Unit IV- BIOFUELS AND FUEL CELLS

Biomass – Biogas – Constituents, manufacture and uses.General outline of fermentation process – manufacture of ethyl alcohol by fermentation process.Combustion – Calorific values – Gross and bet calorific value – problems based on calorific value. Fuel cells – Construction working and applications of Hydrogen Oxygen fuel cells, methanol oxygen fuel cells, solid oxide fuel cells

Biomass

Biomass—renewable energy from plants and animals

Biomass is plant or animal material (organic material) used for energy production (electricity or heat), or in various industrial processes as raw substance for a range of products, and it is a renewable source of energy. Biomass contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat. Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels.

Biomass is fuel that is developed from organic materials, a renewable and sustainable source of energy used to create electricity or other forms of power

Examples of biomass and their uses for energy

- Wood and wood processing wastes—burned to heat buildings, to produce process heat in industry, and to generate electricity
- Agricultural crops and waste materials—burned as a fuel or converted to liquid biofuels
- Food, yard, and wood waste in garbage—burned to generate electricity in power plants or converted to biogas in landfills
- Animal manure and human sewage—converted to biogas, which can be burned as a fuel

Constitution

There are three primary constituents present in the biomass. Biomass is primarily composed of a combination of

(A) Cellulose—a homopolymer of glucose units,

(B) Hemicellulose (xylan—a homopolymer of xylose units), and

(C) lignin (hardwood lignin)—a biopolymer composed of aromatic monomeric units.

Production

Biomass production refers to the increase in the amount of organic matter. It is the addition of organic matter in a given area. Biomass is considered as renewable energy because it is replenished as plants and animals grow.

There are two forms of production –

- **Primary production** refers to the generation of energy by plants through photosynthesis. The excess energy generated is stored and adds up to the total biomass in the ecosystem. Primary production could be estimated from the total forest cover in a given year.
- **Secondary production** is the absorption of organic matter as body tissues by organisms. It includes ingestion by animals i.e. feeding, whether on other animals or on plants. It also involves decomposition of organic matter by microorganisms. Secondary production could be estimated as the total meat produced per year.

Though biomass could be measured as mass of organisms (living and dead) in a given environment, production is harder to estimate. It can only be estimated as the increase in volume though part of the additional biomass may have been replaced through natural processes.

There are methods of utilisation of biomassin the form of energy

1. burn the biomass directly to obtain energy

2. convert the matter into ethanol and methanol or it its fermented anaerobically to obtain gaseous fuel, biogas

Uses of Biomass

(i) Production of Biofuels

- Used in the production of Cellulosic Ethanol.
- Used in the production of Bio diesel

- Gasification process to produce synthesis gas (*syngas*)

(ii) Green Power & Renewable Energy

- Co-firing at an existing power generation facility
- Standalone fuel for greenhouse boilers and cement kilns
- Used at a Green Choice Bio-Recovery facility to produce steam and electrical energy required to operate the facility

Bio gas

Biogas is the mixture of gases produced by the breakdown of organic matter in the absence of oxygen (anaerobically), primarily consisting of methane and carbon dioxide. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste**.**

Biogas is produced by the degradation of biological matter by bacterial action in the absence of free oxygen.

- Microbially controlled production of biogas is an important part of the global carbon cycle.
- It is a renewable energy source.
- The main source of raw material for production of biogas is Plant and Animal biomass.
- Biogas differs from natural gas in that it is a renewable energy source produced biologically through anaerobic digestion rather than a fossil fuel produced by geological processes

Constitution

Biogas comprises primarily **methane** (**CH_4**) and **carbon dioxide (CO_2**) and may have small amounts of hydrogen sulphide (H_2S), moisture and siloxanes. The chemical composition of **biogas** is as follows: 50–85% CH_4 (methane); 20–35% CO_2; H_2, N_2 and H_2S form the rest.

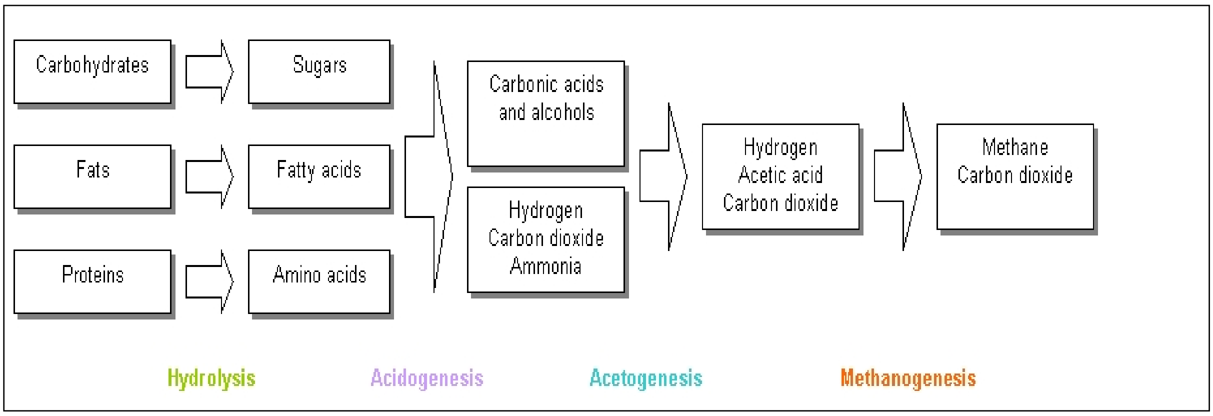
Domestic biogas plants convert livestock manure and night soil into biogas and slurry, the fermented manure. This technology is feasible for small-holders with livestock producing 50 kg manure per day.

