Chapter Name: Chemistry Fuel and Lubricants

Definition of Fuel

A fuel is a substance that produces heat energy when it undergoes combustion. It contains carbon and hydrogen as the main elements, and sometimes sulfur.

The energy released during the combustion process is used for heating, cooking, industrial processes, power generation, etc.

Examples:

- Solid fuels – Coal, wood, coke
- Liquid fuels – Petrol, diesel, kerosene
- Gaseous fuels – LPG, CNG, hydrogen gas

Combustion of Fuel

Combustion is a chemical reaction between a fuel and oxygen (usually from air) that produces heat and light energy.

Chemical Reaction (for Hydrocarbon Fuel):

$$C_xH_y + (x + \frac{y}{4})O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O + \text{Heat}$$

Essential requirements for combustion:

- Fuel – The combustible substance
- Oxygen – From air or other sources
- Ignition temperature – The minimum temperature at which a fuel starts burning

Types of Combustion:

- Rapid Combustion: Takes place quickly with production of heat and light (e.g., LPG in stove).
- Spontaneous Combustion: Occurs without external heat (e.g., phosphorus in air).
- Explosive Combustion: Takes place very fast, producing large pressure (e.g., petrol engine explosion).

Classification of Fuels

Fuels are classified on various bases:

1. Based on Physical State

Type	Example	Characteristics
Solid Fuels	Coal, Wood, Coke	Easy to transport but less efficient and smoky
Liquid Fuels	Petrol, Diesel, Kerosene	Easy to handle, burn efficiently
Gaseous Fuels	LPG, CNG, Biogas	Clean, high calorific value, easy to control

2. Based on Origin

Type	Example	Description
Natural Fuels	Wood, Coal, Natural Gas	Found in nature and used with little processing
Artificial Fuels	Coke, Petrol, Producer Gas	Manufactured from natural fuels to improve efficiency

3. Based on Usage

Type	Example	Use
Primary Fuels	Coal, Natural Gas	Used directly as found
Secondary Fuels	Petrol, Diesel, LPG	Derived from processing of primary fuels

Calorific Value of Fuel

The calorific value of a fuel is the amount of heat energy produced when 1 kilogram (or 1 cubic meter) of the fuel is completely burnt in oxygen.

It is expressed in **kJ/kg** (kilojoules per kilogram) or **kcal/kg** (kilocalories per kilogram).

Types of Calorific Value

Type	Definition	Remarks
Higher Calorific Value (HCV)	Total heat produced when the fuel is burnt completely and the water formed is condensed	Includes latent heat of steam
Lower Calorific Value (LCV)	Actual heat available when water remains as vapour	LCV = HCV - (Mass of water × 587 cal/g)

Note:

- 1 kg of hydrogen produces 9 kg of water.
- 587 cal/g = latent heat of vaporization of water.

Dulong's Formula for Calculating Calorific Value

Dulong's formula gives the theoretical calorific value of a fuel from its elemental composition. If the fuel contains **C% (carbon), H% (hydrogen), O% (oxygen), and S% (sulfur)**, then:

Formula -

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

Where:

- 8080 kcal/kg = heat produced by 1 kg of Carbon
- 34500 kcal/kg = heat produced by 1 kg of Hydrogen
- 2240 kcal/kg = heat produced by 1 kg of Sulphur

To Find LCV (Lower Calorific Value):

$$\text{LCV} = \text{HCV} - 0.09H \times 587$$

Where:

- 0.09H = mass of water formed from H% of fuel
- 587 = latent heat of vaporization of steam (cal/g)

Example Calculation

Given:

C = 80%, H = 10%, O = 5%, S = 1%

$$\text{HCV} = \frac{1}{100}[8080(80) + 34500(10 - \frac{5}{8}) + 2240(1)]$$

$$= \frac{1}{100}[646400 + 34500(9.375) + 2240]$$

$$= \frac{1}{100}[646400 + 323437.5 + 2240] = \frac{972077.5}{100}$$

$$\text{HCV} = 9720.8 \text{ kcal/kg}$$

Now,

$$\text{LCV} = 9720.8 - 0.09(10) \times 587$$

$$\text{LCV} = 9720.8 - 528.3 = 9192.5 \text{ kcal/kg}$$

Importance of Calorific Value

- Helps to compare the efficiency of different fuels.
- Used for designing furnaces, boilers, and engines.
- Determines the economic value of a fuel.
- Essential in energy auditing and fuel selection.

Proximate Analysis of Coal (Solid Fuel)

Proximate analysis determines the percentage composition of moisture, volatile matter, ash, and fixed carbon present in coal or any solid fuel. It is a simple, quick, and practical method used in industries.

