FUEL

Definition:

Whenever a substance is burnt in air or oxygen with the evolution of heat, the process is called combustion and the substance which is burnt is called combustible substance. In the process of combustion, the chemical energy of fuel is converted into heat energy and light energy.

The heat evolved during combustion can be used for household purposes or economically for industrial purposes. All combustible substances which contain carbon as the main constituent are called fuels. Thus fuel can be defined as any combustible substance, containing carbon as the main constituent which on proper burning produces heat that can be used economically for domestic and industrial purposes and in the generation of power.

$$\text{Fuel} + O_2 \longrightarrow \text{Products} + CO_2 + \text{Heat}$$

Classification:

The fuels are broadly classified in two ways, depending on the state of matter

1. Primary Fuels: These include the naturally occurring fuels that are found free on the earth's crust. These are classified as
   i. Solid fuels for eg wood, peat, lignite, coal etc
   ii. Liquid Fuels for eg. Petroleum, crude oil etc.
   iii. Gaseous Fuels like natural gas etc.
2. Secondary or Derived Fuels: These are artificially derived or manufactured from primary fuels. These are further classified into
   i. Solid fuels for eg coke, charcoal, petroleum coke, pulverized coal etc.
   ii. Liquid Fuels for eg. Gasoline, diesel oil, kerosene, coal tar, LPG, alcohol etc.
   iii. Gaseous Fuels like coal gas, water gas, biogas, blast furnace gas etc.

Natural Fuels	Manufactured Fuels
Solid Fuels	
Wood Coal Oil shale	Tanbark, Bagasse, Straw Charcoal Coke Briquettes
Liquid Fuels	
Petroleum	Oils from distillation of petroleum Coal tar Shale-oil Alcohols, etc.
Gaseous Fuels	
Natural gas	Coal gas Producer gas Water gas Hydrogen Acetylene Blast furnace gas Oil gas

Characteristics of a good fuel

While selecting an ideal fuel for domestic or industrial purpose we should keep in mind that the fuel selected must possess the following characteristic properties.

1. It should possess high calorific value.
2. It should have low moisture content as moisture reduces the heating value of fuel
3. It should have low non-combustible substance as its presence reduces heating value and produces more ash
4. It should have proper ignition temperature. The ignition temperature of the fuel should neither be too low nor too high. Very low ignition temperature is harmful for storage and transport while high ignition temperature causes difficulty in igniting the fuel.
5. It should be easy to handle, store and transport.
6. It should not produce poisonous products during combustion. In other words, it should not cause pollution.
7. It should burn with more efficiency and less smoke.
8. It should be easily available in plenty.
9. It should be cheap.
10. It should have moderate rate of combustion.
11. Combustion should be easily controllable i.e., combustion of fuel should be easy to start or stop as and when required.

Relative Merits of Solid, Liquid and Gaseous Fuels

Fuel Characteristics	Solid Fuels	Liquid Fuels	Gaseous Fuels
1. Calorific Value	least	higher	highest
2. Cost	cheap	Costly than solid fuels	costliest
3. smoke	Is produced	Is produced from higher carbon and aromatic components but burning is clean	Is not produced
4. ash	Always produced	Not produced	Not produced
4. environmentally friendly	no	no	yes
5. storage	easy	Should be stored in closed containers	Must be stored in closed containers
6. handling cost	high	low	low
7. safety	highest	least	least
8.Ignition temperature	high	low	least

Calorific Value of a Fuel

It is defined as the amount of heat produced by the complete combustion of a given mass of a fuel, usually expressed in joules per kilogram. It is expressed in two forms:

Gross Calorific Value (GCV) or High Calorific Value (HCV):

It is the total amount of heat generated when a unit mass of fuel is completely burnt and the products of combustion are allowed to cool down to room temperature.