Manufacture

Principle: Biogas is produced by anaerobic digestion with methanogen or anaerobic organisms, which digest material inside a closed system, or fermentation of biodegradable materials. This closed system is called an anaerobic digester, biodigester or a bioreactor.Biogas is produced as landfill gas (LFG), which is produced by the breakdown of biodegradable waste inside a landfill due to chemical reactions and microbes, or as digested gas, produced inside an anaerobic digester.

Biogas is produced by four steps –

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis



Hydrolysis

Breakdown of organic matter to small molecules. This process is known as hydrolysis.

Acidogenesis

Acidogens act on the decomposed matter converting them into volatile fatty acids (VFAs) alongside ammonia, CO_2 and hydrogen sulfide. The process is called acidogenesis.

Acetogenesis

The volatile fatty acids are further broken down into acetic acid, carbon dioxide and hydrogen.

Methanogenesis

The final stage is the combination of emissions above to produce methanol, carbon dioxide, and water.

Production Equipment

The Main parts of a typical biogas plant consist of the following components:-

- Inlet
- Digester
- Gas holder
- Outlet

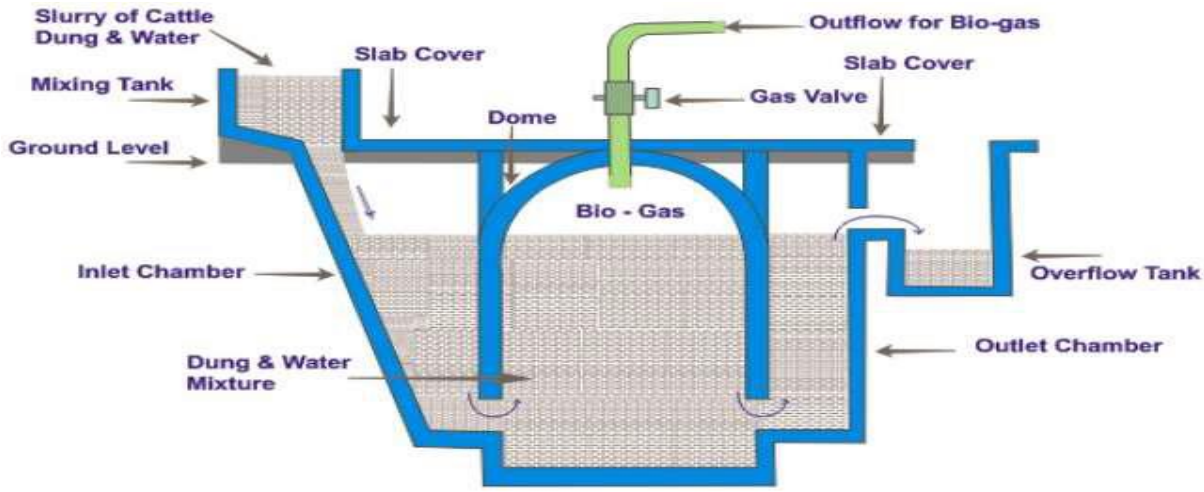
There are different types of biogas production plants. The main two types are as follows:

1. Fixed-dome Plant
2. Floating-drum Plants

Fixed dome type

• A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester

• Advantage - The costs of a fixed-dome biogas plant are relatively low. It is simple as nomoving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected.



Fixed Dome type Bio-gas Plant

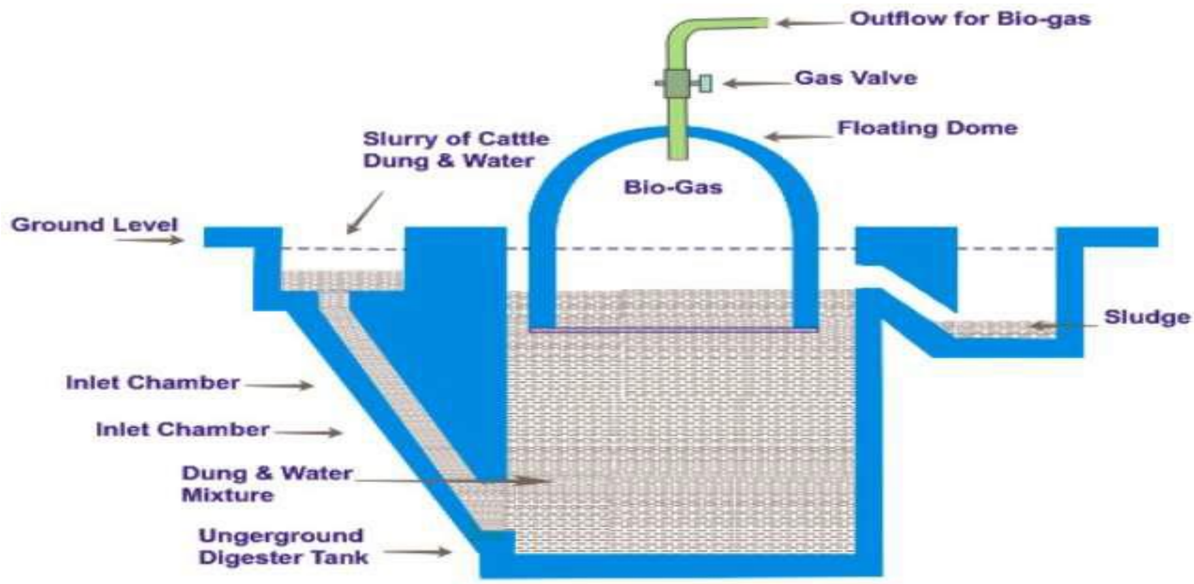
Floating dome type

• Floating-drum plants consist of an underground digester and a moving gas-holder.

