Energy Science

(Fuels & Combustion; Batteries)

Contents: Types of fuels, Calorific value, Determination of Calorific value, Combustion and its calculations, Solid fuel: Coal analysis (Proximate and ultimate analysis), Liquid fuels: IC engine fuel, concept of knocking, antiknocking, octane No and cetane No, Fractional Distillation of petroleum, Cracking of heavy oils; Elementary ideas on some gaseous fuels (Natural gas, Water gas, Producer gas, LPG) (Synthesis is excluded), Battery technology – Fundamentals of primary & Secondary cells, Rechargeable batteries: Lead acid storage battery, Lithium ion battery, Fuel cells: principles, applications. Elementary idea on Photo-voltaics.

Course Outcome: Classify various fuels based on combustion parameters and understand the working principle of various batteries.

Lecture-1

1.0 Introduction

In recent years our dependency on energy has enhanced a lot as a result of the increase in the standard of living and rapid technological advancement. The various types of fuels like liquid, solid and gaseous fuels are available for firing in boilers, furnaces and other combustion equipments. The selection of right type of fuel depends on various factors such as availability, storage, handling, pollution and landed cost of fuel. The knowledge of the fuel properties helps in selecting the right fuel for the right purpose and efficient use of the fuel.

Process industries, businesses, homes, and transportation systems have vast heat requirements that are also satisfied by *combustion* reactions. The energy usually comes from the fuels like petroleum, coal and natural gas known as *Fossil fuel*. Since these sources of energy will never last forever hence their proper utilization is the main concern these days.

** *Combustion* is the conversion of a substance called a *fuel* into chemical compounds known as *products of combustion* by combination with an *oxidizer*.

The combustion process is an *exothermic* chemical reaction, i.e., a reaction that releases energy as it occurs.

** *Fossil fuel*: They are formed by the decay of vegetable and animal matter over many thousands of years under conditions of high pressure and temperature and with a deficiency or absence of oxygen.

2.0 Fuel and its classification

A fuel can be defined as *any combustible substance which during combustion gives large amount of industrially and/or domestically useful heat.* The heat evolved by burning of fuels is used for heating purposes, in locomotive engines, in internal combustion engine, etc. We use coal as a reducing agent in metallurgical industry. Examples of some fuels are coal, coke, LPG, CNG, petrol, diesel, etc.

Classification of fuels:

1. **Based on their occurrence:** Fuels are classified as A. *natural or primary* and B. *artificial or secondary* fuels.
   A. Natural fuels: They are found in nature as such. Examples are coal, wood, petroleum and natural gas.
   B. Artificial fuels: They are prepared from primary fuels. Examples are coke, petrol, diesel, coal gas, etc.
2. **Based on their physical state of aggregation:** Fuels are classified as solid, liquid and gaseous.
   Solid fuels: Coal, coke, wood
   Liquid fuels: Petroleum, petrol diesel, kerosene
   Gaseous fuel: CNG, LPG, coal gas, biogas

3.0Calorific Value (CV) or Heat value

The CV is the total quantity of heat liberated from combustion of a unit mass or unit volume of the fuel in air or oxygen. So, it is the measurement of produced heat or energy. It is measured either as Gross Calorific Value (GCV) or Net Calorific Value (NCV). The difference being the latent heat of condensation of the water vapour produced during the combustion process.

Units of calorific value:

For solid fuels: cal/g; Kcal/Kg
For liquid or gaseous fuels: Kcal/m^3

Gross calorific value (GCV): Gross calorific value (GCV) assumes all vapour ($H_2O_{(g)}$) produced during the combustion process is fully condensed. So, *it is total amount of heat liberated when unit mass or unit volume of the fuel has been burnt completely and products of combustion (CO_2 & H_2O) are cooled to RT.* It is also called as Higher Calorific Value (HCV).

Net calorific value (NCV): Net calorific value assumes the water leaves with the combustion products without fully being condensed. So, it *is total amount of heat liberated when unit mass or unit volume of the fuel has been burnt completely and products of combustion (CO_2 & H_2O) are allowed to escape into the atmosphere.* It is also called as Lower Calorific Value (LCV).

N.B.; *Fuels should be compared based on the NCV*

Relationship between GCV and NCV:

NCV = HCV- Latent heat of water vapour formed
= HCV – 0.09H x 587; where H = % H in the fuel.

So, for a fuel without H-content, NCV = HCV

Calorific value can be determined using a **Bomb Calorimeter.**

N.B.: We have taken H = % H in the fuel

That is 100 g of fuel contains H g of Hydrogen

1 g of fuel contains = H/100 g Hydrogen

All fuels contain some % Hydrogen and this is converted into steam upon burning.

$H_2 + ½ O_2 \rightarrow H_2O$

2g Hydrogen forms 18g of steam upon burning

1g will form = 18/2 = 9g steam

H/100 g will form = 9H/100 = 0.09H g steam

Now, **heat taken by water to form steam (i.e., latent heat of water vapour formed) = 0.09H x 587 cal/g**

4.0 Theoretical calculation of Calorific value by Dulong's Formula:

Assumption: Calorific value of a fuel is the sum of the calorific values due to all the components (C,H, S) present in the fuel. It is also assumed that if oxygen is present in the fuel then it is present in the combined form with hydrogen as H_2O.

The GCV of the component C, H, and S are 8080, 34500, and 2240 cal/g, respectively.

$$GCV = 1/100[8080 \times C + 34500\ (H-O/8) + 2240 \times S] \text{ in cal/g}$$

Where, C = % Carbon in the fuel; H = % Hydrogen in the fuel, and %S= % Sulphur in the fuel

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N.B. Oxygen present in the fuel is assumed to be present in the combined form with water as H_2O; $H_2 + ½\ O_2 \rightarrow H_2O$

So, 2 g of hydrogen combined with 16 g oxygen to form 18 g water

Then 1 g of hydrogen combines with 8 g Oxygen

i.e., 8 parts of oxygen combine with 1 part of hydrogen to form water

So, **fixed hydrogen (unavailable for combustion) = $1/8^{th}$ of mass of oxygen in the fuel = (mass of oxygen/8) = O/8**

We know that total mass of hydrogen in the fuel = available hydrogen + unavailable hydrogen (i.e., fixed hydrogen)

So, amount of hydrogen available for combustion = Total mass of hydrogen-unavailable amount = (H-O/8)

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Solved Examples:

Example-1 Calculate the GCV and NCV of a coal sample having the following composition: C = 80%, H=7%, O=3%, S=3.5%, N=2.1% and ash=4.4% as per proximate analysis.

Solution: N and ash are non-combustible matter, not take part in calculation process
GCV = 1/100[8080C + 34500(H-O/8) + 2240S]
= 1/100[8080x80 + 34500(7-3/8) + 2240 x 3.5] = 8828 cal/g
NCV = HCV – 0.09H x 587 = 8828-0.09x7x587 = 8458 cal/g.

Example-2 Calculate the HCV and LCV of a coal sample having the following composition: C = 75%, H=5.2%, O=12.1%, N=3.2% and ash=4.5%

Solution: N and ash are non-combustible matter
GCV = 1/100[8080C + 34500(H-O/8) + 2240S]
= 1/100[8080 x 75 + 34500(5.2-12.1/8) + 2240 x 0] = 7332.2 cal/g
NCV = HCV – 0.09H x 587 = 8828-0.09x5.2x587 = 7057.5 cal/g.