Components Determined:

Component	Description	Method / Importance
1. Moisture	Water present in the coal	Determined by heating the sample at 105°C–110°C. High moisture reduces calorific value.
2. Volatile Matter	Gases released when coal is heated in the absence of air (CO, CH_4, H_2, etc.)	Determined by heating at 900°C for 7 minutes. High volatile matter indicates easy ignition.
3. Ash	Non-combustible mineral residue after burning	Determined by heating coal in air at 700°C–750°C. High ash reduces heating efficiency.
4. Fixed Carbon	Remaining carbon after removing moisture, volatile matter, and ash	It gives heating power to coal.

Formula:

$$\text{Fixed Carbon (\%)} = 100 - (\text{Moisture} + \text{Volatile Matter} + \text{Ash})$$

Significance:

- Helps to estimate combustion behaviour of coal.
- Used in selection of coal for power plants, furnaces, etc.
- Determines efficiency and storage quality.

Ultimate Analysis of Coal (Solid Fuel)

Ultimate analysis gives the elemental composition of coal, i.e., the percentage of **Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Sulphur (S), and Ash**.

This analysis is more **accurate** and is used for **scientific and design purposes.**

Constituents and Their Determination:

Element	Method	Importance
Carbon (C)	By burning the sample in oxygen and measuring CO_2 formed	Responsible for main heat energy.
Hydrogen (H)	From amount of H_2O formed during combustion	Also adds to heating value.
Oxygen (O)	Calculated by difference	Helps in combustion.
Nitrogen (N)	Estimated by Kjeldahl's method	Inert gas, reduces heating efficiency.
Sulphur (S)	By bomb calorimeter or chemical analysis	Produces SO_2, causes corrosion and pollution.
Ash	Determined by heating in air	Non-combustible part.

Uses of Ultimate Analysis:

- Used for accurate calculation of calorific value using Dulong's formula.
- Helps to predict air required for combustion.
- Useful in designing furnaces and combustion chambers.

Comparison: Proximate vs Ultimate Analysis

Basis	Proximate Analysis	Ultimate Analysis
Purpose	Quick industrial test	Detailed chemical test
Determines	Moisture, Volatile Matter, Ash, Fixed Carbon	C, H, O, N, S, and Ash
Time Required	Less	More
Use	Field/industrial application	Laboratory and design purposes

___ Fuel Rating System ___

1. Octane Number (for Petrol)

The octane number (or octane rating) of a petrol fuel indicates its anti-knocking quality, i.e., its resistance to knocking in spark ignition (SI) engines.

Explanation:

- Knocking is the premature ignition of fuel–air mixture in petrol engines, which reduces engine efficiency.
- A higher octane number means greater resistance to knocking.

Scale Reference: The scale is based on a mixture of two hydrocarbons:

Reference Fuel	Octane Number
Iso-octane (C_8H_{18})	100 (Excellent anti-knock)
n-Heptane (C_7H_{16})	0 (Poor anti-knock)

Example:
If a fuel behaves like a mixture of 80% iso-octane and 20% n-heptane, its octane number = 80.

Improvement Methods:

- Adding anti-knock agents – like Tetraethyl lead (TEL) (now banned), or ethanol.
- Refining processes – catalytic reforming and isomerization.
- Using high-octane components – aromatics, iso-paraffins.

Typical Octane Numbers:

Fuel Type	Octane Rating
Regular Petrol	87–89
Premium Petrol	91–95
Aviation Gasoline	100+

2. Cetane Number (for Diesel)

The cetane number indicates the ignition quality of diesel fuel, i.e., how easily it self-ignites under compression in diesel engines.

Explanation:

- Diesel engines rely on compression ignition.
- A higher cetane number means the fuel ignites faster and smoother, reducing knocking or delay.

Example:

If a diesel behaves like a mixture of 60% n-cetane and 40% α-methyl naphthalene, its cetane number = 60.

Scale Reference:

Reference Fuel	Cetane Number
n-Cetane ($C_{16}H_{34}$)	100 (Excellent ignition)
α-Methyl naphthalene	0 (Poor ignition)

Improvement Methods:

- Blending with high-cetane components.
- Using cetane improvers such as alkyl nitrates.
- Hydrotreating in refining to remove aromatics and improve ignition quality.

Typical Cetane Numbers:

Fuel Type	Cetane Rating
Light Diesel Oil	45–50
High-Speed Diesel	50–55
Biodiesel	60–65

Importance of Fuel Rating:

- Ensures smooth engine performance.
- Reduces engine knocking and excessive wear.
- Helps in designing suitable fuels for different types of engines.