• The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own.

• The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored

• Advantage- Floating-drum plants are easy to understand and operate. They provide gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum



Floating Dome type Bio-gas Plant

Processing of Biogas

- The scrubbing of the biogas in order to remove impurities that are generatedduring the digestion process such as CO_2 (Carbon Dioxide) and H_2S (Hydrogen sulphide)
- Biogas goes through a cleaning process, and becomes biomethane.
- A simple method for Hydrogen sulphide utilizing steel wool in a glass bottle
- For Carbon Dioxide removal, as well as additional Hydrogen sulphide removal amethod of water spray cross flow can be used. In this method the Biogasenters one end of a tube and experiences water streams flowing in the opposite direction.

Uses

Biogas is environment friendly and has various applications.

- They are used in cooking, drying, cooling, heating etc.
- It is used in producing electricity, methanol and production of steam
- Biogas in transport
- Using of carbon dioxide and methane as chemical products
- Scrubbed and used in CHP engine
- Scrubbed, purified , compressed for vehicle fuel (CNG)

General outline of fermentation process

Introduction

Fermentation is a metabolic process in which an organism converts a carbohydrate, such as starch or a sugar, into an alcohol or an acid. For example, yeast performs fermentation to obtain energy by converting sugar into alcohol. Bacteria perform fermentation, converting carbohydrates into lactic acid. It is the reaction that is used to produce alcohol from sugar. It is an anaerobic reaction, which means it requires no oxygen to be present other than the oxygen atoms contained in the sugar. The other ingredient required for the reaction to take place is yeast.

Fermentation is also defined as a process involving yeasts or other microorganisms breaking down a substance, or a state of excitement. When grapes are crushed or transferred into a press, cultured yeast is added, and the sugars in the grapes start to convert into alcohol, this is an example of fermentation.

At the time, people knew that leaving fruits and grains in covered containers for a long time produced wine and beer, but no one fully understood why the recipe worked. The process was named fermentation. The frothing results from the evolution of carbon dioxide gas, though this was not recognized until the 17th century.

The name derived from the Latin verb '**fervere**' meaning **'to boil'**

Our modern understanding of the fermentation process comes from the work of the French chemist Louis Pasteur. Pasteur was the first to demonstrate experimentally that fermented beverages result from the action of living yeast transforming glucose into ethanol. Moreover, Pasteur demonstrated that only microorganisms are capable of converting sugars into alcohol from grape juice, and that the process occurs in the absence of oxygen. He concluded that fermentation is a vital process, and he defined it as respiration without air.

- Louis Pasteur in the 19th century used the term fermentation in a narrow sense to describe the changes brought about by yeasts and other microorganisms growing in the absence of air (anaerobically).
- ethyl alcohol and carbon dioxide are not the only products of fermentation

Fermentation products include:

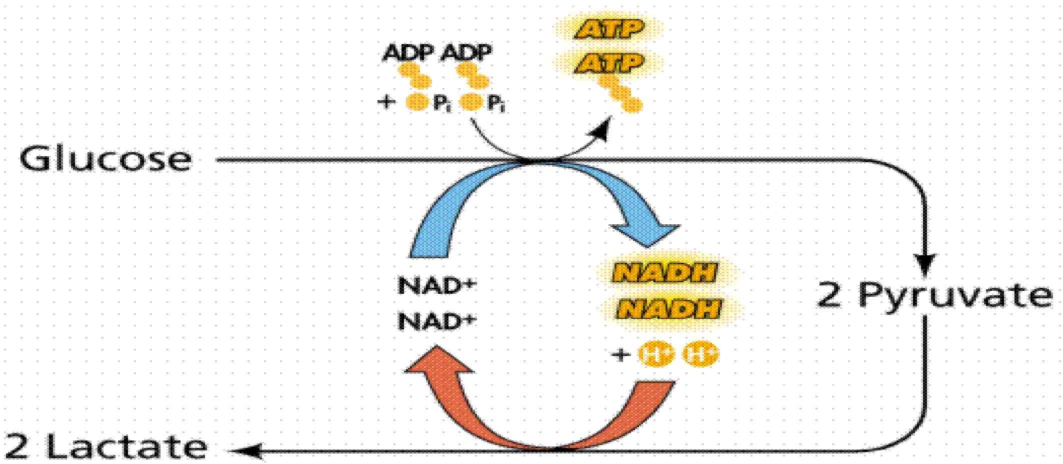
- Food products: from milk (yogurt, kefir, fresh and ripened cheeses), fruits (wine, vinegar), vegetables (pickles, sauerkraut, soy sauce), meat (fermented sausages, salami)
- Industrial chemicals: (solvents: acetone, butanol, ethanol, enzymes, amino acids)
- Specialty chemicals (vitamins, pharmaceuticals)

Fermentation is a metabolic process in which an organism converts a carbohydrate, such as starch or a sugar, into an alcohol or an acid. It is an anaerobic reaction, which means it requires no oxygen to be present other than the oxygen atoms contained in the sugar. The other ingredient required for the reaction to take place is yeast. Fermentation is an enzyme catalysed, metabolic process whereby organisms convert starch or sugar to alcohol or an acid anaerobically releasing energy. The science of fermentation is called “zymology”.Depending upon the end product formed, fermentation can be categorised into various type.

1.**<u>Lactic acid fermentation.</u>**

Humans undergo lactic acid fermentation when the body needs a lot of energy in a hurry. When you are sprinting full speed, your cells will only have enough ATP stored in them, to last a few seconds. Once the stored ATP is used, your muscles will start producing ATP through lactic acid fermentation.