5.0Characteristics of a good fuel

A good fuel should have the following characteristics:

1. It should have High Calorific Value.
2. It should have moderate ignition temperature.
3. It should have low moisture content.
4. It should have low non-combustible matter content.
5. It should have moderate rate of combustion.
6. It should have low cost.
7. It should be easy to transport.
8. It should not emit harmful products.
9. It should have low volatile matter content.

Q. 1. Define calorific value.

Ans. The CV is the total quantity of heat liberated from combustion of a unit mass or unit volume of the fuel in air or oxygen.

Q. 2. 5 Kg of a solid fuel generates 55,000 Kcal of heat. Find its calorific value (CV).

Ans: CV = 55,000/5 = 11,000 Kcal/Kg

Q.3 When 100 m^3 gaseous fuels like LPG undergoes combustion, it generates 110,000 Kcal of heat. Find its CV.

Ans. CV = 110,000/100 = 1100 Kcal/m^3

Q.4 Mention the condition for which HCV will be same as LCV?

Ans. When % H = 0 in a fuel then HCV = LCV

Q. 5. Mention some characteristics of good fuel. (Medium type, 3 marks)

Ans. Refer section 5.0

Q.6.A good fuel should contain very less amount of moisture. Give reason.

Ans. During burning, moisture takes some of the liberated heat in the form of latent heat of vapourization. Therefore, it lowers the effective CV of fuel.

Q. 7 . Distinguish between GCV and NCV.

Ans. Refer section 3.0

Q8. What is meant by Ignition temperature?

Ans. The lowest temperature at which the fuel must be pre-heated so that it starts burning smoothly.

Q. 9. Why should an ideal fuel have moderate ignition temperature?

Ans. Low ignition temperature can cause fire hazards and involves danger in fuel storage and transport; while high ignition temperature causes difficulty in starting ignition of fuel. Hence, an ideal fuel should have moderate ignition temperature.

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Lecture-2 ,3

5.0 Combustion Calculation

✓ *Important points*

1. Substances always combine in definite proportions and these proportions are determined by the mol. masses of the substances involved and the products formed.

   $$C + O_2 \rightarrow CO_2$$

   Here, 12 g of C combines with 32g of oxygen to form 44g of carbon dioxide
   (Mass proportion ratio 12:32:44)
   For gaseous fuel hydrogen, $H_{2(g)} + 1/2O_{2(g)} \rightarrow H_2O(g)$, 1 vol. of hydrogen combines with ½ vol. of oxygen to form 1 vol of water.

2. 22.4 L of any gas at STP (0 ^{0}C and 1 atm.) has a mass equal to its 1 mol. Thus, 22.4 L of O_2 gas at STP will have a mass of 32g. 22.4 L of Air at STP will have a mass of 28.92 g.

3. Mol. Mass of air is taken as 28.92 g/mol.

4. Air contains 21% of oxygen by volume and 23% by mass. This means 100 g of air contain 23 g of oxygen and 100 L of air contains 21 L of oxygen.

Most Commonly involved combustion Reactions:

1. $\mathbf{H_{2(g)} + 1/2O_{2(g)} \rightarrow H_2O(g)}$
2. $\mathbf{C + O_2 \rightarrow CO_2}$
3. $\mathbf{S + O_2 \rightarrow SO_2}$
4. $\mathbf{CO + 1/2O_2 \rightarrow CO}$
5. $\mathbf{CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}}$
6. $\mathbf{C_2H_{6(g)} + 7/2O_{2(g)} \rightarrow 2CO_{2(g)} + 3H_2O_{(g)}}$
7. $\mathbf{C_2H_{4(g)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 2H_2O_{(g)}}$
8. $\mathbf{C_2H_{2(g)} + 5/2O_{2(g)} \rightarrow 2CO_{2(g)} + H_2O_{(g)}}$

Solved Examples:

A. For Solid fuels

Example-1 *Calculate the weight and volume of air required for the combustion of 5 kg of coke.*

Solution: **Weight of air required:**

$$C\ (coke) + O_2 \rightarrow CO_2$$

12g of C required 32g of oxygen
5000 g of C will need = 32/12 x 5000 = 13333.33 g of O_2

Air reqd. = (100/23) x 13333.33 = **57971 g**

Volume of air required:

We know that 28.92 g of air occupies volume 22.4 L
57971 g will occupy = (22.4/28.94) x 57971 g = **44870.43 L**

Example-2 ***A sample of coal was found to have the following percentage composition: C = 80 %, H =7%, O=5 %, N=3 %, S =2 % and rest is ash. Calculate the minimum air required for complete combustion of 1 kg of coal.***

Solution: Reactions:

1. $C + O_2 \rightarrow CO_2$ (here, 12 g of C needs 32g of O_2)
   12g 32g
2. $H_2 + 1/2O_2 \rightarrow H_2O$ (here 2 g of hydrogen needs 16 g of oxygen)
   2g 16g
3. $S + O_2 \rightarrow SO_2$ (here, 32 g of C needs 32g of O_2)
   32g 32g

As per the data given: 1kg = 1000g of coal contains 800g C, 70g H,50g O, 30g N, 20g S, and 30g ash. (*N and ash are non-combustible matter*)

So, air needed = wt of [C x (32/12) + H x (16/2) + S x (32/32) – O] x 100/23
= [(800 x 32/12) + 70 x (16/2) + 20 x 1 – 50] x 100/23= (2133.33 + 560 + 20 – 50) x 100/23
= 2663.33 x 100/23 =11,579.69 g = **11.57 kg**

Example-3 ***A coal sample was found to have the following % composition: C = 75%, H=5.2%, O=12.1%, N=3.2% and ash=4.5%.***

*(i) **Calculate the weight of air required for complete combustion of 1 kg of coal.***
*(ii) **Find volume of air needed for it.***
*(iii)**Find HCV and NCV.***

Solution:

As per the data given: 1kg = 1000g of coal contains 750 g C, 52g H,121 g O, 32g N, and 32 g ash. (*N and ash are non-combustible matter*)

As no S in the sample, % S = 0

(i). So, wt of air needed = wt of [C x (32/12) + H x (16/2) + S x (32/32) – O] x 100/23
= [(750 x 32/12) + 52 x (16/2)– 121] x 100/23 = (2000 + 416– 121) x 100/23
= 2295 x 100/23 =**9978 g = 9.978 kg**

(ii) Volume of air:
We know that 28.92 g air occupies 22.4 L
9978 g of air will occupy = (22.4/28.92) x 9978 L = 7728.46 L

(ii) **GCV** = 1/100[8080C + 34500(H-O/8) + 2240S]
= 1/100[8080 x 75 + 34500(5.2-12.1/8) + 2240 x 0] = **7332.2 cal/g**
NCV = HCV – 0.09H x 587 = 8828-0.09x5.2x587 = **7057.5 cal/g.**

Example-4

A coal sample gave the following analysis: C = 66 %, H = 4 %, O = 7 %, N = 2 %, S = 3 %, moisture = 8 % and ash = 10 %. Determine the amount of air needed if 1 Kg of coal is burnt with 25% excess air.