Gaseous Fuels

Gaseous fuels are fuels that exist in the gaseous state at room temperature and are used for domestic, industrial, and vehicular applications. They are clean, efficient, and easy to control during combustion.

The main gaseous fuels include:

1. LPG (Liquefied Petroleum Gas)
2. CNG (Compressed Natural Gas)
3. Water Gas
4. Coal Gas
5. Producer Gas
6. Biogas

1. Liquefied Petroleum Gas (LPG)

Chemical Composition:

- Propane (C_3H_8): 40%
- Butane (C_4H_{10}): 60%
- Small traces of ethane and isobutane
- Odorant (ethyl mercaptan) is added for leakage detection.

Calorific Value:

- 11,000–12,000 kcal/kg (≈ 46–50 MJ/kg)

Applications:

- Used in domestic cooking and heating.
- In hotels, laboratories, and small industries.
- As a fuel for internal combustion engines (auto-LPG).
- In welding and cutting operations.

Advantages:

- Burns cleanly without smoke or soot.
- High calorific value.
- Easily liquefied and stored under moderate pressure.
- Instant ignition and easy transport.

2. Compressed Natural Gas (CNG)

Chemical Composition:
- Methane (CH_4): 85–95%
- Ethane (C_2H_6): 4–6%
- Traces of propane, butane, and nitrogen.

Calorific Value:
- 12,000 kcal/kg (≈ 50–55 MJ/kg)

Applications:
- Automobile fuel (buses, cars, taxis).
- Power generation in gas turbines.
- Industrial heating and chemical feedstock.
- Domestic fuel in some cities.

Advantages:
- Environment-friendly (produces less CO and NOx).
- High efficiency and low maintenance in engines.
- Cheaper than petrol or diesel.
- Reduces air pollution drastically.

3. Water Gas

Chemical Composition:
- Carbon monoxide (CO): 50%
- Hydrogen (H_2): 50%

Preparation:
- Produced by passing steam over red-hot coke at about 1000°C:

$$C + H_2O \rightarrow CO + H_2$$

Calorific Value:
- 2,800–3,000 kcal/m³

Note:
Water gas is poisonous due to high CO content and must be handled carefully

Applications:
- Used as a fuel gas for heating and lighting.
- As a reducing agent in metallurgical processes.
- For manufacturing synthetic fuels like methanol.
- In chemical industries for hydrogen production.

4. Coal Gas

Chemical Composition:
- Hydrogen (H_2): 50%
- Methane (CH_4): 30%
- Carbon monoxide (CO): 10%
- Others (CO_2, N_2): 10%

Preparation:
- Produced by carbonization of coal (heating coal in absence of air).

Calorific Value:
- 4,000–5,000 kcal/m³

Note:
Coal gas is toxic because it contains CO.

Applications:
- Used for heating and lighting purposes.
- In laboratories and small industries.
- As a reducing gas in metallurgical furnaces.
- Earlier used as illuminating gas before electricity became common.

5. Producer Gas

Chemical Composition:
- Carbon monoxide (CO): 30%
- Nitrogen (N_2): 60%
- Hydrogen (H_2): 10%

Preparation:
- Produced by passing air and steam over red-hot coke:

$$C + O_2 \rightarrow CO_2 \quad \text{and} \quad C + CO_2 \rightarrow 2CO$$

- Since air is used, it contains a large amount of nitrogen.

Calorific Value:
- 1,200–1,500 kcal/m³

Applications:
- Used in metallurgical furnaces and glass industries.
- For power generation in gas engines.
- As a low-cost industrial fuel for heating processes.

Advantages:
- Cheaper to produce.
- Made from readily available materials (coal or coke).
- Can be generated on-site.

6. Biogas

Chemical Composition:
- Methane (CH_4): 55–65%
- Carbon dioxide (CO_2): 30–35%
- Hydrogen (H_2), Nitrogen (N_2), H_2S: Traces

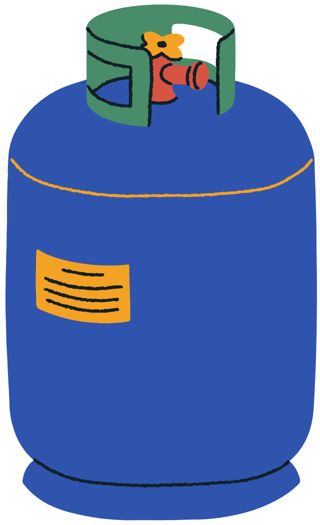
Preparation:
- Produced by anaerobic decomposition of animal dung, agricultural waste, and sewage in a biogas digester.

$$\text{Organic matter} \xrightarrow{\text{Anaerobic bacteria}} CH_4 + CO_2 + H_2 + H_2S$$

Calorific Value:
- 4,500–6,000 kcal/m³

Applications:
- Used for cooking, heating, and lighting in rural areas.
- In biogas engines for power generation.
- Used as a fuel for vehicles (bio-CNG) after purification.
- The leftover slurry is used as a bio-fertilizer.