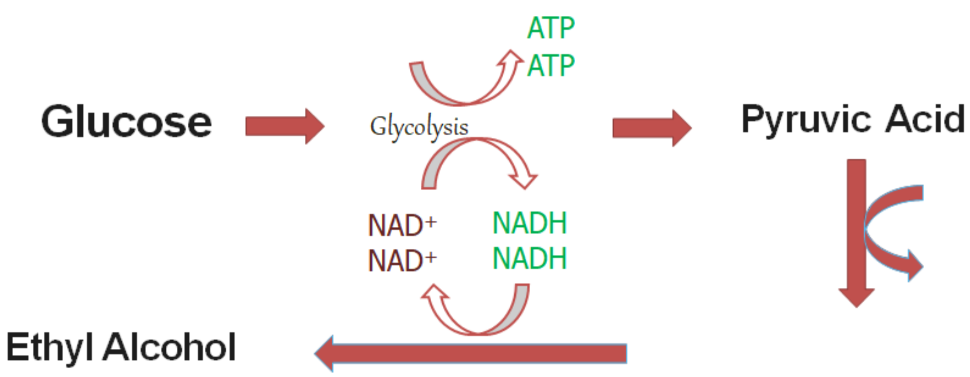
Yeast strains and bacteria convert starches or sugars into lactic acid, requiring no heat in preparation. In this anaerobic chemical reactions, pyruvic acid uses nicotinamide adenine dinucleotide + hydrogen (NADH) to form lactic acid and NAD+. Lactic acid bacteria are vital to producing and preserving inexpensive, wholesome foods, which is especially important in feeding impoverished populations. This method makes sauerkraut, pickles, kimchi, yogurt, and sourdough bread.



2.Ethanol fermentation/alcohol fermentation. This is used in the industrial production of wine, beer, biofuel, etc. The end product is alcohol and CO_2. Pyruvic acid breaks down into acetaldehyde and CO_2 is released. In the next step, ethanol is formed from acetaldehyde. NAD+ is also formed from NADH which is reused in glycolysis. Yeast and some bacteria carry out this type of fermentation. Enzyme pyruvic acid decarboxylase and alcohol dehydrogenase catalyse these reactions.

Yeasts break pyruvate molecules into alcohol and carbon dioxide molecules. The output of the metabolism of glucose ($C_6H_{12}O_6$) is known as glycolysis. Alcoholic fermentation produces wine and beer. Depending upon fermenting, the process can have several stages.

- **Primary fermentation**. In primary fermentation, microbes begin rapidly working on raw ingredients such as fruit, vegetables, or dairy. The microbes present or in the surrounding liquid (such as brine for fermented vegetables) prevent putrefying bacteria from colonizing the food instead. Yeasts or other microbes convert carbohydrates (sugars) into other substances such as alcohols and acids.
- **Secondary fermentation**. In this longer stage of fermentation, which lasts several days or even weeks, alcohol levels rise and yeasts and microbes die off and their available food source (the carbohydrates) becomes scarcer. Winemakers and brewers use secondary fermentation to create their alcoholic beverages. The pH of the ferment can differ significantly from when it started out, which affects the chemical reactions taking place between the microbes and their environment. Once alcohol is between 12–15% and it kills the yeast, preventing further fermentation, distillation is needed to remove water, condensing alcohol content to create a higher percentage of alcohol.



Alcoholic fermentation of glucose

$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{ethanol}}{2\ C_2H_5OH} + \underset{\text{carbon dioxide}}{2\ CO_2}$$

Manufacture of ethyl alcohol by fermentation process.

Ethanol is an important industrial chemical; it is used as a solvent, in the synthesis of other organic chemicals, and as an additive to automotive gasoline (forming a mixture known as a gasohol). Ethanol is also the intoxicating ingredient of many alcoholic beverages.

Solvent:-

Resins, pharmaceuticals, cosmetics,household cleaning products, industrial solvent

Fuel:-

Used as a bio fuel-in internal combustion engines

Chemical intermediate:-

- petroleum derived chemicals
- Butadiene production

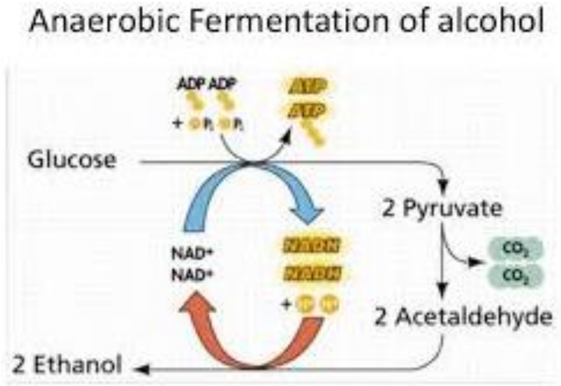
There are two main processes for the manufacture of ethanol: the fermentation of carbohydrates (the method used for alcoholic beverages) and the hydration of ethylene.

Process:

Aqueous solutions of ethanol can be produced when sugar solutions are fermented using yeast. The fermentation method is used to make alcoholic drinks. Fruit juices, such as grape juice, contain a source of sugar glucose (C6H12O6). When yeast is added it feeds on the sugar in the absence of oxygen to form wine (a solution of ethanol) and carbon dioxide.