When a fuel containing hydrogen is burnt, the hydrogen present in fuel produces steam. If the products of combustion are allowed to cool to room temperature, the latent heat of condensation of steam gets included in the measured heat. This is called the gross calorific value (GCV)

Net Calorific Value (NCV) or Low Calorific value (LCV)

It is the net amount of heat produced when unit mass of fuel is completely burnt and the products are allowed to escape.

Net Calorific Value = Gross Calorific Value – Latent heat of condensation of steam

= Gross Calorific Value – Latent heat of vaporization of water vapor

= Gross Calorific Value – (Mass of hydrogen per unit weight of fuel burnt x 9/100 x Latent heat of vaporization of water vapor)

For the reaction;

$$\begin{array}{lcl} H_2 + \ - O_2 & \longrightarrow & H_2O \\ 2g & & 18g \\ 1g & & 9g \end{array}$$

One part by weight of hydrogen gives nine parts by weight of H_2O.

Let H% be the hydrogen content in a fuel.

Thus 1 g of fuel contains H/100 g of H_2

H/100 g of H_2 will produce 9*H/100 g of H_2O (because 1g of H_2 produces 9g of H_2O)

=0.09H*(latent heat of steam) =0.09H*587 cal/g

Latent heat of steam = 587cal/g of water vapor produced.

Thus,

$$\boxed{\begin{array}{l}\textbf{NCV = HCV – 0.09 x H x 587} \\ \textbf{where H = mass of hydrogen in fuel}\end{array}}$$

Units of calorific value of fuel:

Calorific values of solid and liquid are expressed in Calories/g (cal/g) or kilocalories/kg (kcal/kg) or British Thermal unit/pound (BTU/lb)

Calorific values of gaseous fuels are expressed in kilocalories/m^3 kg (kcal/m^3) or British Thermal unit/ft^3 (BTU/ ft^3)

Determination of Calorific Value (Bomb calorimeter)

The gross calorific value of solid and liquid fuels is determined by Bomb Calorimeter.

Principle: A known unit mass of fuel is burnt completely and the quantity of heat produced is absorbed in water and measured. Then the quantity of heat produced by burning unit mass of fuel is calculated. According to principle of calorimetry, heat liberated by fuel = heat absorbed by water, apparatus.

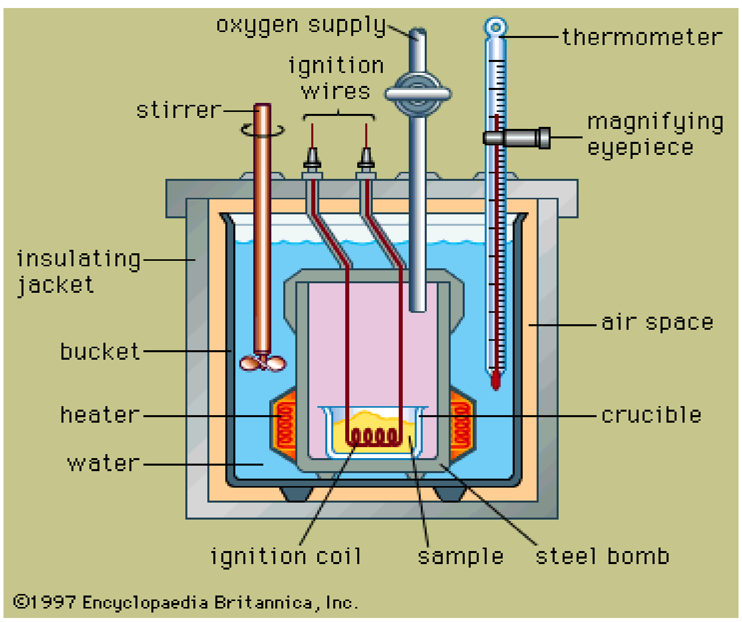
Construction: It consists of the following parts:

1. A strong cylindrical bomb made of stainless steel, resistant to corrosion and capable of withstanding high pressure up to 50 atmospheres. It is provided with a lid which can be

screwed firmly to the bomb. The lid is provided with two electrodes and an oxygen inlet valve. A small ring is attached to one of the electrodes which act as a support for the crucible.