Advantages:
- Renewable and eco-friendly.
- Utilizes waste effectively.
- Reduces deforestation and pollution.
- Provides organic manure as by-product.



Summary Table on Different Types of Fuels

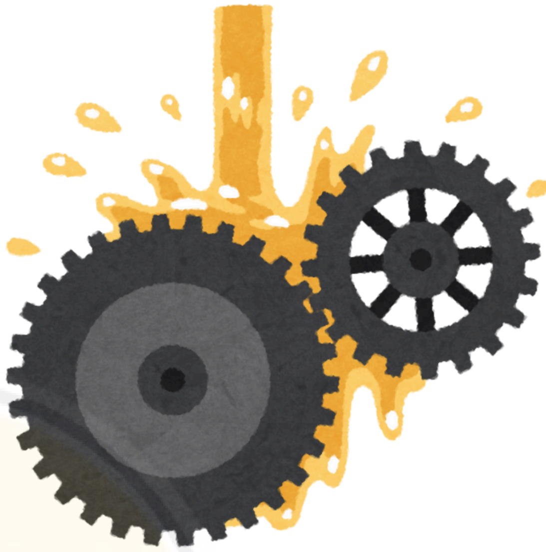
Fuel	Main Components	Calorific Value (kcal/m³ or kg)	Major Applications
LPG	Propane, Butane	11,000–12,000 kcal/kg	Domestic cooking, heating, vehicles
CNG	Methane	12,000 kcal/kg	Automobiles, industries, power generation
Water Gas	CO, H_2	2,800–3,000 kcal/m³	Metallurgy, chemical synthesis
Coal Gas	H_2, CH_4, CO	4,000–5,000 kcal/m³	Lighting, heating
Producer Gas	CO, N_2, H_2	1,200–1,500 kcal/m³	Furnaces, industries
Biogas	CH_4, CO_2	4,500–6,000 kcal/m³	Cooking, power, rural energy

Differences between LPG, CNG, and Biogas

Parameter	LPG	CNG	Biogas
Main Gas	Propane, Butane	Methane	Methane, CO_2
Storage	Liquefied under pressure	Compressed gas	Low-pressure digester
Origin	Petroleum	Natural gas wells	Organic waste
Use	Domestic and industrial	Automobiles	Rural areas

Definition of Lubrication

Lubrication is the process of applying a lubricating substance (lubricant) between two moving or sliding surfaces in contact, in order to reduce friction, wear, and heat generation.



Definition of Lubricant

A lubricant is a substance (usually oil or grease) introduced between two moving surfaces to reduce friction and wear.

Example: Mineral oils, greases, graphite, molybdenum disulphide (MoS_2), and synthetic oils.

Functions of Lubricants

A. Reduce Friction:
- Forms a thin film between moving surfaces to reduce direct metal-to-metal contact.

B. Minimize Wear and Tear:
- Protects surfaces from damage and increases the life of machine parts.

C. Cooling:
- Carries away heat generated due to friction.

D. Sealing:
- Prevents leakage of gases or liquids from cylinders and pistons.

E. Cleaning:
- Removes dirt, dust, and metal particles from moving parts.

F. Protecting from Corrosion:
- Forms a protective film that prevents oxidation and rusting.

G. Transmit Power:
- Used in hydraulic systems as hydraulic oil.

Characteristics of a Good Lubricant

A good lubricant should possess the following properties:

Property	Description
High Viscosity Index	Maintains suitable viscosity at different temperatures.
High Flash and Fire Point	Should not vaporize or catch fire easily at high temperature.
High Oiliness	Should adhere well to metal surfaces.
Low Volatility	Should not evaporate easily.
Low Freezing (Pour) Point	Should flow easily at low temperature.
Chemical Stability	Should not oxidize or decompose easily.
Non-corrosive	Should not react with metal surfaces.
Good Detergency	Should remove dirt and deposits.

Classification of Lubricants

Lubricants are classified based on physical state and source.

1. Based on Physical State

Type	Examples	Characteristics
Solid Lubricants	Graphite, Molybdenum disulphide (MoS_2), PTFE	Used at high temperature and pressure; forms a thin film layer.
Semi-solid Lubricants (Greases)	Calcium grease, Sodium grease	Mixture of lubricating oil and thickener (soap); used in bearings, joints.
Liquid Lubricants	Mineral oils, Vegetable oils, Synthetic oils	Commonly used; provides hydrodynamic lubrication.
Gaseous Lubricants	Air, CO_2	Used in special high-speed machines.