A chemical reaction called fermentation takes place in which the glucose is broken down to ethanol by the action of enzymes in the yeast.

$$\underset{\text{Glucose (fermentable carbohydrate)}}{C_6H_{12}O_6} \xrightarrow{\text{Yeast Enzyme}} \underset{\text{Ethyl alcohol}}{2C_2H_5OH} + 2CO_2$$



Yeast is a single cell organism and a type of fungi. It contains the enzyme zymase which acts as a catalyst for the reaction. The juices of other fruits i.e. apples, plums, pears etc. can be fermented to produce wines of various flavours.

The fermentation reaction requires the following conditions:

Temperature – The temperature must be between the range of 25°C and 50°C. Enzymes are affected a great deal by temperature. If the temperature is too cold the enzymes move around too slowly to meet the substrate and for a reaction to occur. As the temperature increases though, so does the rate of reaction. This is because heat energy causes more collisions between the enzyme and the substrate. However, all enzymes are proteins and at too high temperatures the proteins break down. The active site of the enzyme becomes distorted and so the substrate no longer fits and hence the reaction does not occur, the enzyme is said to be denatured.

Substrate (the glucose solution) - Enzymes work best when there is a high enough substrate concentration for the reaction they catalyse. If too little substrate is available the rate of the reaction is slowed and cannot increase any further.

Absence of Oxygen – Air must be excluded from the vessel in which fermentation is being carried out. Air contains a large proportion of bacteria called Acetobacter. Acetobacter bacteria use atmospheric oxygen from air to oxidise ethanol in the wine, producing a weak solution of ethanoic acid (vinegar).

Yeast – the fermentation of the glucose solution to ethanol cannot take place without the presence of yeast. Yeast contains the enzyme zymase which acts as a catalyst for the reaction

Wine contains ethanol of a concentration up to about 14 -15%. This is because above this level the ethanol kills the yeast and fermentation stops.

Calorific values – Gross and bet calorific value

Combustion

In a combustion reaction a substance reacts with oxygen from the air and transfers energy to the surroundings as light and heat. A fuel is a combustible substance containing carbon as the main constituent which on proper burning gives large amount of heat that can be used economically for domestic and industrial purposes. During the process of combustion of a fuel, the atoms of carbon, hydrogen, etc combine with oxygen with simultaneous liberation of heat. The calorific value of a fuel depends mainly on the two elements.

$$C + O_2 \longrightarrow CO_2 + 94\text{kcals.}$$
$$2H_2 + O_2 \longrightarrow 2H_2O + 68.5\text{kcals.}$$

So, carbon compounds have been used for many centuries as the source of heat and energy.

The main source of fuel is coal and petroleum. These are stored fuels available in earth's crust and are generally called fossil fuels because they were formed from the fossilized remains of plants and animals.

Classification of Fuels

1. **Primary fuels** which occur in nature as such, e.g. coal, petroleum and naturalgas.
2. **Secondary fuels** which are **derived from the primary fuels**, e.g. coke, gasoline, coal gas,etc.

Both primary and secondary fuels may be further classified based upon their physical state as

(i) solid fuels (ii) liquid fuels and (iii) gaseous fuels.

Calorific values

The prime property of a fuel is its capacity to supply heat. Fuels essentially consist of carbon, hydrogen, oxygen and some hydrocarbons and the heat that a particular fuel can give is due to the oxidation of carbon and hydrogen. Normally when a combustible substances burns the total heat depends upon the quantity of fuel burnt, its nature, air supplied for combustion and certain other conditions governing the combustion. Further the heat produced is different for different fuels and is termed as its calorific value

Calorific value is defined as the amount of heat liberated when a unit mass of fuel is burnt completely in presence of air or oxygen.

There are different units for measuring the quantity of heat. They are;

1. Calorie:

It is the amount of heat required to increase the temperature of 1 gram or water through one degree centigrade.

2. Kilocalorie:

This is the unit of heat in metric system, and is defined as "the quantity of heat required to raise the temperature of one kilogram of water through one degree centigrade".

1 k.cal = 1000 cal

3. British thermal unit (B.Th.U.):

This is the unit of heat in English system. It is defined as "the quantity of heat required to increase the temperature of one pound of water through one degree Fahrenheit.

1 B.T.U. = 252 cal = 0.252 kcal

1 kcal = 3.968 B.T.U.

4. Centigrade heat unit (C.H.U.):

It is the quantity of heat required to raise the temperature of one pound of water through one degree centigrade.

Inter conversion of various units:

1 k.cal = 1000 cal = 3.968 B. Th. U. = 2.2 C.H.U

During the process of combustion of a fuel, the atoms of carbon, hydrogen, etc combine with oxygen with simultaneous liberation of heat. The calorific value of a fuel depends mainly on the two elements.

Calorific value is of two types as follows:-

1) Higher calorific value. (HCV) or Gross calorific value. (GCV)
2) Lower calorific value. (LCV) or Net calorific value. (NCV)

1) **HCV**: - **Higher or gross calorific value**: Usually, all fuels contain some hydrogen and when the calorific valueof hydrogen-containing fuel is determined experimentally, the hydrogen is converted into steam. If the products of combustion are condensed to the room temperature (15°C or 60°F), the latent heat of condensation of steam also gets included in the measured heat, which is then called "higher or gross calorificvalue".So,**grossorhighercalorificvalue(HCV)is"thetotalamountofheatproduced, when unit mass/volume of the fuel has been burnt completely and the products of combustion have been cooled to room temperature**"(i.e., 15°C or 60°F).
2) **<u>Lower or net calorific value (LCV)</u>**

In actual use of any fuel, the water vapour and moisture, etc., are not condensed and escape as such along-with hot combustion gases. Hence, a lesser amount of heat is available. So, **net or lower calorific value (LCV) is "the net heat produced, when unit mass /volume of the fuel is burnt completely and the products are permitted to escape**".

