UNIT 4

CHEMICAL FUELS

PART-A
SHORT QUESTIONS WITH SOLUTIONS

Q1. Define fuel. How are fuels classified?

Answer :

Fuel

A fuel is defined as a naturally occurring or artificial combustile material (with carbon as a main constituent) which on proper burning acts as a source of heat and light energy.

Classification of Fuels

Fuels can be classified as primary and secondary fuels. They may be solid, liquid or gaseous according to the state of phase. Figure below shows the classification of fuels based on their occurrence and physical state.

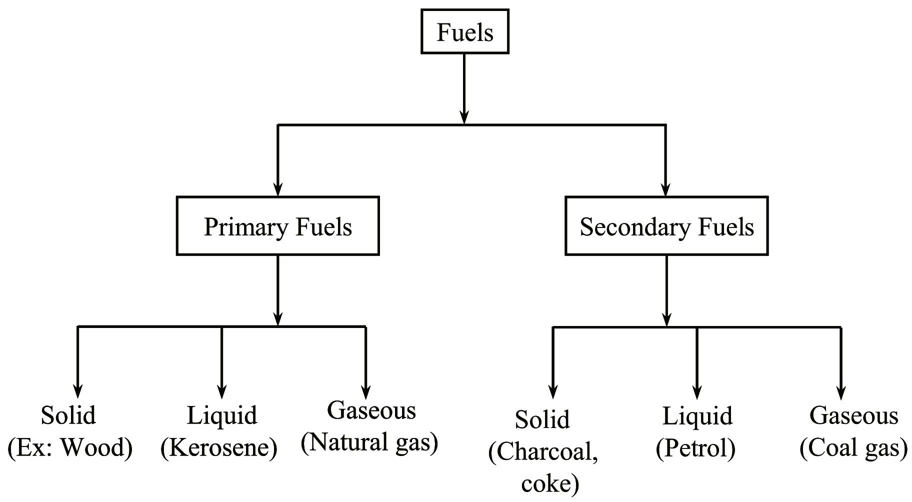

Figure: Classification of Fuels

Q2. What are primary and secondary fuels? Give examples.

Answer :

Primary Fuel

The fuel that occurs naturally and requires no chemical processing before utilization, is called primary fuel.

Examples: Wood, coal, peat, crude petroleum and natural gas.

Secondary Fuel

The fuel that is produced by changing chemical composition of naturally occurring substances is called secondary fuel.

Examples: Coke, coal gas and gasoline.

Q3. What are the requirements of a good fuel?

Answer : (April-16, Q7 | June-11, Q9)

The various requirements of a good fuel are,

(i) High calorific value.

(ii) Efficient and controllable combustion.

(iii) Optimum ignition temperature.

(iv) Moderate velocity of combustion.

(v) Less amount of non-combustible matter (such as ash and clinker)

(vi) Combustion should not produce harmful by-products.

(vii) Less content of moisture (i.e., dry fuel).

(viii) Suitable for easy storage, handling and transportation.

(ix) Less expensive.

Q4. What are the advantages of liquid fuels over solid fuels?

Answer :

The advantages of liquid fuels over solid fuels are,

(i) Liquid fuels do not form ash, clinkers and dust during combustion.

(ii) The calorific value of liquid fuels is higher than that of solid fuels.

(iii) Liquid fuels undergo quick combustion and causes less pollution than solid fuels.

(iv) Unlike solid fuels, combustion processes of liquid fuels can be controlled easily by monitoring its supply.

(v) Liquid fuels require less furnace space (or less amount of oxygen) than solid fuels for their complete combustion.

(vi) A liquid fuel is much lighter in weight (typically 30% less) than solid fuel.

(vii) Volume of a liquid fuels is 50% less than that of solid fuels.

(viii) Unlike solid fuels, liquid fuels are extensively used as fuel in automobiles (I.C engines).

Q5. What is meant by Calorific value of a fuel?

Answer :

Calorific Value of a Fuel

Calorific value of a fuel is defined as the total quantity of heat developed during the combustion of a unit mass (or unit volume) of a fuel.

Units

(i) Solid and Liquid fuels – Calories per gram (cal/g), kilocalories per kilogram (kcal/kg) or British thermal units per pound (B.Th.U/lb)

(ii) Gaseous fuels – kilocalories per cubic metre (kcal/m^3) or British thermal units per cubic feet (B.Th.U/ft^3).

Q6. Define the terms,

(i) HCV and

(ii) LCV

Answer : June-17, Q7

Higher Calorific Value (HCV)

It is defined as the total quality of heat produced during the combustion of unit mass of fuel and condensing of combustion products to room temperature (15^{o}C or 60^{o}F or 288^{o}K).

Lower Calorific Value (LCV)

It is defined as the total amount of heat generated during the complete combustion of unit mass of fuel and escaping of products obtained in the process.

Q7. Give the relationship between Higher Calorific Value (HCV) and Lower Calorific Value (LCV).

Answer : June-14, Q9

The relationship between Higher Calorific Value (HCV) and Lower Calorific Value (LCV) is given by,

$$LCV = \left[\text{HCV} - \frac{m \times 587}{V}\right] \text{kcal/m}^3$$

Where,

$$HCV = \frac{\text{Weight of water} \times (\text{Change in temperature})}{\text{Volume}}$$

V – Volume of fuel under test (at STP condition)

m – Mass of Condensed steam in a particular time.

Q8. What is coal? How it is formed?

Answer :

Coal

Coal is a primary solid fuel which is a non-renewable source of energy. It is a highly carbaneous matter which consists of Carbon(C), Hydrogen(H), Nitrogen(N), Oxygen(O) and Non-combustile inorganic substances.

Formation of Coal

Coal is naturally formed from the vegetable and animal matters, which are decomposed under high temperatures and pressures. This process of conversion of vegetable and animal matters into coal is known as coalification.

Q9. Discuss the importance of ultimate analysis of coal.

Answer :

Ultimate analysis of coal gives the elemental description of coal. It determines the percentage of Carbon, Hydrogen, Nitrogen, Sulphur, Oxygen and ash present in the sample of a coal. This analysis provides information regarding the net contents of the elements in order to yield better quality coal.

(i) Carbon and Hydrogen

The amount of carbon and hydrogen present in the sample of a coal determines its quality and calorific value. Coal with higher percentages of carbon and hydrogen has high calorific value and better quality.

(ii) Nitrogen

Presence of Nitrogen in coal is undesirable as it does not have any calorific value. Thus, lower the percentage of nitrogen better is the quality of coal.

(iii) Sulphur

Sulphur enhances the calorific value of a coal. However, it is undesirable because of its adverse combustion effects such as polluting environment and corroding equipments.

(iv) Oxygen

Oxygen reduces the calorific value of coal and hence it is undesirable in coal. In other words, lower the percentage of oxygen better is the quality of the coal.

Q10. Differentiate proximate and ultimate analysis of coal.

Answer :

	Proximate Analysis		Ultimate Analysis
1.	Proximate analysis is an empirical method of analyzing coal.	1.	Ultimate analysis is an elemental method of analyzing coal.
2.	It provides information regarding the practical suitability of coal.	2.	It gives information on the net amount of constituents present in a sample of coal.
3.	It determines the percentage of moisture, volatile matter, ash and fixed amount of carbon present in a sample of coal.	3.	It determines the percentage of carbon, hydrogen, nitrogen, sulphur, oxygen and ash present in a sample of coal.
4.	Proximate analysis is relatively better than ultimate analysis.	4.	Ultimate analysis is not as useful as proximate analysis.

Q11. What is petroleum? Give the average composition of a crude oil.

Answer :

Petroleum

Petroleum or crude oil is one of the important liquid fuels which forms the basis for various secondary liquid fuels (such as kerosene and diesel). It is generally considered as a mineral oil which is naturally formed under the inner crust of the earth.

Table (i) illustrates the characteristics of a crude oil or petroleum.

S.No.	Characteristics	Description
1.	Nature	Viscous liquid
2.	Color	Dark-greenish brown
3.	Odour	Unpleasant

Table (i): Characteristics of Petroleum

Composition

Petroleum is a complex mixture of organic and inorganic compounds. Table (ii) illustrates an approximate composition of petroleum (or crude oil).

S.No.	Constituents	Percentage
1.	Carbon	80 – 87.1%
2.	Hydrogen	11.1 – 15%
3.	Sulphur	0.1 – 3.5%
4.	Nitrogen	0.4 – 0.9%
5.	Oxygen	0.1 – 0.9%

Table (ii): Composition of Petroleum

Q12. What is meant by knocking in I.C. engine? What are its adverse effects?

Answer :

Knocking

Knocking can be defined as a type of explosion which produces a rattling sound in internal combustion (I.C) engines. It is mainly caused due to the instantaneous combustion of the last portion of the fuel.

Adverse Effects

The various adverse effects of knocking are,

(i) Knocking reduces the efficiency of the internal combustion engines. In other words, knocking produces decreased power output.

(ii) It causes overheating of the cylinder parts, thereby resulting in the mechanical failure of the engine.

(iii) It also increases the rate of heat transfer in the system.

(iv) Knocking produces noise, roughness and pre-ignition in the internal combustion engines.

Q13. Explain octane rating.

June-14, Q10

OR

What is octane number? What is its significance?

May/June-12, Q9

OR

Define octane number. What is its significance?

Answer : Jan.-12, Q9

Octane Number

Octane number is an arbitrary scale that gives the measure of knocking characteristics of an internal combustion engine fuel. It can be defined as the percentage of 'lso-octane' present in a mixture of 'n-heptane' and 'Iso-octane', that resembles the combustion characteristics of fuel under test.

Example: A fuel with octane number 86 implies that it has same combustion characteristics as 86:14 mixture of iso-octane and n-heptane.

A fuel with greater octane number offers greater resistance to knocking. For instance, n-heptane which has an octane number equal to zero knocks severely whereas iso-octane with octane number equal to 100 offers high resistance to knocking.

Significance

(i) Octane number helps in expressing the knocking characteristics of a fuel.

(ii) It is also used in determining the quality of a fuel.

Q14. Define

(i) Octane and

(ii) Cetane numbers.

June-17, Q8

OR

Define octane and cetane number.

Jan.-13, Q9

OR

Define octane and cetane number of a fuel.

Answer : June-11, Q10

Octane Number

For answer refer Unit-4, Q13.