2. Based on Source

Type	Example	Description
Animal Lubricants	Lard oil, Tallow	Good oiliness but become rancid.
Vegetable Lubricants	Castor oil, Coconut oil	Good film strength, used for light machines.
Mineral Lubricants	Petroleum oils	Most common, economical, and stable.
Synthetic Lubricants	Silicon oil, Ester-based oil	High-temperature stability and long service life.

Lubrication Mechanisms

Lubrication mainly occurs in two ways:

1. Hydrodynamic Lubrication

- A thick film of lubricant completely separates the two moving surfaces.
- Friction is only due to viscosity of the oil, not metal contact.
- Occurs in bearings, turbines, and crankshafts.
- Requires high speed and sufficient oil supply.

Advantages:
- Very low friction.
- No wear of surfaces.
- Effective cooling.

2. Boundary Lubrication

- Occurs when the lubricant film is very thin or partially broken.
- There is partial metal-to-metal contact.
- Takes place at low speeds, high pressures, or start-up conditions.
- Oiliness of lubricant plays a major role here.

Examples:
- In gear teeth, piston-cylinder, or bearings during start/stop.

Lubricants Used:
- Oil with high oiliness like lard oil, castor oil, etc.

Physical Properties of Lubricants

1. Viscosity

Definition:
Viscosity is the property of a fluid that resists flow or internal friction. *It indicates the thickness of a lubricant.*

- **High viscosity** = thick oil (slow flow)
- **Low viscosity** = thin oil (fast flow)

Unit: Centipoise (cP) or Centistokes (cSt)

Importance:
Correct viscosity ensures formation of continuous oil film and proper lubrication.

2. Viscosity Index (VI)

Definition:
It indicates the change of viscosity with temperature.

- A **high VI** means viscosity changes **little** with temperature (desirable).
- A **low VI** means viscosity changes **greatly** (undesirable).

Example:
Synthetic oils have higher VI than mineral oils.

3. Oiliness

Definition:
Oiliness is the ability of a lubricant to adhere or stick to the metal surface even under high pressure.

Importance:
Higher oiliness ensures better boundary lubrication and less metal contact.

4. Flash Point and Fire Point

Property	Definition	Importance
Flash Point	Lowest temperature at which lubricant vapour ignites momentarily when exposed to flame	Indicates volatility and safety during storage
Fire Point	Lowest temperature at which vapour burns continuously for at least 5 seconds	Should be higher than operating temperature

5. Cloud Point and Pour Point

Property	Definition	Importance
Cloud Point	Temperature at which wax starts separating and oil becomes cloudy	Indicates low-temperature flow characteristics
Pour Point	Lowest temperature at which oil just begins to flow	Important for cold weather operations

Chemical Properties of Lubricants

1. Coke Number (Carbon Residue)

Definition:
It is the percentage of carbon residue left after evaporating a lubricant at high temperature in the absence of air.

Significance:
- Indicates tendency to form carbon deposits in engines.
- Lower coke number = better lubricant quality.

2. Total Acid Number (TAN)

Definition:
It is the amount of potassium hydroxide (KOH) in mg required to neutralize the acids present in 1 gram of oil.

Significance:
- Measures oxidation and corrosion tendency.
- High TAN means lubricant is deteriorated or oxidized.

3. Saponification Value

Definition:
It is the number of milligrams of KOH required to saponify 1 gram of oil or fat.

Used for:
- Detecting the presence of vegetable or animal oils (since mineral oils do not saponify).
- Checking lubricant purity.

High Value: indicates presence of vegetable/animal oil.
Low Value: indicates pure mineral oil.

Typical Physical and Chemical Properties of Lubricants

Property	Mineral Oil	Vegetable Oil	Synthetic Oil	Grease
Flash Point (°C)	180–250	220–270	200–300	180–250
Fire Point (°C)	200–280	250–300	220–320	200–280
Cloud Point (°C)	-15 to -5	0 to 5	-20 to -10	-10 to 0
Pour Point (°C)	-12 to -6	-5 to 0	-30 to -15	-10 to -5
Coke Number (% Carbon Residue)	0.1–0.3	0.1–0.2	0.05–0.2	0.2–0.5
Total Acid Number (mg KOH/g)	0.05–0.1	0.2–0.5	0.05–0.1	0.1–0.3
Saponification Value (mg KOH/g)	0	180–200	0–5	50–100