Ans. As per the data given: 1kg = 1000g of coal contains 660 g C, 40g H,70 g O, 20g N, 30 g S, 80 g moisture and 100 g ash. (*N , moisture and ash are non-combustible matter*)

Air needed = = wt of [C x (32/12) + H x (16/2) + S x (32/32) – O] x 100/23 x 125/100
= [(660 x 32/12) + 40 x (16/2) + 30 x (32/32) – 70] x 100/23 x 125/100
= (1760 + 320 + 30 – 70) x 100/23 x 125/100 = 11,086.956 g

B. For gaseous fuels

Example-1 ***Calculate the volume of air needed for the complete combustion of 100 L of hydrogen gas.***

Solution: Combustion rxn: $H_{2(g)} + 1/2O_{2(g)} \rightarrow H_2O_{(g)}$
1 vol ½ vol

It means, 1 L of hydrogen needs ½ L of oxygen
So, 100 L needs = 50 L O_2
Vol of air needed = vol of Oxygen x (100/21) = 50 x 100/21 = **238.095 L**

Example-2 ***A gaseous fuel has the following composition by volume: CH_4 = 70 %, CO_2 = 20 % and N_2 = 10 %. Find the volume of air required for the complete combustion of 1 m^3 of this fuel.***

Solution: CO_2 and N_2 gas are non-combustible. 1 m^3 of gas contains 0.7 m^3 CH_4

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

Here, 1 vol.of methane gas needs 2 vol of oxygen
Then, 0.7 m^3 CH_4 needs = 2 x 0.7 = 1.4 m^3 O_2
Vol of air needed for 1 m^3 of gas = 1.4 x 100/21 = **6.66 m^3**

Example-3 ***A gaseous fuel has the following composition by volume: CH_4 = 70 %, H_2 = 20 % CO_2 = 5% and N_2 = 5 %. Find the volume of air required if 1 m^3 of this fuel is burnt with 40% excess air.***

Solution: **:** 1 m^3 of gas contains 0.7 m^3 CH_4, 0.2 m^3 *H_2,* 0.05 m^3 *CO_2 and* 0.05 m^3 *N_2. Here,* CO_2 and N_2 gas are non-combustible.

Combustion equation	Volume of Oxygen needed
$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$	0.7 x 2 = 1.4 m^3
$H_{2(g)} + 1/2O_{2(g)} \rightarrow H_2O_{(g)}$	0.2 x ½ = 0.1 m^3
	Total Vol. of O_2 = 1.4 + 0.1 = 1.5 m^3

Vol. of air needed = Vol of O_2 x 100/21 x 140/100 = 1.5 x 100/21 x 140/100 = 10 m^3 = 10 x 10^3 L = 10^4 L

Example-4 ***A gaseous fuel has the following composition by volume: CH_4 = 80 %, H_2 = 5 %, O_2 = 10 % and N_2 = 5 %. Find the volume and weight of air required if 1 m^3 of this fuel is completely burnt.***

Solution: Solution: 1 m^3 of gas contains 0.8 m^3 CH_4, 0.05 m^3 *H_2, 0.1 m^3 O2, and* 0.05 m^3 *N_2. Here,* N_2 gas is non-combustible.

Combustion equation	Volume of Oxygen needed
$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$	0.8 x 2 = 1.6 m^3
$H_{2(g)} + 1/2O_{2(g)} \rightarrow H_2O_{(g)}$	0.05 x ½ = 0.025 m^3
	Total Vol. of O_2 = 1.4 + 0.025 = 1.625 m^3 **Fuel contains O_2 = 0.1 m^3** **So, net O_2 needed = 1.625-0.1 = 1.525 m3**

Vol. of air needed = Vol of O_2 x 100/21 x 140/100 = 1.525 x 100/21 = 7.261 m^3 = 7.261 x 10^3 L

Wt. of air needed:

We know that 22.4 L of air weigh 28.92 g

So, 7.261 x 10^3 L will weigh = (28.92/22.4) x 7.261 x 10^3 = 9.374 x 10^3 g = 9.374 Kg.

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Lecture-4

7. Solid Fuels

Solid fuel refers to various forms of solid material that can be burnt to release energy, providing heat and light through the process of combustion. Solid fuels have been used throughout human history to create fire and it is still in extensive use all over the world in the present day.

They are of two types: 1. *Natural (wood, coal)* and 2. *Artificial (coke, paddy straw, corn, etc.).*

Characteristics of a good solid fuel:

1. High calorific value, 2. Low moisture content, 3. Low cost, 4. Low sulphur content, 5. Low ash content, 6. Low volatile matter content, etc.

Advantages of solid fuels: 1. They are easy to transport; 2. Easy to store; 3. Low cost; 4. Possess moderate ignition temperature.

Disadvantages of solid fuels: 1. Ash content is high, 2. Thermal efficiency is low, 3. Burn with clinker formation, 4. Calorific value is lower as compared to liquid fuels, 5. Causes lot of air pollution

7.1 Coal and its analysis

Coal is a fossil fuel. It is a highly carbonaceous matter that has been formed as result of anaerobic microbial decomposition of cellulosic materials of plants under high temperature and pressure condition. Coal is classified into three major types namely anthracite, bituminous, and lignite. Anthracite is the highest rank coal with calorific value ~8700 cal/g. The common coals used in Indian industry are bituminous.

Selection of coal: For the selection of coal for different uses, the following factors are taken into consideration:

1. Calorific value should be high.
2. Moisture content should be low.

3. Ash content should be low.
4. Calorific intensity should be high.
5. S and P content should be low.

7.2 Analysis of coal

There are two methods: (A) ultimate analysis and (B) proximate analysis. **The proximate analysis determines only the fixed carbon, volatile matter, moisture and ash percentages whereas the ultimate analysis determines all coal component elements, solid or gaseous.** The ultimate analysis is determined in a properly equipped laboratory by a skilled chemist.

A. Proximate Analysis: The proximate analysis determines only the fixed carbon, volatile matter, moisture and ash percentages using simple apparatus.

1. **Measurement of Moisture**

Determination of moisture is carried out by placing a sample of powdered raw coal of size 200-micron size in an uncovered crucible and it is placed in the oven kept at 108±2 °C. Then the sample is cooled to room temperature and weighed again. The loss in weight represents moisture.

% moisture = (loss in wt/wt of coal) x 100

Suppose we have taken 1 g of coal and after the removal of moisture its weight is 0.95g. Then % moisture = (1-0.95/1) x 100 = 5 %

2. **Measurement of Volatile Matter (VM)**

After the removal of moisture, dried sample of coal is then covered with a lid is placed in an electric furnace maintained at 900 °C. The crucible is taken out after 10 min of heating. The sample is cooled and weighed. Loss in weight is reported as VM.

% VM = (loss in wt due to removal of VM/wt. of coal) x 100

3. **Measurement of Ash**

The cover from the crucible used in the last test is removed and the crucible is heated in a furnace maintained at 750 ^{0}C until all the carbon is burned. The residue is weighed, which is the incombustible ash.

% ash = (wt. of ash/wt. of coal) x 100

4. **Fixed Carbon**

In actual practice, Fixed Carbon or FC derived by subtracting from 100 the value of moisture, volatile matter and ash.