2. A copper calorimeter vessel is used which contains a known weight of water and in which the bomb is placed.
3. The calorimeter is surrounded by an air jacket and a air jacket to prevent loss of heat due to radiation.
4. The calorimeter is provided with an electrical stirrer for stirring water and a Beckman Thermometer to measure temperature.
5. The crucible in which the sample is kept is made of stainless steel or fused silica

Design of Bomb Calorimeter:
The design of a typical bomb calorimeter is shown in the picture below:



A Bomb Calorimeter

Working:
A weighed amount of sample (fuel) is placed in the silica crucible supported over the ring. A fine magnesium wire touching the sample of the fuel is stretched across the electrodes. About 10mL of distilled water is introduced into the bomb to absorb vapors of sulphuric acid and nitric caid formed during the combustion. Oxygen supply is forced into the bomb to a pressure of 25-30 atmosphere. The bomb is then carefully placed in the calorimetric vessel containing a known

amount of water. Water is stirred with the stirrer and temperature is recorded. The electrodes are connected to a battery and the circuit is completed. The combustion of fuel takes place with the evolution of heat. The heat produced by burning is transferred to water which is stirred throughout the experiment with the stirrer. Maximum temperature is recorded and the gross calorific value is calculated as follows;

Let x = mass of fuel sample taken in crucible (g)

W = mass of water in the calorimeter (g)

w = water equivalent of calorimeter, stirrer, bomb, thermometer etc (g)

= mass x specific heat of apparatus = W' x S

T1 = initial temperature of water in calorimeter (°C)

T2 = final temperature of water in calorimeter (°C)

L = Gross Calorific Value of fuel (cal/g)

S = specific heat

Heat liberated by burning of fuel = xL cal

Heat absorbed by water = [W x S x (T2-T1)] cal

Heat absorbed by apparatus = [W' x S x (T2-T1)] cal = w(T2-T1) cal

Specific heat of water = 1 cal/g°C and 1 cal = 4.2J

Therefore, total heat absorbed by water, apparatus =

[W x 1 x (T2-T1) + w x 1 x (T2-T1)] = [(W+w) x 1 x (T2-T1)] cal

According to principle of calorimetry, heat liberated by fuel = heat absorbed by water, apparatus

xL = [(W+w)(T2-T1)]

L = Gross calorific value of fuel = HCV = GCV = $\frac{(W+w)(T2-T1)}{x}$ **cal/g**

LCV = Low calorific value = (HCV – 0.09 H x 587) cal/g

<u>Corrections</u>

Accurate reading of calorific value requires the following corrections:

1. Fuse wire Correction: The heat liberated as GCV includes the heat given out by ignition of the fuse wire used. Hence it must be subtracted from total value.

2. Acid Correction: Fuels containing S and n are oxidized during combustion producing H_2SO_4 and HNO_3 respectively. Such reactions are exothermic and hence the measured heat includes the heat given out during the acid formation. Such heat is subtracted from total value.
3. Cooling correction: Time is required to cool the water in the calorimeter from maximum temperature to room temperature is noted. This time is recorded and the cooling correction is calculated by multiplying it by rate of cooling. The cooling correction is then added to rise in temperature.
4. Cotton Thread correction: As the cotton thread is used for igniting the fuel, its burning thus liberates heat which is then subtracted from total heat.

Gross calorific Value = GCV =

$$\frac{(W+w)(\Delta T+cooling\ corection)-(acid\ correction+fuse\ wire\ correction+\text{Cotton correction}}{weight\ of\ fuel}$$

Advantage of liquid Fuels:

1. They have higher calorific value than solid fuels.
2. They burn without ash, smoke
3. They are easy to transport, store and handle.
4. They can be easily used in internal combustion engines.
5. Liquid fuels can be easily kindled. Combustion can be started and stopped at once.

Conventional source of energy

The energy sources which cannot be compensated, once these are used (after their exploitation) are termed as conventional energy sources. Examples are coal, wood, petroleum, natural gas and nuclear energy.