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Net calorific value = Gross calorific value - Latent heat of condensation of water vapour produced

= GCV - Mass of hydrogen per unit weight of the fuel burnt x 9 x Latent heatof condensation of watervapour

Dulong's formula for calorific value from the chemical composition of fuel is :

HCV = 1/100 [8,080 C + 34,500 (H – O/8)+ 2,240 S] kcal/kg where C, H, 0, and S are the percentages of carbon, hydrogen, oxygen and sulphur in the fuel respectively.Inthisformula,oxygenisassumedtobepresentincombinationwithhydrogenaswater,and

LCV = [HCV - 9H/100 x 587] kcal/kg = [HCV - 0.09 H x 587] kcal/kg

This is based on the fact that 1 part of H by mass gives 9 parts of H_2O, and latent heat of steam is 587 kcal/kg.

1. Higher (or) Gross calorific value (GCV)

2. Lower (or) Net Calorific Value (NCV)

When a fuel containing hydrogen is burnt, the hydrogen is converted into steam. If the combustion products are cooled to room temperature, the steam gets condensed into water and latent heat is evolved. Thus, the latent heat of condensation of steam is also included in gross calorific value.

NCV = GCV – Latent heat of condensation of water vapour produced.

= GCV – Mass of hydrogen × 9 × Latent heat of condensation of water vapour

1 part by weight of H2 produces 9 parts by weight of H2O as follows. The latent heat of steam is 587 cal/gm

HCV = GCV - 0.09H X 587

Where

H = % of H2 in the fuel.

THEORETICAL CALCULATION OF CALORIFIC VALUE

Dulong’s formula for the theoretical calculation of calorific value is

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

where C,H,O and S represent the % of the corresponding elements in the fuel.

It is based on the assumption that the calorific values of C, H and S are found to be 8080, 34500 and 2240 kcal, when 1 kg of the fuel is burnt completely.

However, all the oxygen in the fuel is assumed to be present in combination with hydrogen in the ratio H : O as 1:8 by weight

So the surplus hydrogen available for combustion is

H - O/8

$$\therefore \text{N C V (or) L C V} = \left[\text{HCV} - \frac{9}{100}\text{H X } 587\right] kcal/kg$$

Problems For the calculation of Calorific value

Problem:1

Calculate the gross and net calorific values of a coal sample having the following composition C = 80%; H = 7%;O = 3%; S = 3.5%; N = 2.5% and ash 4.4%

Solution

(I) G.C.V = 1/100[8080*%C+34500(%H - %O/8)+2240*%S] kcal/kg

= 1/100[8080*80+34500(7 - 3/8)+2240*3.5] kcal/kg

= 8828.0 kcal/kg

(II) N.C.V = G.C.V – [0.09H*587]kcal/kg

= 8828 – [0.09*7*587]kcal/kg

= 8458.2 k cal/kg

Problem:2

Calculate the gross and net calorific value of coal having the following composition carbon - 85%, hydrogen – 8%, sulphur – 1%, nitrogen – 2%, ash – 4%, latent heat of steam – 587 cals/g Solution:

Solution:

(I) G.C.V = 1/100[8080*%C+34500(%H - %O/8)+2240*%S] kcal/kg

GCV= 1/100[8080*85+34500*(8-0/8)+2240*1] Kcal/Kg

= 1/100[686800+276000+2240] Kcal/Kg

= 9650.4 Kcal/Kg

(II) N.C.V = G.C.V – [0.09H*587]kcal/kg

NCV= 9650.4 - 0.09*8*587

= 9227.76 Kcal/Kg

Fuel cells

Fuel cell is a class of devices that convert the chemical energy of a fuel directly into electricity by electrochemical reactions. A fuel cell resembles a battery in many respects, but it can supply electrical energy over a much longer period of time. This is because a fuel cell is continuously supplied with fuel and air (or oxygen) from an external source, whereas a battery contains only a limited amount of fuel material and oxidant that are depleted with use. For this reason fuel cells have been used for decades in space probes, satellites, and manned spacecraft.

- It is an electrochemical device which convert hydrogen and oxygen into water producing electricity and heat in the process.
- It is much like a battery that can be recharged while you are drawing power from it.
- It provides a DC voltage that can be used to power motors, lights and any number of electrical appliances.

Most of our current sources of energy are obtained from fossil fuels, such as coal, oil, and natural gas. Fuel cells are one type of alternative energy. Fuel cells offer several advantages over traditional energy sources, such as lower emissions of pollutants and greater efficiency.

- Fuel cell was first demonstrated by Welsh scientist Sir William Robert Grove in February 1839.

Why we need Fuel cell

- Due to energy crisis all over the world.
- Due to the issue of global warming.
- Due to the unavailability of different renewable sources at each and every place due to geographic condition.
- Fuel cell provides an alternate efficient non pollutingpowersource that produces no noise and has no moving parts.
- It is expected that by 2050 the global energy demand is going to rise by 2 to 3 times.
- This calls for optimization of generation of energy through well- known sources, preferably renewable energy for commercial exploitation

A fuel cell is a device that converts the chemical energy of a fuel (hydrogen, natural gas, methanol, gasoline, etc.) and an oxidant (air or oxygen) into electricity.

Eg. H_2-O_2 fuel cell, Methanol-O_2 fuel cell

Every fuel cell has two electrodes, one positive and one negative, called, respectively, the cathode and anode. The reactions that produce electricity take place at the electrodes. It also has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes. Hydrogen is the basic fuel, but fuel cells also require oxygen. One great appeal of fuel cells is that they generate electricity with very little pollution, much of the hydrogen and oxygen used in generating electricity ultimately combine to form a harmless byproduct, namely water.