Cetane Number

Cetane number gives the measure of ignition capability of a fuel under compression. It can be defined as the percentage of cetane (or n-hexa decane) present in a mixture of cetane and α - methyl naphthalene, that resembles the ignition characteristics of fuel under test.

Example: A fuel with cetane number 60 implies that it has the same ignition characteristics as 60 : 40 mixture of cetane and α-methyl naphthalene.

A fuel with greater cetane number has very short ignition delay. For instance, cetane or hexadecane (Cetane number = 100) has very short ignition delay whereas α-methyl naphthalene (cetane number = 0) has longer ignition delay.

Significance

(i) Cetane number helps in expressing ignition characteristics of a fuel.

(ii) A fuel with greater cetane number has better quality as it eliminates diesel knock.

Q15. Define octane number. How will you improve the anti-knocking value of fuel?

Answer : **(Dec.-17, Q7 | June/July-15, Q7)**

Octane Number

For answer refer Unit-4, Q13.

Prevention

(i) Knocking can be controlled by adding blending agents or antiknocking agents such as Tetra Ethyl Lead (TEL) or Tetra Methyl Lead (TML) or Diethyl Telluride $(C_2H_5)_2Te$.

(ii) Use of high octane gasoline also prevents knocking of engines.

(iii) Increase in the amount of fuel injection lowers the air to fuel ratio, which inturn prevents knocking.

(iv) Use of knock sensors connected to the ECU (Engine Control Unit) helps in detecting a ‘knock’ before hand. When a ‘knock’ is detected, the ignition timing of fuel is slowed down. This inturn reduces knocking tendency of the engines.

Q16. What is LPG? Give the typical composition calorific value of LPG.

Dec.-17, Q8

OR

What is the approximate composition of LPG?

Answer :

LPG (liquefied petroleum gas) is a non-renewable source of energy extracted from crude oil and natural gas. It composed primarily of propane and butane with smaller amount of propylene and butylene. The normal composition of LPG includes propane (60%) and butane (40%). Depending on the season - in winter more propane and in summer more butane. Depending on the source of the LPG and how it has been produced, components other than hydrocarbons may also be present.

The calorific value of LPG is about 11,250 kcal/kg.

Q17. What does the abbreviation CNG stands for? Why is CNG preferred over gasoline?

Answer :

CNG

CNG is an abbreviated form of ‘Compressed Natural Gas’.

Preparation

Natural gas when compressed to 1% (or less) of its total volume at high pressures of about 1,000 atmosphere yields Compressed Natural Gas (CNG).

Advantages of CNG over Gasoline

Compressed natural gas is increasingly replacing gasoline because of its following advantages,

(i) CNG ignites at a higher temperatures than gasoline and diesel. Due to this, use of CNG is considered to be much safer than that of gasoline.

(ii) Amount of pollutants (such as CO and unburnt hydrocarbons) released during the combustion of CNG is less when compared to gasoline.

(iii) CNG is less expensive than gasoline.

(iv) CNG can easily blend with air when compared to gasoline and other liquid fuels.

(v) CNG operated vehicles do not emit unregulated pollutants such as SO_2, SO_3 and $C_6 H_6$.

(vi) Gasoline operated automobiles can be easily converted into the CNG driven vehicles.

Q18. Write the uses of compressed natural gas (CNG).

Answer :

Compressed Natural gas (CNG) is used as,

1. Fuel for spark ignition engines
2. Fuel for diesel engines in automobiles
3. Fuel for internal combustion engines
4. Feedstock in various chemical industries etc.

Q19. Define,

(a) Combustion

(b) Ignition temperature of fuel.

Answer :

(a) Combustion

Combustion may be defined as an exothermic chemical reaction that releases a significant amount of heat on reaction of air with substances (maintained at their ignition temperatures).

(b) Ignition Temperature of Fuel

Ignition or kindling temperature of a fuel is defined as the lowest temperature at which the fuel catches fire and burns smoothly without further heating.

PART-B
ESSAY QUESTIONS WITH SOLUTIONS

4.1 CLASSIFICATION OF FUELS

4.1.1 Introduction, Definition and Classification of Chemical Fuels – Primary and Secondary Fuels – Solids, Liquid and Gaseous Fuels. Requirements of a Good Fuel

Q20. What are chemical fuels? How are they classified? Give suitable examples for each class.

(Dec.-17, Q14(a) | June/July-15, Q14(a))

OR

What are chemical fuels? Give their classification with examples?

Answer : **(Jan.-13, Q15(a) | Jan.-12, Q15(a))**

Classification of Fuels

Fuels can be classified on the basis of following two factors,

1. Occurrence or Mode of availability
2. Physical state or state of Aggregation.

1. Occurrence or Mode of Availability

Based on the occurrence of fuels, these are classified as,

(i) Primary or natural fuels

(ii) Secondary or artificial fuels.

(i) Primary or Natural Fuels

For answer refer Unit-4, Q2, Topic: Primary Fuel.

(ii) Secondary or Artificial Fuels

For answer refer Unit-4, Q2, Topic: Secondary Fuel.

2. Physical State (or) State of Aggregation

Depending on the physical states of fuels (either primary or secondary), these are classified as,

(a) Solid fuels

(b) Liquid fuels and

(c) Gaseous fuels.

Table below illustrates the various types of fuels and their examples.

Physical State	Primary Fuels	Secondary Fuels
Solid fuels	(i) Wood (ii) Peat (iii) Lignite (iv) Coal	(i) Charcoal (ii) Coke
Liquid fuels	(i) Anthracite (ii) Crude petroleum (iii) Kerosene (iv) Fuel oil	(i) Petrol (ii) Diesel oil
Gaseous fuels	(i) Natural gas	(i) Coal gas (ii) Water gas (iii) Producer gas (iv) Gobar gas

Table: Classification of Fuels

Figure below illustrates the classification of fuels based on the occurrence and physical states.

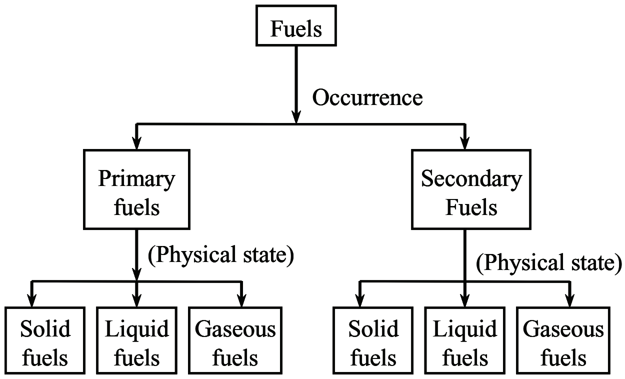

Figure: Classification of Fuels

Q21. Discuss the relative merits and demerits of solid, liquid and gaseous fuels.

Answer :

Solid Fuels

The fuels which exist in solid state are called solid fuels.

Examples

Primary or Natural solid fuels: wood, peat, lignite, coal and dung,

Derived (or) secondary solid fuels : coke, charcoal, petroleum coke and briquette.

Advantages

(i) Solid fuels offer safety against instantaneous explosion.

(ii) Solid fuels are convenient for storage handling and transportation.

(iii) These fuels have optimum ignition temperatures.

(iv) Production cost of solid fuels is low.

(v) Solid fuels have low risk of fire hazards.

Disadvantages

(i) Solid fuels burn with the formation of large amount of smoke, dust and clinkers.

(ii) Combustion processes of solid fuels cannot be controlled easily.

(iii) These fuels have high handling costs.

(iv) Combustion of solid fuel consume large quantity of air.

(v) Solid fuels have low thermal efficiency.

(vi) Calorific value of a solid fuel is relatively low.

(vii) Solid fuels are not suitable for internal combustion engines.

Liquid Fuels

The fuels which exist or obtained in liquid state are called liquid fuels.

Examples

Primary or natural liquid fuel: Crude oil.

Secondary or derived liquid fuels: Tar, kerosene, diesel, petrol, fuel oil, synthetic gasoline and L.P.G

Advantages

(i) Liquid fuels do not form dust, ash and clinkers during combustion.

(ii) These fuels are clean in use and hence loss of heat is very low.

(iii) Combustion operation of liquid fuels consumes less quantity of air.

(iv) Combustion processes can be controlled easily by regulating the fuel supply.

(v) Storage, handling and transportation of liquid fuels can be accomplished without any loss.

(vi) Liquid fuels are suitable for internal combustion engines.

(vii) These fuels have higher calorific value and thermal efficiency than solid fuels.

Disadvantages

(i) Storage of liquid fuels require special care and expensive tanks.

(ii) Cost of production of liquid fuels is greater than that of solid fuels.

(iii) Liquid fuels have bad odour and have more risk of fire hazards.

(iv) Liquid fuels require special burners and spraying apparatus for its combustion.

Gaseous Fuels

The fuels which exist in gaseous state are known as gaseous fuels.

Examples

Primary or natural gaseous fuels : Natural gas.

Secondary or derived gaseous fuels : Coal gas, water gas, oil gas, biogas, blast furnace gas and coke oven gas.

Advantages

(i) Gaseous fuels have higher calorific value than solid and liquid fuels.

(ii) Combustion of gaseous fuel consumes less amount of air.

(iii) These fuels burn without smoke, ash and clinker formation.

(iv) Transportation of gaseous fuels can be easily done through pipelines.

(v) These fuels undergo very fast combustion.

(vi) Combustion of gaseous fuels causes least pollution (i.e., smokeless and ashless). Hence, these are environmentally clean.

(vii) Gaseous fuels have greater thermal efficiency than solid and liquid fuels.

(viii) These fuels are easy to ignite.

(ix) Combustion processes of gaseous fuels can be readily controlled.

(x) Gaseous fuels are suitable for use in internal combustion engines.

Disadvantages

(i) Storage of gaseous fuel require very large tanks with special care.

(ii) Gaseous fuels have higher risks of fire hazards, as they are highly inflammable.

(iii) Production cost of gaseous fuels is higher than that of solid and liquid fuels.

Q22. Give an account of the advantages and disadvantages of solid fuels (coal) over gaseous fuels.

Answer :

Advantages of Coal (or Solid Fuels) over Gaseous Fuels

(i) Solid fuels (or coal) are less expensive than gaseous fuels.

(ii) Storage of solid fuels (or coal) is relatively easy than that of gaseous fuels.

(iii) Solid fuels (or coal) are less prone to fire hazards when compared to gaseous fuels.