% FC = 100 - % (Moisture + VM + ash)

Significance of Various Parameters in Proximate Analysis

(a) Fixed carbon:

Fixed carbon is the solid fuel left in the furnace after volatile matter is distilled off. It consists mostly of carbon but also contains some hydrogen, oxygen, sulphur and nitrogen not driven off with the gases. Fixed carbon gives a rough estimate of heating value or calorific value of coal.

(b) Volatile Matter:

Volatile matters are the methane, hydrocarbons, hydrogen and carbon monoxide, and incombustible gases like carbon dioxide and nitrogen found in coal. Thus the volatile matter is an index of the gaseous fuels present. Typical range of volatile matter is 20 to 35%.

Volatile Matter

• Proportionately increases flame length, and helps in easier ignition of coal. But higher % is unwanted because it decreases the CV.

(c) Ash Content:

Ash is an impurity that will not burn. Typical range is 5 to 40%

Ash

- Reduces handling and burning capacity
- Increases handling costs
- Affects combustion efficiency
- Causes clinkering
- Reduces Calorific value

(d) Moisture Content:

Since it replaces combustible matter, it decreases the heat content per kg of coal. Typical range is 0.5 to 10%

Moisture

• Increases heat loss, due to evaporation

Q. What should be the characteristics of an ideal solid fuel?

Q. What is proximate analysis of coal? Mention its significance. (Long question)

L-5 and 6

Ultimate Analysis: The ultimate analysis indicates the various elemental chemical constituents such as Carbon C, Hydrogen H, Oxygen O, Sulphur S, Nitrogen N, etc. It is useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. Typical ultimate analyses of various coals are given in the **Table 1**.

TABLE 1 TYPICAL ULTIMATE ANALYSIS OF COALS

Parameter	Indian Coal, %	Indonesian Coal, %
Moisture	5.98	9.43
Mineral Matter (1.1 × Ash)	38.63	13.99
Carbon	41.11	58.96
Hydrogen	2.76	4.16
Nitrogen	1.22	1.02
Sulphur	0.41	0.56
Oxygen	9.89	11.88

Importance of Ultimate Analysis:

1. **% C and % H:** Greater the % of C & H, better is the coal in quality and calorific value. However, higher % H indicates large content of VM in the sample.

2. **% N:** As N has no calorific value; its presence in the coal is unwanted. So, a good quality of coal should have no or very less % of N.

3. **% S:** It should be small. It generates harmful SO_2 & SO_3 gas on combustion. For metallurgical industries it is undesirable because it combines with Fe and makes it brittle. So, a good quality of coal should have no or very less % of S.

4. **% Ash**: It is determined as per the procedure of proximate analysis. So, a good quality of coal should have very less % of ash.

5. **% O:** Oxygen content decreases the calorific value of the coal. High O-content in the fuel means high content of moisture in it. Usually an increase in 1% O-

content decreases the calorific value by about 1.7%. So, a good quality of coal should have very less % of O.

$$\textbf{\% O = 100 - \% of (C + H + N + S + ash)}$$

Q. Why ultimate analysis of the coal should be carried out?

Ans. Because it is helpful in: 1. Classification of coals, 2. in determining the quantity of air required for combustion and the volume & composition of the combustion gases.

8. Liquid Fuels

They are of two types: 1. Natural (Petroleum) and 2. Artificial (petrol, diesel, furnace oil, etc.).

Advantages of liquid fuels

1. They possess higher CV per unit mass than solid fuels.
2. They burn without forming dust, ash, clinkers, etc.
3. They are easy to transport through pipelines.
4. They can be used in internal combustion (IC) engine.
5. They require less furnace space for combustion.

Disadvantages of liquid fuels

1. The cost of liquid fuel is relatively much higher than solid fuels.
2. Storage cost is high.
3. Greater risk of fire hazards.

8.1 Petroleum-A Natural liquid fuel

It is a primary liquid fuel (a fossil fuel). It is dark greenish-brown viscous oil found deep in Earth's crust. The word petroleum is derived from Latin word *Petra = rock* and *oleum = oil*. It is otherwise known as *rock oil, mineral oil or crude oil*.

It is the main source of many secondary fules like petrol, diesel, kerosene, etc., and petrochemicals (e.g, alkanes, alkenes, benzene, etc.).

Petroleum is a complex mixture of paraffinic, olefinic and aromatic hydrocarbons with small quantities of organic compounds of O, N, and S. The average composition of petroleum is: C =80-87%, H = 11-15%, S = 0.1-3.5%, O = 0.1-0.9%, N = 0.4-0.9%.

Refining of Petroleum:

Petroleum mined from the oil well contains many unwanted substances. As such it is of no use. Its purification and fractionations is needed. *Petroleum refining or Oil refining* is an industrial process in which crude oil is extracted from the ground and transformed and refined into useful products like Liquefied Petroleum Gas (LPG), petrol, diesel, kerosene, asphalt base, jet fuel, gasoline, heating oil, fuel oils etc.

The process of refining involves the following stages:

1. ***Separation of water (Cottrell's process):*** The oil is separated from water by allowing it to flow between two highly charged electrodes. The colloidal water-droplets coalesce to form large drops, which separate out from the oil.

2. ***Removal of sulphur compounds:*** They are removed by treating the oil with copper oxide. The reaction results in the formation of copper sulphide (CuS) in solid form which can be removed by filtration.

3. ***Fractional Distillation:***

After the removal of water and S-compounds, the crude oil is heated about 400 0C in a furnace. The hot vapours are then passed up a fractionating column. As the vapours go up, they become gradually cooler and fractional condensation takes place at different heights of column. Higher boiling fractions condense first while lower boiling fractions condenses later.

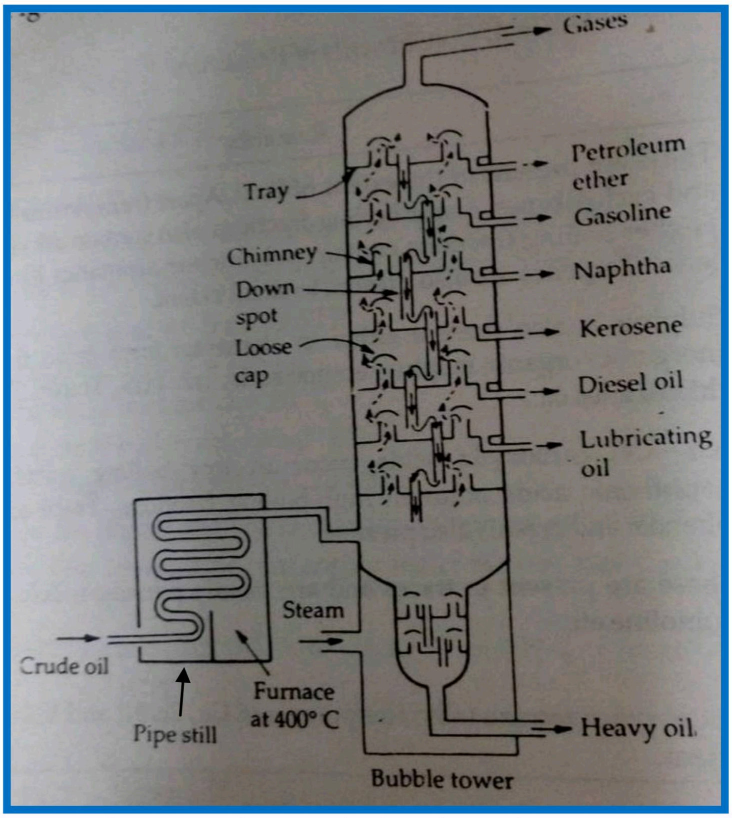


Fig. Fractional distillation of crude petroleum

N.B.: The fractions at the top of the fractionating column have lower boiling points than the fractions at the bottom.