Non-Conventional source of energy

The conventional energy sources discussed above are exhaustible and, in some cases, installation of plants to get energy is highly expensive. In order to meet the energy demand of increased population, the scientists developed alternate nonconventional natural Resources sources of energy which should be renewable and provide a pollution free environment.

Some examples of non-conventional source of energy are

1. solar energy
2. wind energy
3. tidal energy
4. geo-thermal energy
5. Biomass based energy
6. Biogas
7. Bagasse based plants
8. energy from urban waste (sewage and municipal solid waste)

Liquefied Petroleum gas (LPG) is a liquid fuel naturally derived from crude oil and natural gas. About 60% of the world's LPG is obtained from natural gas, and the remaining 40% is achieved from refining crude oil. When natural gas is pulled from the ground, the resulting hydrocarbon is a mix of several gases and liquids. About 90% of what is recovered is methane, or natural gas. The other 10% is made up of propane, butane and ethane -- or LPG.

LPG used for cooking purpose is made up of Propane and Butane, or a combination of the two. It is labeled as "liquefied gas" because LPG is very easily converted to a liquid state. LPG requires only slight pressure or refrigeration to transform it from its natural gaseous state into a liquid. As a gas, LPG occupies 274 times its volume as a liquid, making the liquid state much preferred for transportation and storage.

LPG is considered a clean-burning fossil fuel. This is because LPG burns completely, leaving no waste and emitting significantly less pollutants into the environment than other hydrocarbons.

Easily stored in massive tanks, LPG is many times used as a fuel source in remote areas where obtaining other products via pipeline or transport would be impossible.

Compressed natural gas (**CNG**) is a gaseous fuel which can be used in place of petrol, diesel and LPG. Its composition is methane and is compressed to less than 1% of the volume that it occupies at standard atmospheric pressure. CNG is stored in cylindrical or spherical containers at very high pressure of 20–25 MPa.

Advantages of CNG

1. Combustion of CNG produces fewer undesirable gases (e.g., carbon dioxide (CO_2), unburned hydrocarbons (UHC), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x) and PM (particulate matter) than the petroleum derived fuels. Due to lower carbon dioxide emissions, switching to CNG can help reduce greenhouse gas emissions and hence is environmentally safe.
2. It is safer than other fuels in the event of a leak or spill, because CNG is lighter than air and disperses quickly when released.
3. Being a gaseous fuel, its calorific value is higher as compared to liquid or solid fuels. Hence its efficiency as a fuel is higher.
4. CNG does not contain lead and does not react with metals; hence the maintenance cost of engines of transportation vehicles is increased.

Disadvantage of CNG

The drawback is that being a gaseous fuel, CNG occupies greater amount of space for fuel storage than liquid fuels like petrol, diesel or conventional gasoline

Biomass and Bioenergy

Biomass—renewable energy from plants and animals

Biomass is organic material that comes from plants and animals, 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.

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

Biogas

Biogas is produced by the degradation of organic matter by the action of bacteria or fungi in the absence of oxygen (anaerobic). The cheapest and easily obtainable biogas is obtained from cattle dung and is known as gobar gas.

The process of formation of gobal gas is carried out in steel chambers placed above or below the ground into which a slurry made by mixing equal parts of fresh cattle dung and water is poured. Anaerobic bacteria present in the dung digests this sludge generating carbon dioxide and methane. The optimum temperature for fermentation is 34-48°C. The gas generated is collected in a steel gas holder placed on top of the digestion tank.