Disadvantages of Coal (or Solid Fuels) over Gaseous Fuels

(i) Combustion process of coal (or solid fuels) is comparatively slower than gaseous fuels.

(ii) Coal (or solid fuels) produces a large amount of ash content after its combustion. In contrast to this, combustion process of gaseous fuels is ashless and smokeless.

(iii) Combustion of coal (or solid fuels) produces more pollution when compared to gaseous fuels.

(iv) Amount of oxygen consumed in the combustion of coal (or solid fuels) is much greater than that of gaseous fuels.

(v) Calorific value of solid fuels is relatively less than gaseous fuels.

Q23. Give the comparison between solid, liquid and gaseous fuels.

Answer :

Parameter	Solid Fuels	Liquid Fuels	Gaseous Fuels
(i) Physical state	Solid	Liquid	Gaseous
(ii) Examples	Coal, wood and coke.	Crude oil, diesel and petrol	Natural gas, coal gas and oil gas.
(iii) Storage	Storage of solid fuels is very easy.	Liquid fuels should be stored with little care in closed containers.	Gaseous fuels should be stored with special care in leak proof tanks of large volumes.
(iv) Ash content	Solid fuels have more percentage of ash.	Liquid fuels are ashless.	Gaseous fuels are ashless.
(v) Rate of combustion	Combustion rate of solid fuels is very slow.	Liquid fuels undergo quick combustion.	Combustion rate of gaseous fuels is very high.
(vi) Combustion control	Controlling of combustion of solid fuels is difficult.	Combustion of liquid fuels can be controlled easily.	Combustion process of gaseous fuel can be controlled easily.
(vii) Consumption of oxygen	Solid fuels consume more oxygen for their combustion.	Combustion process of liquid fuels require small amount of oxygen.	Liquid fuels require least amount of oxygen for its combustion.
(viii) Fire hazards	Solid fuels are less prone to fire hazards.	Risk of fire hazards in liquid fuels is much greater than solid fuels.	Gaseous fuels have high risk of fire hazards.
(ix) Pollution	Combustion of solid fuels gives more pollution.	Liquid fuels produce less pollution on their combustion.	Combustion of gaseous fuels gives least pollution.
(x) Calorific value	Solid fuels have low calorific value.	Liquid fuels have higher calorific value.	Solid fuels have highest calorific value.
(xi) Thermal efficiency	Thermal efficiency of solid fuels is low.	Thermal efficiency of liquid fuels is higher than that of solid fuels.	Thermal efficiency of gaseous fuels is higher than solid and liquid fuels.
(xii) Cost	Solid fuels are less expensive.	Liquid fuels are costlier than solid fuels.	Gaseous fuels are costlier than solid fuels and liquid fuels.
(xiii) Use in vehicles	Solid fuels cannot be used in vehicles.	It is possible to use liquid fuels in vehicles.	Gaseous fuels can be used as fuel in vehicles.

Q24. Give the requirements of a good fuel.

Answer : June-14, Q15(a)

Requirements of a Good Fuel

Requirements that play vital role in selecting a good fuel are,

(i) High Calorific Value

A good fuel should possess high calorific value. In other words, a fuel should generate large quantity of heat on combustion.

(ii) Efficient and Controllable Combustion

A good fuel should burn without smoke. It must undergo controllable combustion operation i.e., start and stop of combustion should be easy.

(iii) Optimum Ignition Temperature

Ignition (or kindling) temperature of a fuel is defined as the lowest temperature at which the fuel catches fire and burns smoothly without further heating.

A fuel with low ignition temperature can cause fire hazards during its storage, handling and transportation. In contrast, a fuel with high ignition temperature is safe for storage, handling and transportation but causes problems in ignition. Hence, a fuel with moderate ignition temperature is always preferred.

(iv) Moderate Velocity of Combustion

A good fuel should possess moderate velocity of combustion. This is because, low rate of combustion cannot produce desired heat whereas high combustion rate can cause fire accidents.

(v) Less Amount of Non-combustible Substances

Non-combustible substances such as ash and clinker tend to minimize the calorific value of the fuel. These also increase the storage and handling costs with additional problem of waste disposal. Hence, a good fuel should yield less amount of non-combustible matter on its combustion.

(vi) Harmless By-products

Combustion of a good fuel should not liberate harmful and polluting gases such as CO, SO_2 and H_2S.

(vii) Less Amount of Moisture

Large quantity of moisture in a fuel tends to reduce its calorific value and increases its handling cost. Thus, a good fuel should have less amount of moisture in it.

(viii) Easy Storage, Handling and Transportation

A good fuel should be stored, handled and transported easily at low costs.

(ix) Less Expensive

A good fuel should be easily available at low costs.

4.1.2 Calorific Value – HCV and LCV – Theoretical Calculations of Calorific Value by Dulongs Formula – Numerical Problems

Q25. What is meant by calorific value of a fuel? Define calorie and kilocalorie.

Answer :

Calorific Value of a Fuel

For answer refer Unit-4, Q5.

Calorie

'Calorie' is the measure of heat liberated during an exothermic process. It can be defined as the quantity of heat required to increase the temperature of one gram of water by 1°C.

Kilocalorie (or) Kilogram Centigrade Unit

Kilocalorie is defined as the amount of heat required to increase the temperature of one kilogram of water by 1°C.

1 kilocalorie $= 1 \times 10^3$ Calories

$= 1000$ Calories.

Q26. Differentiate between high calorific value and low calorific value of a fuel.

Jan.-12, Q10

OR

Differentiate between high and low calorific value of a fuel

Answer :

June-11, Q15(a)

Differences between Gross and Net Calorific Values of a Fuel

	Higher Calorific Value (HCV)/ Gross Calorific Value (GCV)		Lower Calorific Value (LCV)/ Net Calorific Value (NCV)
1.	Higher calorific value is defined as the total quantity of heat produced during the combustion of unit mass of fuel and condensing of combustion products to room temperature (15°C or 60°F or 288°K)	1.	Lower calorific value is defined as the total amount of heat generated during the complete combustion of unit mass of fuel and escaping of products obtained in the process.
2.	It is a measure of total heat of fuel.	2.	It is a measure of practical heat of fuel.
3.	Higher calorific value includes the latent heat of condensation of steam.	3.	Lower calorific value does not include latent heat of condensation of steam.
4.	The total heat energy recovered after the combustion of fuel is comparatively less	4.	Heat energy recovered after the complete combustion of fuel is comparatively high

Q27. Write the Dulong's formula for the calculation of the calorific value of a fuel and explain its usefulness.

Answer :

Dulong's Formula

Calorific value of a fuel can be calculated theoretically using Dulong's formula, which is given as,

$$\text{High Calorific Value } (HCV) = \frac{1}{100}\left[8080\ C + 34500\left(H - \frac{O}{8}\right) + 2240\ S\right] \text{ kcal/kg}$$

Where, C – Percentage of Carbon in fuel

H – Percentage of Hydrogen in fuel

O – Percentage of Oxygen in fuel

S – Percentage of Sulphur in fuel.

Also, Low Calorific Value, $(LCV) = \left[HCV - \frac{9}{100} H \times 587\right]$ kcal/kg ($\because$ 1 part of H by mass gives 9 parts of H_2O and patent heat of steam = 587 kcal/kg).

Usefullness

Dulongs formula helps in estimating the gross and net calorific value of the fuel.

Q28. A sample of coal contains 60% Carbon, 33% Oxygen, 6.0% Hydrogen, 0.5% Sulphur, 0.2% Nitrogen and 0.3% Ash. Calculate GCV and NCV of coal.

Answer :

Given that,

For a sample of coal,

Carbon = 60%

Oxygen = 33%

Hydrogen = 6.0%

Sulphur = 0.5%

Nitrogen = 0.2%

Ash = 0.3%

The expression for Gross Calorific Value (GCV) of a coal is given by,

$$GCV = \frac{1}{100}\left[8080\ C + 34500\left(H - \frac{O}{8}\right) + 2240\ S\right] \text{kcal/kg}$$

$$= \frac{1}{100}\left[8080 \times 60 + 34500\left(6 - \frac{33}{8}\right) + 2240 \times 0.5\right] \text{kcal/kg}$$

$$= 5506.\ 075 \text{ kcal/kg}$$

$$\therefore\ GCV = 5506.075 \text{ kcal/g}$$

The expression for Net Calorific Value (NCV) of a coal is given by,

$$NCV = (GCV - 0.09\ H \times 587) \text{ kcal/kg}$$

$$= 5506.075 - (0.09)(6)(587) = 5189.095 \text{ kcal/kg}$$

$$\therefore\ NCV = 5189.095 \text{ kcal/kg}$$

4.2 SOLID FUELS

4.2.1 Coal and its Ranking. Analysis of Coal – Proximate and Ultimate Analysis

Q29. What is coal? How it is formed? Discuss the qualities of a good coal.

Answer :

Coal

For answer refer Unit-4, Q8.

Formation of coal is explained using two theories. They are,

(i) In-situ Theory

In-situ theory states that the coal is formed at the area of vegetation itself. In other words, the place where the coal is found is the original place of its formation.

(ii) Drift or Transportation Theory

Drift theory states that the place where the coal is found is not the original place of its formation. According to this theory, the vegetable matter (such as trees) was moved from rivers to big lakes and other deep basins. This lead to the formation of various filled and blocked layers of wood. Due to the various conditions (such as absence of oxygen, presence of bacteria, high temperature, excessive pressures and long time) the wood experience a gradual decomposition, thereby leading to the formation of coal.

Qualities of a Good Coal

For answer refer Unit-4, Q30.

Q30. What are the factors taken into consideration for selection of coal for different uses?

Answer :

The factors that are to be taken into consideration for selecting coal are,

(i) Calorific Value

A good quality coal should have high calorific value, so as to produce large quantity of heat from smaller quantity of coal. High calorific value also minimizes the storage and handling costs of coal.

(ii) Moisture Content

The quantity of moisture in coal should be low as it reduces the calorific value of coal. Presence of moisture in coal also increases its cost.

(iii) Ash Content

Presence of ash in coal contributes towards the reduction of calorific value. Typically, 1% of ash in coal reduces 1.5% of the total heat liberated during combustion.

Hence, large amount of ash is highly undesirable in coal.

(iv) Calorific Intensity

The maximum temperature obtained after the complete combustion of coal in excess amount of air is known as its calorific intensity.

A fuel is said to have high calorific intensity, if it burns without any flame. Higher the calorific intensity, better is the quality of a coal.