The *three important secondary liquid fuels* obtained are:

1. **Gasoline or petrol:** It contains hydrocarbons from pentane to octane (C_5-C_8). This fraction is obtained between 80-150 ^{0}C. *Its calorific value is about 11,250 cal/gm.*
2. **Kerosene:** It contains higher hydrocarbons (C_{10}-C_{16}). This fraction is obtained between 150-200 ^{0}C. *Its calorific value is about 11,100 cal/gm.*

3. **Diesel:** It contains higher hydrocarbons (C_{15}-C_{18}). This fraction is obtained between 250-300 ^{0}C. *Its calorific value is about 11,000 cal/gm.*

S.No.	Fraction's Name	Boiling temperature	Approx. composition in terms of hydrocarbon containing C atoms	Applications
1.	Uncondensed gas. (Refinery gas)	<30° C	C_1 to C_4 (such as ethane, propane, isobutane) Lower Hydrocarbons	Used as domestic industrial fuel under the name L.P.G. (liquefied petroleum gas).
2.	Petroleum ether.	30° to 70° C	$C_5 - C_7$	Used as a solvent.
3.	Gasoline or petrol or motor spirit.	40 to 120° C	$C_5 - C_9$ (calorific value = 11,250 kcal/kg)	Used as fuel for IC engines, solvent and in dry cleaning.
4.	Naphtha or solvent spirit.	120 to 180° C	$C_9 - C_{10}$	As solvent for paints and varnishes and in dry cleaning.
5.	Kerosene oil.	180 to 250° C	$C_{10} - C_{16}$ (calorific value = 11,000 kcal/kg)	As an illuminant jet engine fuel and for preparing laboratory gas.
6.	Diesel oil or fuel oil or gas oil.	250 to 320° C	$C_{10} - C_{18}$ (calorific value = 11,000 kcal/kg)	used as diesel engine fuel.
7.	Heavy oil.	320 to 400° C	$C_{17} - C_{30}$	For getting gasoline by cracking.
	This on refractionation gives :			
(i)	Lubricating oil.			As lubricants
(ii)	Petroleum jelly.(Vaseline)			In cosmetics and medicines.
(iii)	Grease.			As lubricant.
(iv)	Paraffin wax.			In candles, boot polishes, wax paper, tarapaulin cloth, etc.
8.	Residue may be either :	> 400° C	C_{30} and above	
(i)	Asphalt.			used for Water-proofing of roofs and road making.
(ii)	or Petroleum coke.			As a fuel and in moulding arc light rods.

Lecture-7

8.2 Fuels for Internal Combustion (IC) Engines

We use petrol and diesel in IC engines. In an IC engine, a mixture of fuel and air is ignited in a cylinder, either by means of a spark (Spark-ignition engine, e.g., petrol engine) or by compressing the air & fuel mixture (compression-ignition engine, e.g., diesel engine) and the gases evolved under high pressure push the piston down, thus providing the power stroke.

In a 4-stroke engine, following four strokes complete their working cycle:

1. **Suction stroke:** A mixture of air and fuel vapour is drawn into the cylinder.
2. **Compression stroke:** The piston compresses the mixture
3. **Power stroke/Ignition stroke:** The mixture is ignited by an electric spark. The hot products of combustion increase the pressure and push the piston down, providing an output power.
4. **Exhaust stroke:** The piston ascends and expels the exhaust gases from the cylinder.

8.3 Some important terms

Knocking and anti-knocking

The efficiency of an IC engine depends on a factor called compression ratio (CR).

Compression ratio: It is defined as the ratio of gaseous volume (V_1) in the cylinder at the end of the suction-stroke to the volume (V_2) at the end of compression-stroke of the piston.

$$\text{As } V_1 > V_2 \Rightarrow CR = (V_1/V_2) > 1$$

CR indicates the extent of compression of fuel-air mixture by the piston.

With increase in CR, efficiency of IC engine also increases but after critical CR, the tendency to knock also increases. The CR at which fuel tends to knock is called critical CR.

Knocking: It is a metallic sound emitted from the cylinder due to abnormal type of combustion of fuel-air mixture.

Consequences of knocking:

Knocking is unwanted due to following reasons:

1. It decreases the power output
2. Results in mechanical damage of the cylinder part

Factors affecting knocking: Some of the factors are:

1. Design of the engine
2. Running condition
3. Chemical structure of the fuel hydrocarbons (HCs)

How chemical structure affects knocking?

Knocking tendency decreases in the order-

n-alkanes; mono-substituted alkanes; cycloalkanes; alkenes; poly-substituted alakanes; aromatics

Aromatic HCs have higher anti-knocking properties than paraffins and olefins.

Anti-knocking substance:

The substance which can reduce the knocking property is aknown as anti-knocking substance. For example Tetra Ethyl Lead (TEL) $(C_2H5)_4Pb$, Diethyl Telluride $(C_2H5)_2Te$ are most commonly used anti-knocking substance. These substances are added to fuel to check knocking in IC engines. During combustion, TEL gives rise to Pb and PbO. These particles are act as free-radical chain inhibitors. As knocking proceeds via a free radical chain reaction, these inhibitors arrest the propagation of the explosive chain reaction.

N.B.: As Pb and PbO deposition decreases the life of IC engine, they must be removed from it. This can be done by adding ethylene dibromide along with TEL to the fuel.

(Pb, PbO) + $C_2H_4Br_2 \rightarrow PbBr_2$, as $PbBr_2$ is volatile in nature it escapes into the atmosphere through the exhaust pipe (Silencer).

Petrol and Diesel engine fuel

Petrol engine fuel

In a petrol engine, the fuel is burnt by a spark obtained by a spark-plug. Petrol engine fuel contains mainly constituents like **branched alkanes, aromatics**, etc. Usually consists of less % of straight chain HCs. The quality of a petrol fuel is determined by its **Octane number**.

Octane Number

The resistance offered by a petrol or gasoline to knocking cannot be defined in absolute terms. It is generally expressed on an arbitrary scale, known as Octane rating proposed by Graham Edgar in 1926. It has been found that n-heptane knocks very badly and iso-octane gives very little knocking.

Fuel	Octane Number	Characteristics
n-heptane (C_7H_{16})	0	Knocks severely
Iso-octane (2,2,4-	100	High Resistance to

trimethyl pentane)		knocking

As knocking increases, octane number decreases.

Definition: *Octane number* is the % of iso-octane present in the mixture of n-heptane & iso-octane which has the same knocking characteristics as the gasoline sample, under the same set of conditions.

In this way, a "**90-octane**" number fuel is one which has the same knocking characteristics as a 90:10 mixture of iso-octane and n-heptane.

Diesel engine fuel

In the diesel engine, air is first drawn into the cylinder and compressed to a pressure of about 500 psi Pascal per square inch (34 atm). This compression is accompanied by a rise in temperature to about 500 ^{0}C towards the end of compression stroke, diesel is injected in the form of finely-divided spray into the hot air in the cylinder. The oil absorbs the heat from the air and it ignites spontaneously as it attains the ignition temperature. This rises the temperature and pressure. The piston is pushed by expanding gases in the power stroke.

