuel) + N_2\ (from\ air) = 4.19\ m^3$

Total volume of dry products = 0.69 + 4.19 = 4.88 m^3

$\%\ CO_2 = \frac{0.69}{4.88} \times 100 = 14.139\ \%$

$\%\ N_2 = \frac{4.19}{4.88} \times 100 = 85.861\ \%$

4. A gaseous fuel has the following composition by volume – CH_4 = 4.0 %; CO = 26%; CO_2 = 10%; H_2 = 10%; N_2= 0.50%. If 20% excess air is supplied calculate the volume of air supplied and the % composition of dry flue gases.

Solution

Constituents	Volume in 1 m^3 of gas	Combustion Reaction	O_2 required (in m^3)	Volume of dry flue gases(m^3)
CH_4	0.04 m^3	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	$0.04 \times 2 = 0.08$ m^3	$CO_2 = 0.04 \times 1 = 0.04$ m^3
CO	0.26 m^3	$CO + \frac{1}{2} O_2 \rightarrow CO_2$	$0.26 \times \frac{1}{2} = 0.13$ m^3	$CO_2 = 0.26 \times 1 = 0.26$ m^3
H_2	0.10 m^3	$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	$0.10 \times \frac{1}{2} = 0.05$ m^3	
CO_2	0.10 m^3	-	-	$CO_2 = 0.10$ m^3
N_2	0.50 m^3	-	-	0.50 m^3 + N_2 in total air supplied
			Volume of O_2 required = 0.260 m^3	Total CO_2 in flue gas = 0.40 m^3

$$\text{Minimum volume of air required} = 0.260 \times \frac{100}{21} = 1.238 \text{ m}^3$$

$$\text{Excess air} = 1.238 \times \frac{20}{100} = 0.2476 \text{ m}^3$$

Total air supplied = 1.238 m^3 + 0.2476 m^3 = 1.4856 m^3

Calculation of volume of dry flue gases

The flue gas contains CO_2, O_2 from excess air and N_2 of fuel + N_2 of total air supplied.

CO_2 = 0.40 m^3

$$O_2 = 0.2476 \times \frac{21}{100} = 0.052 \text{ m}^3$$

$$N_2 = 0.50 \text{ m}^3 \text{ (of fuel gas)} + 1.4856 \times \frac{79}{100} \text{ (from total air supplied)}$$

$N_2 = 0.50 + 1.1174 = 1.674$ m^3.

Total volume of dry flue gases = $(0.40 + 0.052 + 1.674)m^3 = 2.126$ m^3

$$\% CO_2 = \frac{0.40}{2.126} \times 100 = 18.81 \%$$

$$\% O_2 = \frac{0.052}{2.126} \times 100 = 2.446 \%$$

$$\% N_2 = \frac{1.674}{2.126} \times 100 = 78.74 \%$$

Practice problems

1. Calculate the volume of air (volume % of oxygen in air = 21) required for the complete combustion of one 1L of CO.
[Ans = 2.381 L]

2. Calculate the volume of air required for the complete combustion of 1 m^3 of gaseous fuel having the composition CO = 46%; CH_4 = 10%; H_2 = 40%; C_2H_2 = 2.0%; N_2 =1.0% and remaining being CO_2
[Ans = 3.238m^3]

3. A gaseous fuel has the following composition by volume – CH_4 = 6 %; CO = 22%; O_2 = 4%; CO_2 = 4%; H_2 = 20%; N_2= 44%. 20% excess air is used. Find the weight of air actually supplied per m^3 of this gas. Molecular weight of air = 28.97.
[Ans = 2143.107g]

4. A gaseous fuel has the following composition by volume : H_2 = 25 %; CH_4 = 30%; C_2H_6 = 11%; C_2H_4 = 4.5%; C_4H_8 = 2.5%; CO = 6.0%; CO_2 = 8%; O_2 = 2% and N_2 = 12%. Calculate the air fuel ratio and volumetric analysis of dry products of combustion if 40% excess air is used.
[Ans (i) 9.366:1 (ii) CO_2 = 8.415%; N_2 = 77.166%; O_2 =14.418%]