(v) Size of Coal

A coal of uniform size is always preferred because of its easy handling and convenient regulation of combustion process.

(vi) Coking Quality

Coal which gives porous, hard and strong reside (or coke) on heating is known as coking coal. This type of coal is generally preferred in metallurgical applications.

(vii) Sulphur and Phosphorous Contents

The amount of sulphur and phosphorous present in coal should be low in order to prevent the quality of metals in high percentage of sulphur and phosphorous also tends to corrode the equipments and pollute the surroundings.

Q31. How is coal graded? Explain your answer with the composition, calorific values and applications of the different grades of coal.

Answer :

Formation of Coal

Coal is naturally formed from the vegetable and animal matters, which are decomposed under high temperatures and pressures. This process of conversion of vegetable and animal matters into coal is known as coalification.

Depending on the transformation stages (or coalification), coal is graded as,

Wood → Peat → Lignite → Bituminous → Anthracite

(Stage 1) (Stage 2) (Stage 3) (Stage 4)

Table below illustrates the composition, calorific value and applications of different grades of coal.

Grades of Coal	Composition	Nature	Colour	Calorific value	Applications
1. Peat	Carbon 45 - 60% Hydrogen 4 - 7% Oxygen 20 - 45% Nitrogen 0.7 - 3% Volatile matter 65 - 70% Moisture 25%	Highly Fibrous	Light brown	4100 - 5400 kcal/g	❖ Peat can be used as a fertilizer and packaging material.
2. Lignite	Carbon 60 - 70% Hydrogen 4 - 7% Oxygen 17 - 35% Nitrogen 0.7 - 2.5% Volatile matter 45 - 50% Moisture 20%	Fibrous and immature coal	Brown	6500 - 7000 kcal/g	❖ Lignite is used in preparing producer gas. ❖ It is also used in thermal power plants for steam raising.
3. Bituminous coal	Carbon 80 - 83% Hydrogen 4 -5.5% Oxygen 15 - 25% Nitrogen 0.7 - 2% Volatile matter 20 - 45% Moisture 4%	Brittle with a laminated structure	Black	8000 - 8500 kcal/g	❖ Bituminous coal is the most commonly used coal in domestic and industrial applications (such as steam raising, production of coke and gas).
4. Anthracite	Carbon 92 - 95% Hydrogen 3 - 4% Oxygen 2 - 3% Nitrogen 0.5 - 2% Volatile matter 3-7% Moisture 1%	Lustrous and most matured coal	Black	8500 - 8600 kcal/g	❖ Anthracites are extensively used in, (i) Metallurgical operations (ii) Naval applications (iii) Central heating furnaces (iv) Production of producer gas (v) Preparing cathodes for industrial purposes (vi) As a filtering agent in water treatment.

Q32. Explain proximate analysis of coal and write its significance.

June-17, Q14(b)

OR

Describe the analysis of coal by proximate analysis method. What is its significance?

Jan.-13, Q15(b)

OR

Explain the proximate analysis of coal what is its significance? **June-11, Q15(b)**

OR

Explain the significance of the following constituents present in coal,

(a) Moisture

(b) Volatile matter

(c) Ash content and

(d) Fixed carbon.

Answer :

Proximate Analysis of Coal

Proximate analysis is an empirical method of analyzing a sample of coal. This method provides essential information about the practical suitability and commercial classification of coal in any particular application. In other words, this analysis helps in assessing the quality of a coal.

It determines the percentage of moisture, volatile matter, ash and fixed amount of carbon present in the sample of a coal.

(a) Moisture

The various steps involved in the determination of percentage of moisture are,

(i) A silica crucible of weight, 'x' grams is filled with a finely powdered and air dried coal of weight 'y' grams.

(ii) The second step is to heat the crucible to a temperature of about 105-115°C in an electrical oven. After heating for an hour, the crucible is removed using tongs and cooled in a desiccator. This step removes the moisture present in coal, in the form of water vapour.

(iii) The next step is to weigh the cooled crucible, which is considered as the weight of crucible + residue i.e., coal without moisture (say z grams).

(iv) Heating, cooling and weighing is repeated till a constant weight of crucible is obtained.

Calculations

Percentage of moisture is calculated by determining the loss in weight of the coal.

i.e., Percentage of moisture = $\dfrac{\text{Weight of moisture}}{\text{Weight of coal}} \times 100$

Notations

❖ Weight of empty crucible - x grams

❖ Weight of crucible + Coal - y grams

❖ Weight of crucible + Residue (or coal without moisture) - z grams

❖ Weight of the coal sample - $(y - x)$ grams

❖ Weight of the moisture - $(y - z)$ grams.

$$\therefore \text{Percentage of moisture} = \frac{(y-z)}{(y-x)} \times 100$$

(b) Volatile Matter

Determination of percentage of volatile matter in coal involves the following steps,

(i) An anhydrous coal (i.e., coal without moisture obtained in the moisture analysis) of known weight is filled in a crucible which is provided with a lid.

(ii) The next step is to heat crucible in an electric muffle furnace, which is maintained at 925 ± 25°C.

The crucible is removed after heating for about 7 minutes.

(iii) The crucible is now cooled using a desiccator and weighed. The amount of weight lost gives the amount of volatile matter present in coal.

Calculations

Notations

❖ Weight of empty crucible - *a* grams

❖ Weight of crucible + moisture free coal - *b* grams

❖ Weight of crucible + residue (coal without volatile matter) - *c* grams

❖ Weight of moisture free coal - $(b - a)$ grams

❖ Weight of volatile matter - $(b - c)$ grams

$$\therefore \text{ Percentage of volatile matter} = \frac{\text{Weight of volatile matter}}{\text{Weight of moisture free coal}} \times 100$$

$$\therefore \text{Percentage of volatile matter} = \frac{(b-c)}{(b-a)} \times 100$$

(c) Ash Content

Amount of Ash present in coal is determined using following steps,

(i) The residual coal (obtained in the analysis of volatile matter) is heated in a crucible without lid. The heating process is carried out in an electric muffle furnace which is maintained at 700 ± 50°C.

(ii) After heating for an hour, the crucible is taken out, cooled in a desiccator and weighed again.

(iii) The process of heating, cooling and weighing crucible is continued till a constant weight of ash content is obtained.

Calculations

Notations

❖ Weight of empty crucible - *p* grams

❖ Weight of crucible + coal sample - *q* grams

❖ Weight of crucible + residue (ash) - *r* grams

❖ Weight of coal sample - $(q - p)$ grams

❖ Weight of ash - $(r - p)$ grams

$$\therefore \text{ Percentage of ash} = \frac{\text{Weight of ash}}{\text{Weight of coal sample}} \times 100$$

$$\therefore \text{Percentage of ash} = \frac{(r-p)}{(q-p)} \times 100$$

(d) Fixed Carbon

The amount of fixed carbon present in coal is calculated as,

Percentage of fixed carbon = 100 – [Percentage of moisture + Volatile + Ash content]

Significance of Proximate Analysis

(i) Moisture

Moisture present in coal is evaporated during combustion and consumes a significant amount of heat in the form of latent heat of evaporation. This wastage in heat reduces the effective calorific value of coal. Thus, coal with less amount of moisture content is always desirable.

(ii) Volatile Matter

Presence of large amount of volatile matter in coal leads to incomplete combustion of fuel. It also produces long smoky flame which considerably reduces the calorific value of coal. Hence, a better quality coal must contain less amount of volatile matter in it.

(iii) Ash Content

Ash content in coal is always considered as a trash (or waste) component as it is a non-combustible matter. It produces hindrance to the flow of air and heat, thereby reducing the calorific value of the coal.

Ash also increases the transport, handling and storage costs of the coal. Moreover, disposal of ash also causes a big problem and adds additional cost to coal. Hence, presence of ash in coal is highly undesirable.

(iv) Fixed Carbon

Amount of fixed carbon in coal represents the pure carbon content present in it. Greater the percentage of carbon, greater is the combustion efficiency of coal. It is used in designing the furnace and shape of the firebox. Thus, a coal with large amount of fixed carbon has better quality.

Q33. Explain the significance of the following constituents present in coal,

(i) Total carbon
(ii) Hydrogen
(iii) Nitrogen
(iv) Sulphur and
(v) Oxygen.

OR

Explain the ultimate analysis of a solid fuel and its significance.

OR

Give an account of the analysis of coal by ultimate analysis and its significance.

Answer :

Ultimate Analysis of Coal

Ultimate analysis of coal provides percentage contents of carbon, hydrogen, nitrogen, sulphur, oxygen and ash so as to yield better quality coal. This analysis is also known as qualitative analysis.

(a) Carbon and Hydrogen

The sequence of steps that are to be carried out in determining the percentage of *C* and *H* are,

(i) A combustion tube is filled with a known sample of coal (of weight '*p*' grams) and is burned in the presence of surplus oxygen.

(ii) This combustion of coal yields two gaseous products namely CO_2 and H_2O, which are respectively collected in KOH and $CaCl_2$ tubes of known weights.

(iii) Amount of carbon present in KOH tube is determined using the increase in the weight of KOH bulb.

Combustion reaction: $C + O_2 \rightarrow CO_2$

Absorbing reaction: $2KOH + CO_2 \rightarrow K_2CO + H_2O$

$$\therefore \quad \text{Percentage of } C = \frac{\text{Increase in weight of KOH}}{\text{Weight of coal sample}} \times \frac{\text{Molecular weight of C}}{\text{Molecular weight of } CO_2} \times 100$$

$$\therefore \text{Percentage of } C = \frac{\text{Increase in weight of KOH}}{\text{Weight of coal sample}} \times \frac{12}{44} \times 100$$

(iv) Similarly, amount of H_2 present in $CaCl_2$ tube is determined using the increase in the weight of $CaCl_2$ bulb.

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

Absorbing reaction: $CaCl_2 + 7H_2O \rightarrow CaCl_2.7H_2O$.

$$\therefore \quad \text{Percentage of } H_2 = \frac{\text{Increase in weight of } CaCl_2}{\text{Weight of coal sample}} \times \frac{\text{Molecular weight of } H_2}{\text{Molecular weight of } H_2O} \times 100$$

$$\therefore \text{Percentage of } H_2 = \frac{\text{Increase in weight of } CaCl_2}{\text{Weight of coal sample}} \times \frac{2}{18} \times 100$$

(b) Nitrogen

Amount of nitrogen present in the sample of coal is determined using Kjeldahl's method. The sequence of steps involved in determining the percentage of nitrogen are,

(i) Powdered coal of known weight is taken into Kjeldahl's flask (a long-necked flask). The sample is then heated with a concentrated sulphuric acid (H_2SO_4) in the presence of a catalyst, K_2SO_4 until a clear solution is obtained.