So, in a diesel engine the fuel is exploded not by a spark, but by the application of heat and pressure.

N.B.: The combustion of fuel in a diesel engine is not instantaneous; the interval between the start of fuel injection and its ignition is called "*Ignition Delay*". Ignition delay is due to the time taken for the vaporization of the individual droplets and rising of the vapors to its ignition temperature. Ignition delay is relatively short for paraffinic fuel, than olefinic, napthalenic and aromatic fuels. Ignition delay is the main cause of knocking in a diesel engine.

Cetane Number

The suitability of diesel engine is determined by its “Cetane Value”. Cetane number of a fuel is primarily depends on: (1) *Nature* and (2) *Composition of its HCs*. In the following series the cetane number decreases from left to right.

n-alkanes > cycloalkanes > alkenes > branched alkanes > aromatics

- As Ignition delay increases from left to right
- Knocking increases from left to right
- So, Cetane number decreases from left to right

Definition of cetane number: It is the % of hexadecane (cetane) in a mixture of hexadecane & 2-methyl naphthalene which have the same ignition characteristics as the diesel fuel sample under the same set of conditions.

In this way, a “**90-cetane”** number fuel is one which has the same knocking characteristics as a 90:10 mixture of hexadecane and 2-methyl napthalene.

Q.1 Define the term knocking. How to avoid knocking in IC engines?

Q. 2. A small amount of ethylene di-bromide is added to the gasoline along with TEL. Give reason.

Q. 3. Define the term Octane number.

Q. 4. Define Cetane number.

Q.5 Gasoline containing TEL is used in IC engine. Give reason.

Lecture-8

8.4 Cracking of Heavy oils

Cracking is defined as the decomposition of heavy oils with high molecular weight HCs into light oil of lower molecular weight HCs in absence of air.

$C_{10}H_{22}$ decane (Heavy oil) → C_5H_{10} (pentene) + C_5H_{12} (pentane)

Objectives of cracking:

1. To fulfill the high demand for gasoline
2. To prepare good quality gasoline

Types of cracking

It is of two types: (1) *Thermal*, and (2) *Catalytic* cracking

Thermal cracking

When the heavy oils are subjected to high temperature (475-650 ^{0}C) and pressure (10-70 atm.) in absence of catalyst, it is called as thermal cracking. Here, the bigger HC molecule breaks down to give smaller molecules of the paraffins, oleifins and some hydrogen. $C_{12}H_{24} \rightarrow H_2 + C_4H_{10} + C_4H_8 + C_4H_4$

Catalytic cracking

When the heavy oils are subjected to lower temperature (400-450 ^{0}C) and pressure (1-2 atm.) in presence of a suitable catalyst, it is called as catalytic cracking. In short, it is written as **cat cracking**. The various catalyst used are aluminium silicate $Al_2(SiO_3)_3$, alumina Al_2O_3, Pt/Rh, etc. Better quality with good quantity of gasoline is produced by this method.

8.4.1 Advantages of catalytic cracking over thermal cracking

1. The yield of petrol is higher.
2. The quality of petrol produced is better
3. Petrol possess better anti-knocking characteristic as it contain a higher amount of aromatics HCs
4. Petrol contain a lesser amount of undesirable sulphur compounds
5. Low pressure is needed
6. Cracking process can be easily controlled, so desired products can be obtained
7. % of gum forming compounds (i.e., unsaturated HCs) are very low
8. Production cost is very low as it occurs at low T and P

Q. Define thermal cracking with a suitable example.

Q. Petrol obtained by catalytic cracking is better than thermal cracking process. Give reason.

Ans. Refer above (section 8.4.1)

Q. What is cat cracking?

Ans. When the heavy oils are subjected to lower temperature (400-450 ^{0}C) and pressure (1-2 atm.) in presence of a suitable catalyst, it is called as catalytic cracking or cat cracking.

Q. What is straight-run petrol?

Ans. The petrol obtained by fractional distillation of petroleum is known as straight-run petrol.

Q. Mention the name of two catalysts used in catalytic cracking.

Ans. Aluminium silicate $Al_2(SiO_3)_3$ and alumina Al_2O_3

Q. What is synthetic petrol?

Ans. The petrol obtained by cracking of heavy oils are call synthetic petrol.

9. Gaseous fuels

They are of two types: 1. Natural (Natural gas) and 2. Artificial (LPG, water gas, producer gas, biogas, etc.).

Advantages of gaseous fuels:

1. They can be conveyed easily through pipelines to actual place of need
2. They can be lighted at moment's notice
3. They have relatively high calorific value
4. They can burn without any smoke and are ash free.
5. They are free from solid and liquid impurities.
6. Complete combustion without pollution is possible
7. They can be used in IC engines

Disadvantages:

1. Very large and special storage tanks are needed for them.
2. They are highly inflammable, so chances of fire hazards are high in their use.
3. They are relatively costlier than solid fuels.

9.1 Some gaseous fuels

A. Liquefied Petroleum Gas (LPG)

- LPG is a secondary gaseous fuel.
- It is obtained as a by-product during the cracking of heavy oils. It consists of smaller HCs like butane, iso-butane, propane, butylenes, etc. with little or no propylene and ethane.
- Its calorific value is about 27,800 Kcal/m^3.
- The larges use of LPG is as a domestic fuel.
- It is also used as motor fuel.

B. Natural gas

- Natural gas is a fossil fuel or primary fuel.
- It is formed as a result of anaerobic bacterial decomposition of buried plant and animal matters in presence of high T and P.
- Its calorific value varies from 12,000-14,000 Kcal/m^3.

- The average composition is: CH_4 = 70-90 %, C_2H_6 = 5-10%, H_2 = 3%, CO + CO_2 = rest.
- It mainly contains methane CH_4 gas.
- It is used as raw material for the manufacture of carbon black- filler for rubber.
- It is used as raw material for the manufacture of H_2 gas.
- It is used for domestic as well as industrial heating.

C. Producer gas

- It is a secondary fuel obtained from coal or coke.
- It is a mixture of CO & H_2 associated with *large % of non-combustible gases N_2 & CO_2.*
- Its calorific value is about 1300 Kcal/m^3.
- The average composition is: CO = 22-30%; H_2 = 8-12%; N_2 = 52-55%, and CO_2 = 3%.
- So, mainly contains **CO and N_2** gas.
- It is used for heating open-hearth furnace in steel & glass industries.
- It is used as reducing agent in metallurgical industry.

D. Water gas

- It is a secondary fuel obtained from coal or coke.
- It is a mixture of CO & H_2 associated *with little % of non-combustible gases N_2 & CO_2.*
- Its calorific value is about 2800 Kcal/m^3.
- The average composition is: H_2 = 51%; CO = 41%; N_2 = 4%, and CO_2 = 4%.
- So, mainly contains **CO and H_2** gas.
- **It is used as a source of H_2.**
- It is used for heating open-hearth furnace in steel & glass industries.
- It is used as reducing agent in metallurgical industry.

Q. Mention some uses of LPG.

Q. Mention the main constituent present in CNG.

Ans. Methane

Q. Water gas has higher calorific value than producer gas. Give reason.

Ans. Water gas contains 92 % combustible gases (CO + H2) whereas producer gas contains (30-42%).