In principle, a fuel cell operates like a battery. Unlike a battery however, a fuel cell does not run down or require recharging. It will produce electricity and heat as long as fuel and an oxidizer are supplied.

H_2-O_2 Fuel cell

Construction

Fuel cell construction generally consists of a fuel electrode (anode) and an oxidant electrode (cathode) separated by an ion-conducting membrane. Oxygen passes over one electrode, and hydrogen over the other, generating electricity, water and heat. Fuel cells chemically combine the molecules of a fuel and oxidizer without burning or having to dispense with the inefficiencies and pollution of traditional combustion.

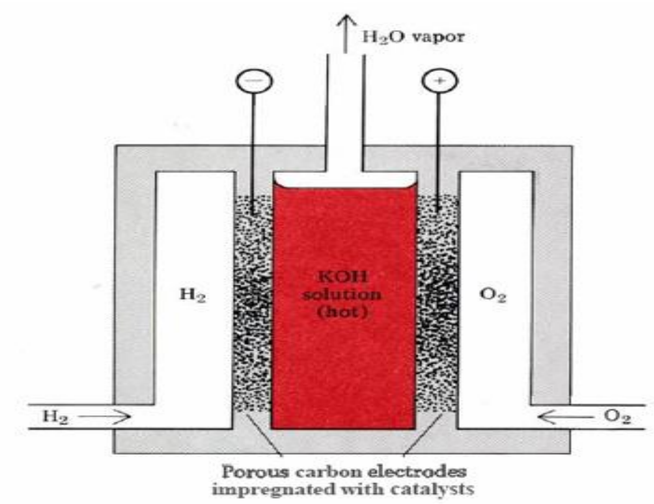


Fig. Hydrogen Oxygen fuel cell

Working

At the anode, hydrogen and its electrons are separated so that the hydrogen ions (protons) pass through the electrolyte while the electrons pass through an external electrical circuit as a Direct Current (DC) that can power useful devices. The hydrogen ions combine with the oxygen at the cathode and are recombined with the electrons to form water. The reactions are shown below.

Anode Reaction : $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode Reaction : $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Overall Cell Reaction : $2H_2 + O_2 \rightarrow 2H_2O$

Advantages:

1. They do not store chemical energy; (ie) Production of electricity from the reactants isa continuous process
2. It has more efficiency than rechargeable batteries.
3. Fuel cells are free from pollution.
4. Water is the by-product.

Disadvantages:

1. Storage of current is not possible
2. Poor battery voltage
3.It's electrodes and catalysis were costly
4. It cannot be used for commercial applications

Application:

It is used as a drinking water for astronauts.

Methanol-oxygen fuel cell

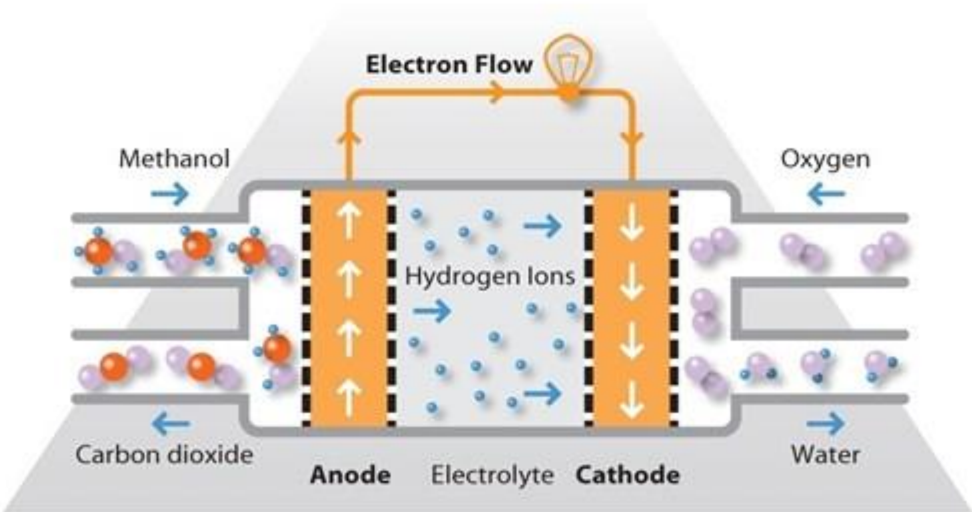
Methanol- a better substitute for hydrogen in fuel cell.

- Energy density: Methanol: 4.8 Wh/cm^3
- Hydrogen: 2.7 Wh/cm3
- Easy transportation and handling
- Readily available, relatively lesser cost
- Stable at all atmospheric conditions
- Environmental Concerns

It was invented and developed in the 1990s by researchers at several institutions in the United States, including NASA. Methanol oxygen fuel cell is a relatively recent addition to the suite of fuel cell technologies; it was invented and developed in the 1990s by researchers at several institutions in the United States, including NASA and the Jet Propulsion Laboratory. Methanol offers several advantages as a fuel. It is inexpensive but has a relatively high energy density and can be easily transported and stored. It can be supplied to the fuel cell unit from a liquid reservoir which can be kept topped up, or in cartridges which can be quickly changed out when spent.