(ii) The clear solution attained is made alkaline by treating with potassium hydroxide (KOH). This process liberates ammonia, which is absorbed in a standard acid solution of known volume.

(iii) The acid (clear solution) is again treated back with a standard base solution (NaOH) in order to determine the untreated acid.

Therefore, the percentage of nitrogen present in coal is then determined as,

$$\text{Percentage of nitrogen} = \frac{\text{Volume of acid used}}{\text{Weight of coal sample}} \times \text{Normality} \times 1.4$$

(c) Sulphur

Amount of sulphur present in coal is calculated using Bomb calorimeter. In this process, the sulphur is converted into a sulphate. This sulphate is then treated with a Barium chloride ($BaCl_2$) solution which yields a precipitate of Barium Sulphate ($BaSO_4$)

The precipitate so obtained is then filtered, washed and weighed. Therefore, the percentage of sulphur in coal is determined as,

$$\text{Percentage of sulphur} = \frac{\text{Weight of } BaSO_4}{\text{Weight of coal sample}} \times \frac{\text{Molecular weight of sulphur}}{\text{Molecular weight of } BaSO_4} \times 100$$

$$\therefore \text{ Percentage of sulphur} = \frac{\text{Weight of } BaSO_4}{\text{Weight of coal sample}} \times \frac{32}{233} \times 100$$

(d) Ash

For answer refer Unit-4, Q32, Topic: Ash Content.

(e) Oxygen

Amount of oxygen present in coal is determined using the expression,

Percentage of oxygen = 100 – [Percentage of carbon + Hydrogen + Sulphur + Nitrogen + Ash]

Significance of Ultimate Analysis

For answer refer Unit-4, Q9.

4.3 LIQUID FUELS

4.3.1 Fractionation of Petroleum. Composition and Uses of Gasoline, Diesel and Kerosene. Cracking and its Significance – Catalytic Cracking by Moving Bed Method, Knocking. Fuel Rating – Octane and Cetane Numbers

Q34. What are the constituents of petroleum? Describe the origin of petroleum.

Answer :

Petroleum

For answer refer Unit-4, Q11, Topic: Petroleum.

Origin of Petroleum

Origin of petroleum is explained using two main theories. They are,

(i) Carbide or Mendeef's Theory or Inorganic Theory

Carbide theory states that the metals present in the earth's crust combine with carbon and form metallic carbides. These carbides on reaction with moisture or steam form hydrocarbons, which on further hydrogenation yields petroleum.

However, carbide theory could not explain the presence of gases such as nitrogen, sulphur and optically active compounds.

(ii) Engler's or Organic Theory

Organic theory states that the animal and vegetable remains got collected in the sea due to certain natural calamities such as volcanic eruption. Under the influence of high temperature and excessive pressures, anaerobic bacteria decompose the vegetable matters into several hydrocarbons, so as to yield a dark viscous liquid called petroleum.

Q35. Write an account on the refining of petroleum by explaining the composition, boiling range and uses of different fractions obtained during refining.

OR

Give an account of production of petrol from crude oil.

Answer :

Refining of Petroleum

For answer refer Unit-4, Q36.

Extraction of Petroleum

Crude oil present in the deep earth is extracted by drilling holes in the earth's crust. The pipes are then sinked into the holes upto the oil-bearing porous rocks. Due to the hydrostatic pressure of natural gas (present in petroleum), the oil rushes out from the holes.

Figures (1) illustrates the mining of crude oil by drilling holes in the earth's crust.

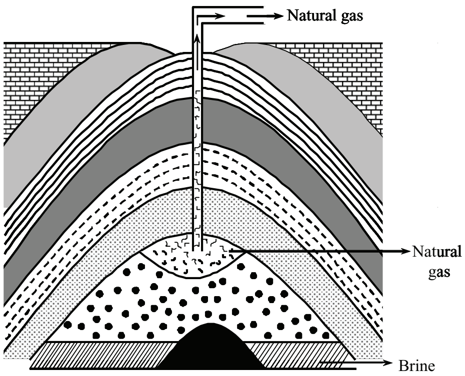

Figure (1): Extraction or Mining of Crude Oil

Another method of extracting petroleum is to use lift pump or air-lift pump for mechanically mining the crude oil. The lift pump has two co-axial pipes namely outer pipe and inner pipe. These pumps are sinked into the bottom of the crude oil bed as shown in figure (2).

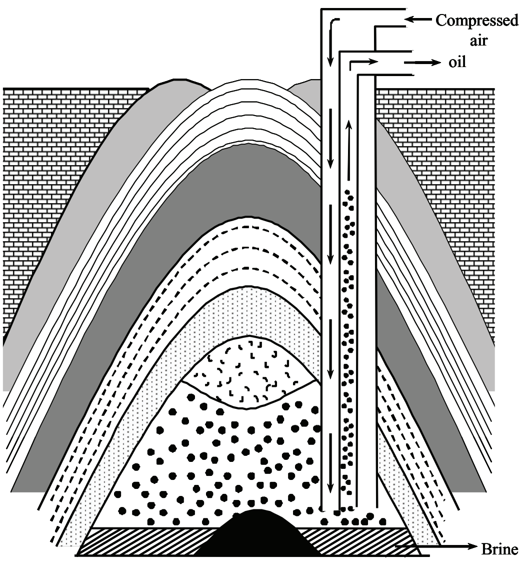

Figure (2): Use of Air-lift for Extracting Petroleum

The outer pipe is provided with compressed air to force out the oil from earth's crust and the oil is collected from the inner pipe. This oil is then transported to refinery through pipelines.

The various steps involved in the refining of crude oil are,

Step 1: Separation of Water by Cottrell's Process

Water from the crude oil is separated by passing it between two highly charged electrodes. Due to this, all the small droplets of water come together and form big droplets of water. These water droplets can be easily separated from the crude oil.

Step 2: Removal of Sulphur Compounds

The crude oil obtained from the cottrell's process is treated with copper oxide to remove sulphur compounds present in it. The copper oxide reacts with sulphur and forms copper sulphide. This solid material can be easily removed by the process of filtration.

Step 3: Fractional Distillation

Fractional distillation is the process of separating various crude oil components, depending on their boiling point differences. Fractional distillation is carried out in a tall cylindrical tower, known as 'Fractionating Column'. This column consists of number of horizontal trays with holes (or loose caps) as shown in figure (3).

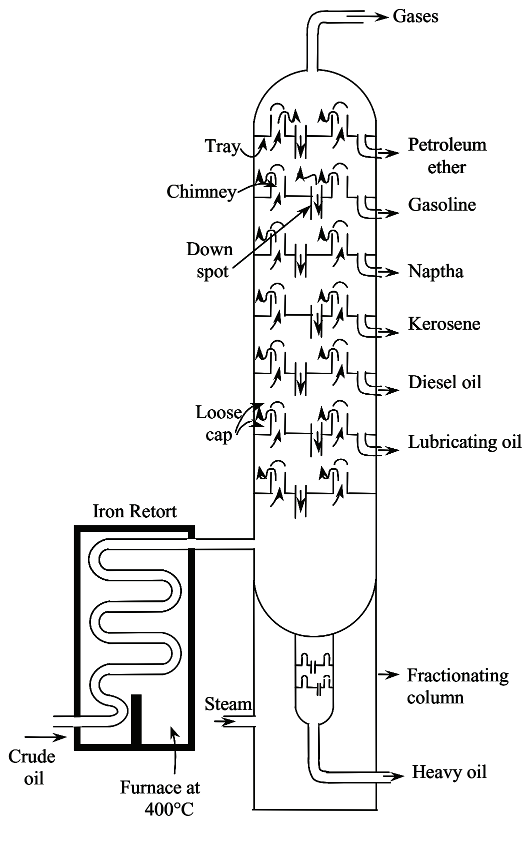

Figure (3): Fractional Distillation of Crude Petroleum

The crude oil is passed into an iron retort, where it is heated to a high temperature of 400°C. This evaporates all the volatile constituents and the residue (i.e., petroleum coke or asphalt) remained is collected at the bottom.

The hot vapours or volatile constituents are then allowed to pass through the fractionating column. As the hot vapours move up, they gradually cool down and hence fractional condensation occurs at various heights of the column. Fractions with high boiling points condense first and those with low boiling points condense step-by-step.

The various fractionation products obtained by fractional distillation are,

S.No	Fractionation Product	Range of Boiling Points	Approximate Composition	Uses
1.	Uncondensed gas	Less than 30°C	C_1 - C_4	Domestic and industrial fuel known as LPG.
2.	Petroleum ether	30 - 70°C	C_5 - C_7	Used as a solvent.
3.	Gasoline or petrol or motor spirit	40 - 120°C	C_5 - C_9	Automobile fuel and solvent.
4.	Naphtha or solvent spirit	120 - 180°C	C_9 - C_{10}	Used in dry cleaning and as a solvent.
5.	Kerosene oil	180 - 250°C	C_{10} - C_{16}	Used as an illuminant, jet engine fuel and in the preparation of laboratory gas.
6.	Diesel oil or fuel oil or gas oil	250 - 320°C	C_{10} - C_{18}	Used as diesel engine fuel.
7.	Heavy oil	320 - 400°C	C_{17} - C_{30}	Used to obtain gasoline by cracking process.
8.	Residue (i.e., asphalt or coke)	Greater than 400°C	C_{30} and above	Asphalt is used as water proofing material. Coke is used as a fuel.

Q36. What is meant by refining of petroleum? List out the various fractions obtained during the refining of crude oil.

Answer :

Refining of Petroleum

Petroleum obtained directly from the earth's crust is a complex mixture of various hydrocarbons. It also contains unwanted impurities such as sand, water and compounds of sulphur. These impurities of petroleum must be removed prior to its use in automobiles. The process of eliminating the unwanted impurities by fractionalising petroleum into different fractions is known as 'Refining of Petroleum'.

Fractions Obtained During the Refining of Crude Oil

The various fractions obtained during the refining of crude oil are,

(i) Uncondensed gas
(ii) Petroleum ether
(iii) Gasoline (or petrol)
(iv) Naphtha (or solvent spirit)
(v) Kerosene oil
(vi) Diesel oil
(vii) Heavy oil.