Q. Which of the following gas possess highest calorific value? LPG, CNG, water gas, producer gas

Ans. LPG

Q. Write a short note on CNG. (3 marks)

Ans.

- Compressed Natural Gas (CNG) is a fossil fuel or primary fuel.
- It is formed as a result of anaerobic bacterial decomposition of buried plant and animal matters in presence of high T and P.
- Its calorific value varies from 12,000-14,000 $Kcal/m^3$.
- The average composition is: CH_4 = 70-90 %, C_2H_6 = 5-10%, H_2 = 3%, CO + CO_2 = rest.
- It mainly contains methane CH_4 gas.
- It is used as raw material for the manufacture of carbon black- filler for rubber.
- It is used as raw material for the manufacture of H_2 gas.
- It is used for domestic as well as industrial heating.

10. Battery

Battery is an electrochemical cell or a group of two or more cells connected in series which converts chemical energy into electrical energy. Examples: Nickel-Cadmium Ni-Cd cell; Lead-acid storage cell, Laclanche (Zn-C) cell, Li-ion battery, etc.

Characteristics of a good commercial battery

A good commercial battery should have:

- ✓ Low cost
- ✓ Light in weight
- ✓ Small in size (i.e., portability)
- ✓ High energy efficiency
- ✓ High cycle life
- ✓ Long shelf life
- ✓ Excellent tolerance to variation of temp., vibration, moisture, EM wave, etc.

Types of batteries

In general, there are two types of batteries are available in the market:

1. Primary or non-rechargeable battery
2. Secondary or rechargeable battery

Primary Battery: Here, cell reaction (i.e., a redox reaction) is not reversible. It is also known as dry cell. Example: Laclanche cell

Secondary Battery

Here, cell reaction can be reversed during charging by the supply of an external source. It is also known as reversible cell. Example: Lad-acid storage cell

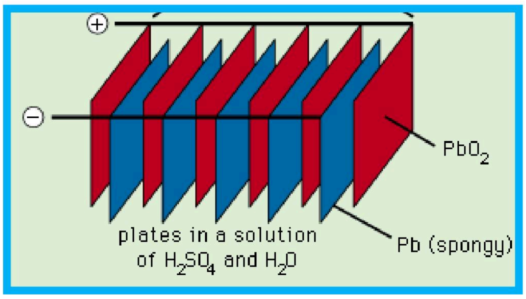
10.1 Lead-Acid Storage Cell-a rechargeable battery

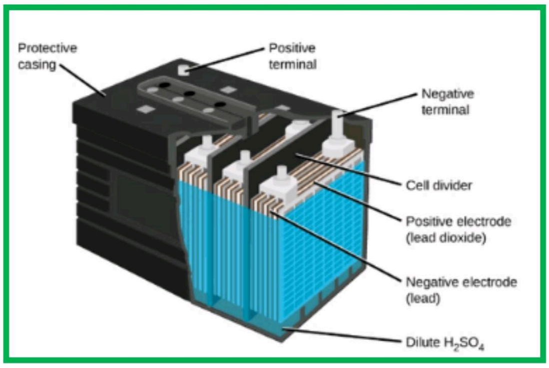
- ✓ It is a secondary cell which can operate both as a electrochemical cell and as a electrolytic cell. It is also known as lead-acid accumulator.
- ✓ It has the ability to supply electrical energy during discharging (i.e., acts as electrochemical cell).

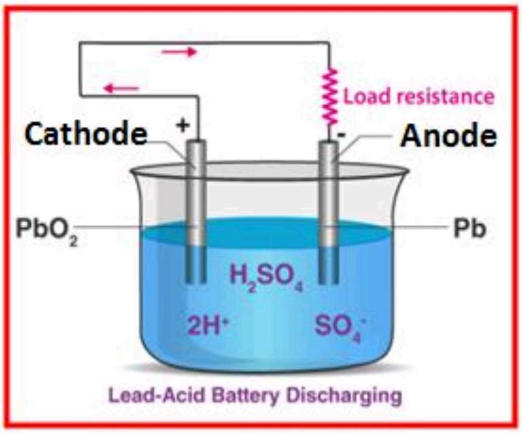
- ✓ Also, it has the ability to receive electrical energy during charging (i.e., acts as electrolytic cell)
- ✓ It can store a lot of charge and provide high current for short periods of time.
- ✓ The lead acid battery is packed in a thick rubber or plastic case to prevent leakage of the corrosive sulphuric acid.

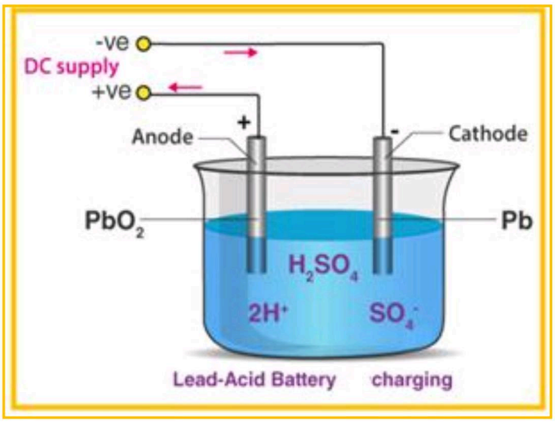
<u>Construction</u>

Like any electrochemical cell, it consists of **an anode, a cathode and an electrolyte**. Here, porous lead (Pb) acts as anode, lead coated with lead oxide (PbO_2) acts as cathode and 20% H_2SO_4 (density ~1.2 g/cc) acts as electrolyte. In general, a storage cell consists of at least six numbers of such cells connected in series to provide a output voltage of ~12V.









<u>Working</u>

Its working consists of two processes: **A.** Discharging, and **B.** Charging

Discharging: It is said to be discharging when the battery is used for supplying electrical energy. So, it acts as an electrochemical cell. The following reactions were occurring during discharging.

Chemical reactions for discharging:

Anode (Oxidation): $Pb + SO_4^{2-} \rightarrow PbSO_4\ (s) + 2e$ -------------- (1)

(Here, Pb(0) is oxidized to Pb^{2+})

Cathode (Reduction): $PbO_2 + 4H^+ + SO_4^{2-} + 2e \rightarrow PbSO_4\ (s) + 2H_2O$ -------- (2)

(Here, Pb^{4+} is reduced to Pb^{2+})

Net cell reaction during discharging (a redox reaction): (1) + (2)

$Pb + PbO_2 + 4H^+ + 2SO_4^{2-} \rightarrow 2PbSO_4\ (s) + 2H_2O + \text{Energy}$

Or $\mathbf{Pb + PbO_2} + 2H_2SO_4 \rightarrow \mathbf{2PbSO_{4\ (s)}} + 2H_2O + \text{Energy}$

- ✓ In the discharged state, both the positive and negative plates become lead(II) sulfate ($PbSO_4$). The electrolyte loses much of its dissolved sulfuric acid and becomes primarily water.

Charging:

During discharging, it acts as electrolytic cell. During discharging, the lead (Pb) of the anode and lead dioxide (PbO_2) of the cathode are covered with lead sulphate ($PbSO_4$).This causes the cell stop working after discharging for some period of time. For further use, it needs to be recharged by passing an external source greater than 2 Volt. This external source causes reversing the cell reactions taking place during discharging.