Construction

- It consists of anodic and cathodic compartment having platinum electrodes
- Methanol containing H_2SO_4 is passed through anodic compartment
- Electrolyte: Sulphuric acid
- A membrane is provided which prevents the diffusion of methanol into cathode



Chemical equation -

- liquid electrode (anode)

$$CH_3OH + H_2O \longrightarrow CO_2 + 6H^+ + 6e^-$$

- Tube electrode (cathode)

$$6H^+ + 6e^- + \frac{1}{2}O_2 \longrightarrow 3H_2O$$

Net reaction -

$$CH_3OH + \frac{3}{2}O_2 \longrightarrow CO_2 + 2H_2O$$

Advantages

- Methanol is electrochemically active at ambient condition

- Methanol is inexpensive as a fuel and does not require definite purification or storage
- It can be produced from petroleum sources
- Simplicity of design of fuel cell
- large availability of Methanol
- Easy handling and distribution

Disadvantages

- Inherent losses occurs due to the moving of parts and mechanical failure
- There will be catastrophic failure of the total system, if there is one pinhole leaking the membrane between O2 and H2
- Methanol is very toxic and highly flammable
- Low activity of catalysts for methanol oxidation and oxygen reduction
- Low performance by methanol crossover

Applications

- It is used in space to provide water and electric current that is required for the astronaut
- Military applications are an emerging application since they have low noise and thermal signatures and no toxic effluent.
- These applications include power for man-portable tactical equipment, battery chargers, and autonomous power for test and training instrumentation.

Solid oxide fuel cell

Solid oxide fuel cell (SOFC) is an electrochemical device operating at a high temperature, converting the chemical energy of a fuel directly to electrical energy.

- Solid oxide fuel cell (SOFC) is considered a promising clean technology for power generation.
- It can convert chemical energy in fuel directly into electricity and heat, thereby resulting in high efficiency and low air pollution over conventional internal combustion engines.

- A solid oxide fuel cell (or SOFC) is an electrochemical conversion device that produces electricity directly from oxidizing a fuel
- Fuel cells are characterized by their electrolyte material; the SOFC has a **solid oxide or ceramic electrolyte**
- Solid oxide fuel cells work at very high temperatures, the highest of all the fuel cell types at around **800°C to 1,000°C.**
- They can have efficiencies of over **60%** when converting fuel to electricity; if the heat they produced is also harnessed; their overall efficiency in converting fuel to energy can be over 80%.

Construction

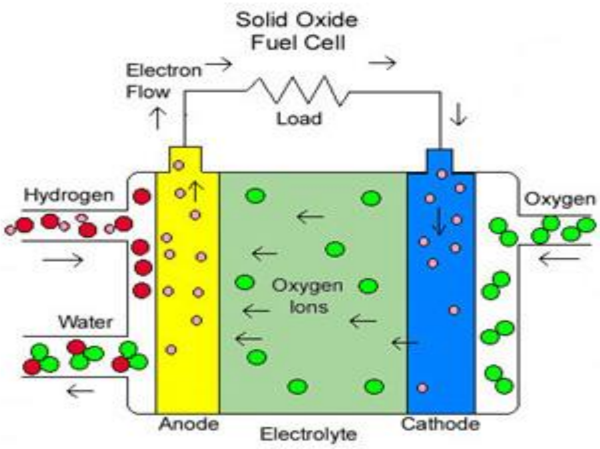
Anode: It is a porous electrode coated with Co and ZrO_2

Cathode: It contains La MnO_3 doped with strontium.

Electrolyte: Zirconia (ZrO_2) doped with about 10 mol% of Yttria (Y_2O_3). Precaution should be taken while using completely non – porous solid oxide as the electrolyte.

The ceramic anode layer must be very porous to allow the fuel to flow towards the electrolyte; consequently, granular matter is often selected for anode fabrication procedures.The cathode is a thin porous layer on the electrolyte where oxygen reduction takes place.

The electrolyte is a dense layer of ceramic that conducts oxygen ions. Its electronic conductivity must be kept as low as possible to prevent losses from leakage currents.



The fuel used here is H_2 or CO

The cell reactions are as follows: (H_2 is used as a fuel)

Anode: $H_2 + O^{2-} \rightarrow H_2O + 2e^-$

Cathode: $\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$

The overall cell reaction: $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

Efficiency is about 60 percent, and operating temperatures are about 1,000 °C (about 1,800 °F). Cells output is up to 100 kW. At such high temperatures a reformer is not required to extract hydrogen from the fuel, and waste heat can be recycled to make additional electricity. However, the high temperature limits applications of SOFC units and they tend to be rather large. While solid electrolytes cannot leak, they can crack.

Their high operating temperature means that fuels can be reformed within the fuel cell itself, eliminating the need for external reforming and allowing the units to be used with a variety of hydrocarbon fuels. They are also relatively resistant to small quantities of sulphur in the fuel, compared to other types of fuel cell, and can hence be used with coal gas.

A**dvantages**:

- Since all the components are solid, as a result, there is no need for electrolyte loss maintenance and also electrode corrosion is eliminated

- high combined heat and power efficiency,
- long-term stability, **fuel** flexibility,
- low emissions, and relatively low cost.
- Releasing negligible pollution is also a commendable reason

Disadvantages:

- high operating temperature which results in longer start-up times
- mechanical and chemical compatibility issues
- The relatively high cost and complex fabrication are also significant problems that need to be solved

Applications:

- It can be adopted ranges from small portable and Military applications to large megawatt class stationary applications
- SOFC are flexible, which makes them a preferred technology for installation with existing infrastructure such as gas pipelines
- SOFC are being targeted for use in powerand heat generation for homes and businesses as well as auxiliary power units for electrical systems in vehicles
- SOFC also can be linked with a gas turbine, in which the hot, high pressure exhaust of the fuel cell can be used to spin the turbine, generating a second source of electricity