Q37. Write the composition and uses of the following,

(a) Gasoline
(b) Diesel
(c) Kerosene.

Answer :

(a) Gasoline

Gasoline is a fractionation product obtained from the fractional distillation of crude oil. It consists of hydrocarbons in the composition range of C_5H_{10} to $C_{10}H_{22}$ and has the boiling point in the range of 30° to 200°C. On the basis of boiling point, gasoline is further divided into various fractions which are as follows,

(i) Aviation spirit : 30° – 150°C

(ii) Motor spirit : 40° – 180°C

(iii) Vapourising oil spirit : 110° – 200°C

(iv) Petroleum other : 40 – 60°C; 60 – 80°C; 80° – 100°C

(v) Sovent naphtha : 150° – 200°C.

Uses

1. Gasoline is widely used as automobile and aviation fuels.
2. It is used as dilvent and solvents for points and varnishes.
3. It is also used for dry cleaning purpose.

(b) Diesel

Diesel or diesel oil is a fractionation product obtained from the fractional distillation of crude oil. It also called as gas oil and consists of hydro carbons in the composition range of $C_{16}H_{34}$ to $C_{18}H_{38}$. The boiling point range of gas oil is 250° to 370°.

Uses

Diesel oil is used widely as fuel for,

(i) Diesel engines

(ii) Heating coils

(iii) Stripping of benzole from coal gas

(iv) Carburetting of water gas.

(c) Kerosene

Kerosene is also a fractionation product obtained from the fractional distillation of crude oil fraction. It consists of hydrocorbons in the range of $C_{11}H_{22}$ to $C_{16}H_{24}$,

The boiling point range of kerosene is 140° – 290°C. Paraffins naphthenes and aromatic compounds.

Uses

Kerosene is used as fuel for,

(i) Domestic purpose

(ii) Aviation turbines

(iii) Tractors.

Q38. What is meant by cracking of petroleum? Write its significance.

Answer :

Cracking of Petroleum

Cracking of petroleum is defined as the process of converting a bigger hydrocarbon molecules into smaller hydrocarbon molecules.

i.e., Higher hydrocarbon molecule $\xrightarrow{\text{Cracking}}$ Smaller saturated hydrocarbon + Smaller unsaturated hydrocarbon

Example: Cracking of a decane molecule ($C_{10}H_{22}$) yields two smaller pentane molecules.

$$\text{i.e., } \underset{\text{(Decane)}}{C_{10}H_{22}} \xrightarrow{\text{Cracking}} \underset{\text{(n-pentane)}}{C_5H_{12}} + \underset{\text{(pentane)}}{C_5H_{10}}$$

Significance of Cracking

1. Gasoline is one of the fraction, obtained after cracking of petroleum.
2. If is used as a motor fuel. It has high value over other fuels.
3. The quality of 'straight run' gasoline is not frequently used hence blending is done to achieve good results.
4. Their is a difficulty in heavier petroleum fractions for this reason cracking, a thermal decomposition process is adopted to get more valuable low boiling fraction.
5. Petrol (gasoline) obtained after cracking has more significance than straight run petrol.

Q39. How gasoline is obtained from moving bed catalytic cracking?

Answer :

Moving Bed or Fluidized Catalytic Cracking

Moving bed catalytic cracking is used to perform repeated cracking of heavy oil. This method of cracking employs a solid catalyst as its raw material.

Figure below illustrates the apparatus arrangement of moving bed catalytic cracking.

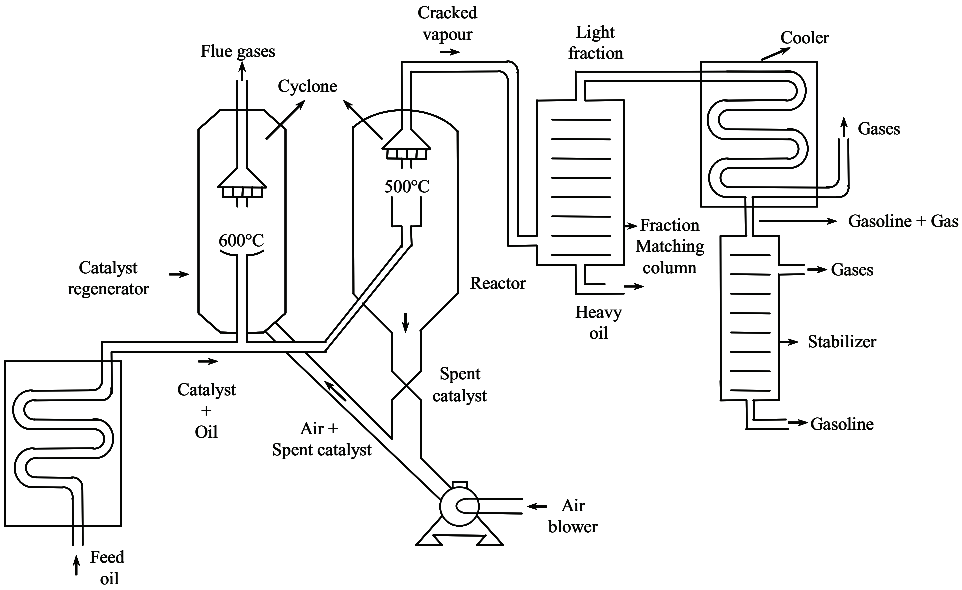

Figure: Moving-bed (or) Fluidised Catalytic Cracking

The sequence of actions carried out in moving bed catalytic cracking are,

(i) Initially the raw material (solid catalyst) is grind to very fine powder such that it nearly behaves as a fluid.

(ii) Vapours of heavy oil along with the fluidized catalyst is passed into a large reactor 'bed'. This reactor breaks down the heavier molecules into lighter molecules.

The reactor is provided with a centrifugal separator (known as cyclone) at its top. This permits the passage of cracked oil vapours over the fractionating column and blocks the catalyst powder in the reactor itself.

(iii) The carbon coating makes the catalyst powder heavier in weight. Hence, it gets collected at the bottom of the reactor. This collected powder is again sent to regenerator using an airblast.

(iv) The regenerator burns the carbon and produces catalyst again. This regenerated catalyst is allowed to pass through a stand-pipe inorder to combine with the untreated incoming cracking oil.

(v) A separator provided at the top of the regenerator allows only gases to pass through it while retaining the catalyst particle at the bottom of the regenerator.

(vi) The gaseous vapours are then moved towards the 'fraction matching column' to divide the various fractions of the heavy oil.

(vii) The fractionated vapours are now led towards a cooler so as to condense the hot vapours.

(viii) The cooled gasoline along with few undissolved gases is sent towards a stabilizer, which eliminates the undissolved gaseous and gives a pure petrol.

Q40. What is knocking? What are its adverse affects? How it is prevented?

Answer :

Knocking and its Adverse Effects

For answer refer Unit-4, Q12.

Prevention

(i) Knocking can be controlled by adding blending agents or antiknocking agents such as Tetra Ethyl Lead (TEL) or Tetra Methyl Lead (TML) or Diethyl Telluride $(C_2H_5)_2Te$.

(ii) Use of high octane gasoline also prevents knocking of engines.

(iii) Increase in the amount of fuel injection lowers the air to fuel ratio, which inturn prevents knocking.

(iv) Use of knock sensors connected to the ECU (Engine Control Unit) helps in detecting a 'knock' before hand. When a 'knock' is detected, the ignition timing of fuel is slowed down. This inturn reduces knocking tendency of the engines.

Q41. What do you understand by the term knocking in I.C engines? Explain its relationship with chemical constituents of fuels.

OR

What is meant by knocking in I.C engine? Explain the mechanism of knocking in chemical terms.

Answer :

Knocking

For answer refer Unit-4, Q12, Topic: Knocking.

Mechanism of Knocking in Chemical Terms

Chemical composition of fuel has great impact on their knocking characteristics. Some of the major impacts are,

(i) Increase in the compactness of the molecules, double bonds and cyclic structure, increases the knocking capability of the fuels.

(ii) Increase in the hydrocarbon chain of the normal paraffins, decreases their anti-knocking tendencies.

Table below illustrates the octane number of the normal paraffins.

S.No.	Paraffin	Octane Number	Remark
1	n-butane	90	Decrease in the octane number, decreases knocking in the fuel.
2.	n-pentane	60	
3.	n-hexane	29	
4.	n-heptane	0	

Table

(iii) Paraffins of branched chain characteristics show higher anti-knocking capability than that of normal isomers.

(iv) Antiknock properties of olefins is much higher than their respective paraffins.

(v) Benzene and toluene (i.e., Aromatic hydrocarbons) knock severely as these have high octane numbers.

Q42. Compare petrol and diesel oil with respect to,

(i) Knocking characteristics

(ii) Octane number and cetane number

(iii) Blending and doping agents.

Answer :

Property		Petrol		Diesel
(i) Knocking Characteristics	1.	Knocking in petrol is due to the instantaneous combustion of the last portion of the fuel.	1.	Knocking is due to the delay in the instantaneous combustion of the first part of the fuel.
	2.	Knocking characteristics are expressed in terms of octane numbers.	2.	Knocking characteristics are expressed in terms of cetane numbers.
	3.	Knocking characteristics of petrol in decreasing order is given as, n-alkanes > branched chain alkanes > cyclo alkanes > alkenes > aromatics.	3.	Knocking characteristics of diesel in decreasing order is given as: n-alkanes > naphthenes (or cycloalkanes) > alkenes > iso-alkanes > aromatics.

Property		Petrol		Diesel
(ii) Octane Number and Centane Number	1.	Octane number is the percentage of iso-octane present in a mixture of iso-octane and n-heptane which matches the combustion characteri-stick of fuel under test.	1.	Cetane number is the percentage of cetane in a mixture of cetane and α-methyl naphthalene which matches the ignition characteristics of the fuel under test.
	2.	High octane number represents less knocking and higher combustion characteristics.	2.	High cetane number indicates less knocking (i.e., very short ignition delay).
	3.	Petrol (iso-octane) with octane number 100 offers high resistance to knocking.	3.	The diesel oil with a cetane number 100 has very short ignition delay and least knocking.
	4.	n-heptane knocks severely and its octane number is zero.	4.	α-methyl napthalene has a long ignition delay and its cetane number is zero.
(iii) Blending and Doping Agents	1.	The octane number of petrol can be raised by adding blending agents like, ❖ Tetraethyl lead (TEL)-Pb$(C_2H_5)_4$ ❖ Tetramethyl lead (TME)-Pb$(CH_3)_4$ ❖ Mixed methylethyl lead.	1.	The cetane number of diesel can be raised by adding doping agents like ❖ Ethylnitrite ❖ Iso-anryl nitrate ❖ Acetone ❖ Peroxide ❖ Ethylnitrate.
	2.	A crude oil that gives petrol of high octane number will give diesel of low cetane number.	2.	A crude oil that gives diesel of high cetane number will give petrol of low octane number.