The following reactions were occurring during discharging.

Chemical reactions for charging:

Anode (Oxidation): $PbSO_4\ (s) + 2H_2O \rightarrow PbO_2 + 4H^+ + SO_4^{2-} + 2e$ -------- (1)

(Here, Pb^{2+} is reduced to Pb^{4+})

Cathode (Reduction):

$$PbSO_4\,(s) + 2e \rightarrow Pb + SO_4^{2-} \text{ -------------- (2)}$$

(Here, Pb^{2+} is reduced to Pb(0))

Net cell reaction during charging (a redox reaction): (1) + (2)

$$2PbSO_4\,(s) + 2H_2O + \text{Energy} \rightarrow Pb + PbO_2 + 4H^+ + 2SO_4^{2-}$$

Or $$2PbSO_4\,(s) + 2H_2O + \textbf{External source} \rightarrow Pb + PbO_2 + 2H_2SO_4$$

*** Notice how the charging reaction is the exact opposite of the discharge reaction.

N.B.: During charging

- ✓ The anodic reaction of discharging becomes cathodic reaction but in reverse order.
- ✓ The cathodic reaction of discharging becomes anodic reaction but in reverse order.

Applications: This cell is used in electrical vehicles, hospitals, trucks, buses, telephone exchange, inverter, UPS, etc.

Limitations:

- ✓ Excessive charging may damage the electrodes
- ✓ Excessive charging may leads to explosion of battery
- ✓ Lead metal is toxic in nature
- ✓ In cold weather, there is a decrease in output voltage.

Q. Write the chemical reactions occur during the discharging.

Q. Write the chemical reactions occur during the charging.

Q. What is an accumulator?

Q. Mention some limitations of lead-acid storage battery.

Q. What do you mean by charging?

Q. What do you mean by discharging?

Q. Briefly discuss the construction and working of lead-acid storage cell. (7 marks)

Fuel cell

- A fuel cell can be defined as an electrochemical cell that generates electrical energy from fuel via an electrochemical reaction.
- These cells require a continuous input of fuel and an oxidizing agent (generally oxygen) in order to continue the reactions that generate the electricity.
- Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied.
- A fuel cell is similar to electrochemical cells, which consist of a cathode, an anode, and an electrolyte that allows ions.
- The first fuel cells were invented by Sir William Grove in 1838. The first commercial use of fuel cells came more than a century later following the invention of the hydrogen–oxygen fuel cell by Francis Thomas Bacon in 1932. The alkaline fuel cell, also known as the Bacon fuel cell after its inventor, has been used in NASA space programs since the mid-1960s to generate power for satellites and space capsules.

Examples: H_2-O_2 fuel cell, propane-O_2 fuel cell, methanol-O_2 fuel cell, etc.

10.3 Hydrogen-Oxygen (H_2-O_2) fuel cell

- *Alkaline fuel cell or Hydrogen-oxygen fuel cell* was designed and first demonstrated publicly by *Francis Thomas Bacon* in 1959. It was used as a primary source of electrical energy in the Apollo space program.
- The cell consists of two inert porous carbon electrodes impregnated with a suitable catalyst such as Pt, Ag, etc. Here, catalyst is used to increase the rate of reaction.
- The space between the two electrodes is filled with a concentrated solution of KOH or NaOH which serves as an electrolyte.
- H_2 gas and O_2 gas are bubbled into the electrolyte through the porous carbon electrodes. Thus the overall reaction involves the combination of hydrogen gas and oxygen gas to form water.
- The cell runs continuously until the reactant's supply is exhausted. They do not store chemical energy.

- This type of cell operates efficiently in the temperature range 343–413 K (70-140 ^{0}C) and provides a potential of about 1.0 V.
- Efficiency is about 70%.

The following chemical reactions are occurring during its working process:

Anode: $2H_{2(g)} + 4OH^-_{(aq)} \rightarrow 4H_2O_{(l)} + 4e$ -------- (1)

Cathode: $O_{2(g)} + 4e + 2H_2O_{(l)} \rightarrow 4OH^-_{(aq)}$ --------- (2)

Net cell reaction: (Eq. 1. + Eq. 2) $2H_{2(g)} + O_{2(g)} \rightarrow 2\,H_2O_{(l)} + 1.23$ V

- One such cell can generate power of about 1 V, far from enough to power a vehicle.
- In actual practice, a large number of such cells are stacked together in series to make a battery**. Cell output ranges from 300 W to 5000 W.**

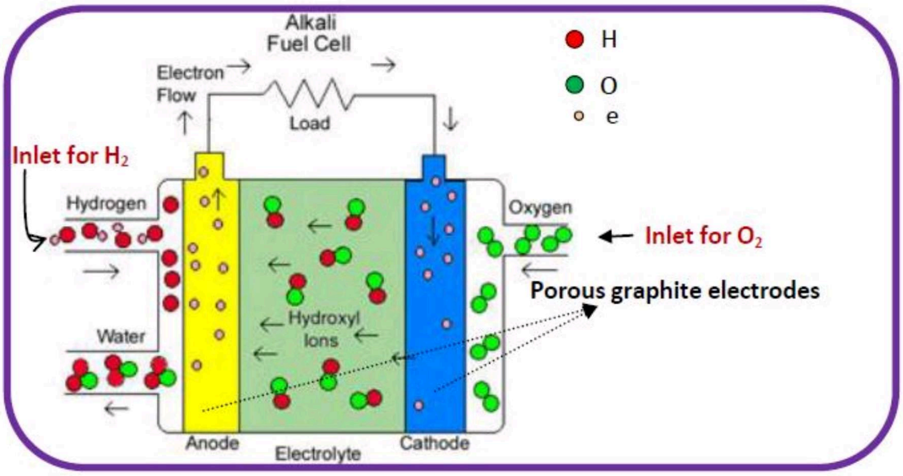


Fig. H_2-O_2 fuel cell

Advantages:

- Energy conversion is high (75-80%).
- Produces water of potable quality.
- Noise and thermal pollution are low.
- Used in space applications and remote areas.
- Saves fossil fuels.

Limitations:

- High cost
- Pure hydrogen is also costly.
- Finding a suitable catalyst for electrode is a tough task.
- H_2 and O_2 cylinder to be carried along with the battery.

Applications: Some of the applications are listed below:

- Fuel cell electric vehicles, or FCEVs, use clean fuels and are therefore more eco-friendly than internal combustion engine-based vehicles.
- They have been used to power many space expeditions including the Apollo space program.
- Generally, the by-product produced from these cells is pure water.
- The portability of some fuel cells is extremely useful in some military applications.
- These electrochemical cells can also be used to power several electronic devices.
- Used in military vehicles, aircrafts, etc.
- Fuel cells are also used as primary or backup sources of electricity in many remote areas.

Q. What is a fuel cell? Give an example.

Ans. A fuel cell can be defined as an electrochemical cell that generates electrical energy from fuel via an electrochemical reaction. Example: H_2-O_2 fuel cell

Q. Mention some limitations of a fuel cell.

Q. Mention some advantages of a fuel cell.

Q. Write the chemical reactions involved during the working of a H_2-O_2 fuel cell.

Q. Discuss the construction and working of a H_2-O_2 fuel cell. (7 marks)