Q43. Distinguish octane number and cetane number of a fuel.

Answer :

	Octane Number		Cetane Number
1.	Octane number gives the measure of knocking characteristics of an internal combustion engine fuel (or gasoline).	1.	Cetane number gives the measure of ignition characteristics of a fuel or diesel.
2.	Hydrocarbons with poor diesel fuel characteristics serve as good gasoline fuels.	2.	Hydrocarbons with poor gasoline fuel characteristics are used a good diesel fuels.
3.	Straight chain hydrocarbon molecules have low octane number. Hence, these are considered as worst fuels.	3.	Straight chain hydrocarbon molecules have high cetane numbers. Hence, these are considered as best fuels.
4.	The most common additives used for increasing the octane number are Tetraethyl Lead (TEL) and Diethyl Telluride.	4.	The most common additives used for increasing the cetane number of a fuel are 'pre-ignition dopes' such as ethyl nitrite, isoamyl nitrite and acetone peroxide.

Table

4.4 GASEOUS FUELS

4.4.1 LPG, CNG Composition and Uses

Q44. Write short note on LPG.

Answer :

Liquefied Petroleum gas (LPG)

Liquefied Petroleum Gas (LPG) is a non-renewable energy source which can be prepared from natural gas or by cracking heavy petroleum products. It contains propane and butane along with other hydrocarbons like isobutane, butylene, propene and ethane. These gaseous hydrocarbons when treated under high pressures attain liquid state. LPG can be compressed to store in containers or cylinders.

Advantages of LPG

(i) LPG is environmentally safe as it gives non-toxic gases (such as CO and water vapour) on its combustion.

(ii) Its calorific value is about 25,000 kcal/m^3.

(iii) Combustion of LPG yields moderate heat, less carbondioxide and unburnt hydrocarbons.
Hence, it causes least pollution.

(iv) Storage of liquefied petroleum gas is simple.

(v) LPG can be easily mixed with air.

(vi) Combustion of LPG is smokless and ashless.

(vii) It highly resists knocking.

(viii) Leakage of LPG can be detected by adding small quantities of sulphur compounds.

(ix) LPG is less expensive than gasoline.

Disadvantages

(i) LPG becomes dangerous on its leakage.

(ii) Use of LPG as fuel is quite difficult.

(iii) It is not suitable in engines with low Compression Ratio (CR).

Applications

(i) LPG is extensively used as domestic fuel and auto fuel.

(ii) It is also used in the preparation of number of chemicals and olefins.

(iii) Industries employ LPG in portable blow lamps, hardening, annealing, steel cutting and welding.

Q45. What is CNG? What is its composition? What are the advantages of CNG as a fuel?

May//June-12, Q15(b)

OR

Write a note on CNG.

Answer : **June-10, Q15(b)**

CNG

CNG is acronym for compressed natural gas. CNG is a fossil fuel substitute for gasoline (petrol), diesel, or propane fuel. Although its combustion does produce greenhouse gases, it is a more environmentally clean alternative to those fuels and it is much safer than other fuels in the event of a spill.

CNG is made by compressing natural gas (which is mainly composed of methane (CH_4)), to less than 1% of its volume at standard atmospheric pressure. It is stored and distributed in hard containers, at a normal pressure of 200-220 bar, usually in cylindrical or spherical shapes.

CNGs volumetric energy density is estimated to be 42% of LNG's and 25% of diesels.

Composition

Compressed natural gas has approximate composition of,

CH_4 = 70 - 90%

C_2H_6 = 5 - 10%

H_2 = 3%

rest of CO and CO_2.

Advantages of CNG

1. CNG is very efficient and produces less pollutants.
2. It is less expensive fuel and is ecofriendly.
3. It is the cleanest burning fuel with less vehicle maintenance and longer engineer life.
4. CNG engines have better performance than gasoline engines because it has octane rating of 130.
5. CNG gives same mileage as gasoline in vehicles.

Q46. Write a short note on LPG and CNG

Answer : **June-11, Q15(c)**

For answer refer Unit-IV, Q44 and Q45.

4.5 COMBUSTION

4.5.1 Ignition Temperature of a Fuel, Calculation of Air Quantities by Weight and Volume Required for Combustion of a Fuel – Numerical Problems

Q47. What is combustion? What is the importance of moisture in coal combustion?

Answer :

Combustion

For answer refer Unit-4, Q19, Topic: Combustion.

Example: $C(S)+O_2(g) \rightarrow CO_2(g) + 97$ kcal

The presence of moisture in coal is undesirable, because it causes waste of heat. Moisture may be present in coal naturally or by wetting the coal before use. The presence of some sort of moisture in coal helps to keep the temperature of the fire bars low and prevents the formation of clinkers. The excess presence of moisture leads to heavy smoke and also causes slow starting of combustion process. Optimum free moisture content is 7 to 9% when coal has minimum density. The presence of optimum amount of moisture in combustion makes the combustion process successful.

Q48. Discuss the fundamental principle of combustion calculations.

Answer :

For answer refer Unit-4, Q19, Topic: Combustion.

Any substance that combines with other substance is in appropriate proportions during combustion. These proportions depends upon the molecular masses and products formed in the process.

For instance, combustion reaction of carbon and oxygen is,

$$C + O_2 \rightarrow CO_2$$

Where,

Molecular mass (or kilogram mole) of carbon is 12

Molecular mass (or kilogram mole) of oxygen is 16.

The definite proportion is one molecule of carbon combines with two molecules of oxygen. Therefore,

$$C + O_2 \rightarrow CO_2$$

12 kg-mole C + 32 kg-mole $O_2 \rightarrow$ 44 kg-mole CO_2

12 kgC + 32 kg $O_2 \rightarrow$ 44 kg CO_2

This gives the fundamental principle of combustion calculations which determines the amount of a reactant or product in a combustion reaction.

Q49. Calculate the weight and volume of air needed for the combustion of 1 kg of carbon. Give the composition of the combustion products.

Answer :

Given that,

In the combustion process of carbon,

Weight of carbon (C) = 1 kg

Combustion Reaction

$$\underset{(12)}{C} + \underset{(32)}{O_2} \longrightarrow \underset{(44)}{CO_2}$$

Weight of Air

The expression for estimating weight of air required for combustion of C is,

$$\text{Weight of air} = \text{Weight of C} \times \frac{\left(\dfrac{\text{Atomic weight of } O_2}{\text{Atomic weight of C}}\right)}{\text{Mass percentage of } O_2 \text{ in air}}$$

$$= 1 \text{ kg} \times \frac{32}{12} \times \frac{100}{23} \qquad (\because \text{ Air contains 23\% of } O_2)$$

$$= 11.594 \text{ kg}$$

$\therefore$ Weight of air = 11.594 kg

Volume of Air

1 kg of C= 1000 gm

$$= 1000 \text{ gm} \times \frac{1 \text{ mole}}{12 \text{ gm}} \qquad (\because \text{ Atomic weight of } C = 12)$$

$$= 83.33 \text{ mole}$$

$\therefore$ 1 kg of C = 83.33 mole.

Since, 1 mole of carbon requires 22.4 L of O_2,

$$\text{i.e., 1 mole of } C = 22.4 \text{ L} \times \left(\frac{100}{21}\right) \text{ of air} \qquad (\because \text{ Volume \% of } O_2 \text{ in air} = 21\%)$$

Hence,

$$83.33 \text{ mole of } C = 22.4 \text{ L} \times \left(\frac{100}{21}\right) \times \left(\frac{83.33}{1}\right)$$

$$= 0.888 \times 10^4 \text{ L}$$

$$= 8.88 \text{ m}^3 \text{ of air}$$

$\therefore$ Volume of air = 8.88 m^3

Q50. A sample of coal was found to have the following percentage composition: C = 75% ; H = 5.2% ; O = 12.1% ; N = 3.2% and ash = 4.5%. Calculate the minimum amount of air necessary for complete combustion of 1 Kg of coal.

Answer : (Dec.-17, Q14(b) | June-17, Q14(a))

Given that,

A sample of coal contains,

Cargon, C = 75% = 0.75 kg

Hydrogen, H = 5.2% = 0.052 kg

Oxygen, O = 12.1% = 0.121 kg

Nitrogen, N = 3.2% = 0.032 kg

Ash = 4.5% = 0.045 kg

The minimum amount of air required for the complete combustion of 1 kg of coal is given by,

$$\text{Weight} = \left[\% \text{ of } C \times \frac{32}{12} + \% \text{ of } H_2 \times \frac{16}{2} + \% \text{ of } O_2 \times \frac{32}{32} - 0.128\right] \times \frac{100}{23}$$

$$= \left[0.75 \times \frac{32}{12} + 0.052 \times \frac{16}{2} + 0.121 \times \frac{32}{32} - 0.128\right] \times \frac{100}{23}$$

$$= 10.474 \text{ kg}$$

$\therefore$ Weight of air = 10.474 kg.

Q51. A gaseous fuel has the following composition by volume. H_2 = 25%, methane = 30%, O_2 ethane = 11%, ethylene = 4.5%, butane = 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 using 40% excess air.

Answer : June/July-15, Q14(b)

Given that,

A gaseous fuel contains the following composition,

Hydrogen, H_2 = 25%

Methane, CH_4 = 30%

Ethane, C_2H_6 = 11%

Ethylene, C_2H_4 = 4.5%

Butane, C_4H_{10} = 2.5%

Carbon monoxide, CO = 6.0%

Carbon dioxide, CO_2 = 8%

Oxygen, O_2 = 2%

Nitrogen, N_2 = 12%

Table below illustrates the calculation of net amount of O_2, CO_2 and H_2O.

Products	Combustion Reaction	Moles/mole Fuel	Volume of O_2 Required	Volume of CO_2	Volume of H_2O
H_2O	$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	0.25	0.125		0.25
CH_4	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	0.30	0.6	0.30	0.6
C_2H_6	$C_2H_6 + \frac{7}{2}O_2 \rightarrow 2CO_2 + 3H_2O$	0.11	0.385	0.22	0.33
C_2H_4	$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$	0.045	0.135	0.09	0.09
C_4H_{10}	$C_4H_{10} + \frac{13}{2}O_2 \rightarrow 4CO_2 + 5H_2O$	0.025	0.1625	0.1	0.125
CO	$CO + O_2 \rightarrow 2CO_2$	0.06	0.03	0.06	
CO_2		0.08		0.08	
O_2		0.02	0.02		
N_2		0.12			
		Total	1.4175	0.85	1.395

Table

A/F ratio

Air required for the combustion of gaseous fuel can be calculated theoretically as,

$$\text{Air required} = \frac{1.4175}{0.21}$$

$$= 6.75$$

$$\therefore A/F \text{ ratio} = 6.75 \text{ moles/mole of fuel}$$

Analysis of Dry Products of Combustion Using 40% Excess Air

$$\text{A/F ratio with excess 40\%} = 6.75 \times \frac{40}{100} \times 6.75$$

$$= 9.45 \text{ moles/mole of fuel.}$$

$$CO_2 \text{ (From table)} = 0.85 \text{ moles}$$

$$O_2 = 0.21 \times 9.45 - 1.4175 = 0.567 \text{ moles}$$

$$N_2 = 0.79 \times 9.45 = 7.465 \text{ moles/mole of fuel.}$$

Total moles of N_2 in product = 7.465 + 0.12

= 7.585 moles

Total volume of Dry Products = 0.85 + 0.567 + 7.465

= 8.882

∴ Volume of product with 40% excess air = 8.882 moles/mole of fuel.

Q52. A sample of coal was found to contain the following constituents : C = 81%; O = 8%; S = 1%; H = 5%; N = 1%; ash = 4%. Calculate the minimum amount of air required for the complete conbustion of 1 kg of coal. Also calculate the percentage composition by weight of the dry product of combustion. Oxygen in air is 23% by weight.

Answer : April-16, Q17(b)

Given that,

A sample of coal contains the following constituents,

C = 81% = 0.81 kg

O = 8% = 0.08 kg

S = 1% = 0.01 kg

H = 5% = 0.05 kg

N = 1% = 0.01 kg

Ash = 4% = 0.04 kg

(i) Minimum amount of air required for the complete combustion of 1 kg of coal is given by,

$$\text{Weight} = \left[\% \text{ of } c \times \frac{32}{12} + \% \text{ of } H_2 \times \frac{16}{2} + \% \text{ of } S \times \frac{32}{32} - 0.08\right] \times \frac{100}{23}$$

$$= \left[0.08 \times \frac{32}{12} + 0.05 \times \frac{16}{2} + 0.01 \times \frac{32}{32} - 0.08\right] \times \frac{100}{23}$$

= 2.373913043

= 2.374

∴ Weight of air = 2.374 kg

(ii) Percentage composition of dry products.

Weight of CO_2 $0.81 \times \frac{44}{12} = 2.97$ kg

$$\text{Weight of } O_2 = \frac{2.374 \times 50 \times 23}{100 \times 100}$$

= 0.27301 kg

$$\text{Weight of } N_2 = \frac{2.374 \times 150 \times 77}{100 \times 100}$$

= 2.74197 kg

$$\text{Weight of } SO_2 = 0.01 \times \frac{64}{32}$$

= 0.02 kg

∴ Total mass of the products = 2.97 + 0.27301 + 2.74197 + 0.02

= 6.00498

$$\therefore \% \, CO_2 = 2.97 \times \frac{100}{6.00498}$$

= 49.459%

$$\therefore \% \, O_2 = 0.27301 \times \frac{100}{6.00498}$$

= 4.546%

$\therefore$ % $N_2 = 2.74197 \times \frac{100}{6.00498}$

$= 45.662\%$

$\therefore$ % $SO_2 = 0.02 \times \frac{100}{6.00498}$

$= 0.333\%$

Q53. The percentage composition of a sample of coal found to contain C = 76%, H_2= 5.2%, O_2 = 12.8%, N_2 = 2.7%, S = 2.1% and ash = 2.2%. Calculate the minimum (i) Weight (ii) Volume of air at STP, required for complete combustion of 1 kg of coal and % composition by weight of dry products.

Answer :

Given weights of elements per kg of fuel,

C = 76% = 0.76 kg

H_2 = 5.2% = 0.052 kg

O_2 = 12.8% = 0.128 kg

N_2 = 2.7% = 0.027 kg

S = 2.1% = 0.021 kg

Ash = 2.2% = 0.022 kg

(i) Weight of air required for complete combustion of 1 kg of coal is given by,

$$\text{Weight} = \left[\%\text{ of } C \times \frac{32}{12} + \%\text{ of } H_2 \times \frac{16}{2} + \%\text{ of } O_2 \times \frac{32}{32} - 0.128\right] \times \frac{100}{23}$$

= 10.116 kg

$\therefore$ Weight of air = 10.116 kg

(ii) Volume of 10.116 kg of air at STP is given by,

$$\text{Volume} = \frac{\text{Weight of air}}{\text{Molecular mass of air}} \times 22.4$$

$$= \frac{10.116}{28.94} \times 22.4\ L \qquad (\because \text{ Molecular mass of air} = 28.94 \text{ g/mol})$$

= 7.830 liters

= 7.83 m^3

$\therefore$ Volume = 7.83 m^3

(iii) Percentage composition of dry products

Weight of $CO_2 = 0.760 \times \frac{44}{12}$

= 2.7867 kg

Weight of $O_2 = \frac{10.116 \times 50 \times 23}{100 \times 100}$

= 1.1633 kg

Weight of $N_2 = \frac{10.116 \times 150 \times 77}{100 \times 100}$

= 11.6840 kg

Weight of $SO_2 = 0.021 \times \frac{64}{32} = 0.042$ kg

$\therefore$ Total mass of products = 2.7867 + 11.6840 + 1.1633 + 0.0240

= 15.658 kg

$\therefore$ $\% CO_2 = 2.7867 \times \frac{100}{15.658} = 17.797\%$

$\therefore$ $\% O_2 = 1.1633 \times \frac{100}{15.658} = 7.429\%$

$\therefore$ $\% N_2 = 11.6840 \times \frac{100}{15.658} = 74.621\%$

$\therefore$ $\% SO_2 = 0.042 \times \frac{100}{15.658} = 0.268\%$

Q54. A fuel containing 92% C and 4% H_2 by mass, was burnt in 90% of air required for complete combustion. Find out the % composition of dry product of combustion by mass, if H_2 is burnt completely and no carbon is left behind.

Answer :

Given that,

For a sample of coal,

% of C = 92%

% of H_2 = 4%

Percentage of air required for complete combustion = 90%

Minimum weight of air required for combustion of 1 kg of fuel is given by,

$$\text{Minimum weight of air} = \text{Weight of} \left[C \times \left(\frac{32}{12}\right) + H_2\left(\frac{16}{2}\right)\right] \times \frac{100}{23}$$

$$= \left[920 \times \frac{32}{12} + 40 \times \frac{16}{2}\right] \times \frac{100}{23}$$ ($\because$ In 1 kg of fuel, % of C = 920 gm, % of H_2 = 40 gm)

$$= [2453.33 + 320] \times \frac{100}{23}$$

= 12057.96 gm

$\therefore$ Weight of air actually used = $12.057 \text{ kg} \times \frac{90}{100}$

= 10.8513 kg

= 10851.3 g

Weight of air actually used = 10851.3

As air is insufficient and all H_2 is oxidized to H_2O, part of 'C' is oxidized to CO_2 and remaining 'C' is oxidized to CO.

Let, x = Weight of C oxidized to CO and

$(920 - x)$ = Weight of C oxidized to CO_2.

$$\therefore \text{Required weight of air} = \text{Weight of} \left[H_2 \times \left(\frac{16}{2}\right) + CO \times \left(\frac{16}{12}\right) + CO_2\left(\frac{32}{12}\right)\right] \times \frac{100}{23}$$

$$= \left[40 \times \frac{16}{2} + x \times \frac{16}{12} + (920 - x) \times \frac{32}{12}\right] \times \frac{100}{23}$$

$$= \left[320 + \frac{4x}{3} + 2453.33x - \frac{8x}{3}\right] \times \frac{100}{23}$$

$$= \left[2773.33 - \frac{4x}{3}\right] \times \frac{100}{23}$$

= 12057.96 – 5.797 x. g

But weight of air actually used = 10851.3

$\therefore$ 10851.3 = 12057.96 – 5.797*x*.

$5.797x = 12057.96 - 10851.13$

$5.797x = 1206.83$

$x = 208.18$

$\therefore$ Weight of C oxidized to CO is x = 208.18 gm and weight of C oxidized to CO_2 is $(920 - x)$

= (920 – 208.18)

= 711.82 gm.

Percentage composition of dry products of combustion per kg fuel,

❖ Weight of CO = Weight of 'C' oxidized to CO(x) $\times \frac{28}{12}$

$= 202.18 \times \frac{28}{12}$

= 485.75 gm

❖ Weight of CO_2 = Weight of 'C' oxidized to CO_2 (920 – x) $\times \frac{44}{12}$

$= 711.82 \times \frac{44}{12}$

= 2,610 gm

❖ Weight of 'N_2' (from air used) = Weight of air actually used $\times \frac{77}{100}$

$= 10851.3 \times \frac{77}{100}$

= 8355.5 gm

$\therefore$ Total weight of dry products = Weight of CO + CO_2 + N_2

= 485.75 + 2610 + 8355.5

= 11451.25 g

$\therefore$ Mass percentage composition of dry products is given by,

❖ $CO = \frac{\text{Weight of CO}}{\text{Total weight}} \times 100$

$= \frac{485.75}{11451.25} \times 100 = 4.24\%$

$\therefore$ CO = 4.24%

❖ $CO_2 = \frac{\text{Weight of } CO_2}{\text{Total weight}} \times 100$

$= \frac{2610}{11451.25} \times 100 = 22.79\%$

$\therefore CO_2 = 22.79\%$

❖ $N_2 = \frac{\text{Weight of } N_2}{\text{Total weight}} \times 100$

$= \frac{8355.5}{11451.25} \times 100$

= 72.96%

$\therefore N_2 = 72.96\%$