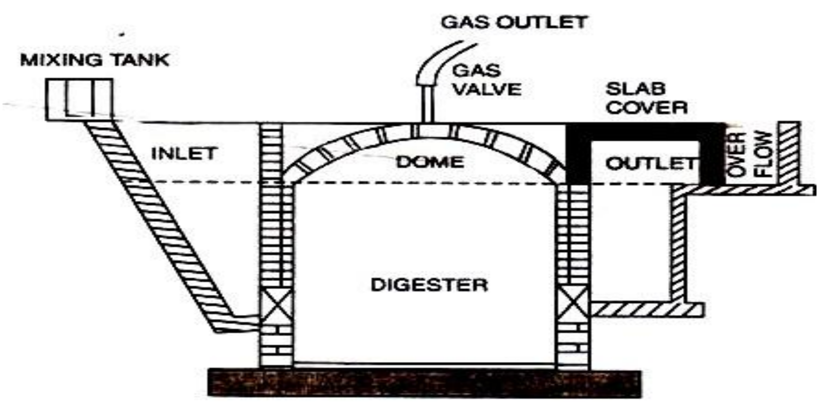


FIG. 4.3 : FIXED DOME TYPE BIOGAS PLANT

The average composition of the gobar gas is

CH_4 = 55%, H_2 = 7.4%, CO_2 = 35%, N_2 = 2.6% and traces of H_2S

Its gross calorific value = 1200kcal/m^3.

Advantages of Gobar Gas:

1. It has been found that 4.25kg of fresh cow dung (1 kg of dry cow dung) gives 160L of gobar gas which can supply 188kcal of heat. On the other hand 1kg of dry dung on direct heating gives 23.4kcal of effective heat. Thus gobar gas production is very economical.
2. The gas has all advantages of gaseous fuel like flexibility, optimum utilization, of waste, cleanliness, absence of dust, smoke, dirt etc.
3. It does not emit poisonous gas like CO.
4. It provides flame temperature of 540°C
5. Gobar gas simultaneously produces excellent yield of manure (N_2 content is 2% as farm manure which is 0.75%)

Limitation of Gobar gas: The gas stove or burner needs to be placed around 10m of the plant

<u>Numerical on Calorific Value</u>

1. On burning 0.83g of a solid fuel in a Bomb Calorimeter, the temperature of water (3500g) inside the calorimeter increased from 25.5˚C to 29.2˚C. Water equivalent of calorimeter and latent heat of steam are 385g and 587cal/g respectively. If the fuel contains 0.7% H, calculate the GCV and NCV of the fuel?

   ans:

   GCV= (3500+385)(29.2-25.5°C)/0.83 = 17,318.6 cal/g

   NCV = 17318.6-(0.09*587*0.7) = 17318.6-36.981 = 17,281.6 cal/g
2. A sample of coal containing 89%C, 8%H and 3% ash. When this coal was tested in the laboratory for its Calorific value in the Bomb Calorimeter, the following data was obtained.

   Weight of coal burnt = 0.85g

   Weight of water = 650g

   Water equivalent of bomb calorimeter = 2500g

   Rise in temp= 2.5˚C

   Cooling Correction = 0.03˚C

   Fuse wire Correction = 10 calories

   Acid Correction = 50 Calories

   Assuming the latent heat of condensation of steam = 580 cal/g

   Calculate the GCV and LCV of coal in cal/g

   ans:

   GCV = [(650+2500)(2.5+0.03) –(10+50)]/0.85 = 9305.29 cal/g

   LCV = 9305.29 – (0.09*8*580) = 9305.29-417.6 = 8887.69 cal/g
3. Calculate LCV of a fuel which has 8.9% hydrogen and its HCV is 6500 cal/g (given latent heat of steam =580 cal/g).

   ans:

   LCV = 6500 – (0.09*8.9*580) = 6500 – (464.58) = 6035.42 cal/g
4. A 0.80g of sample of solid fuel was completely combusted in excess of oxygen using bomb calorimeter. The rise in temperature of water in calorimeter was 2.5°C. Calculate the High Calorific value of the fuel, if water taken in calorimeter is 2000g and water equivalent of calorimeter is 2200g. Also calculate Low calorific value (given % hydrogen in fuel = 2.2)

   ans:

   HCV = (2000+2200)(2.5)/0.80 = 13,125 cal/g

   LCV = 13125- (0.09*2.2*580) = 13125 – 114.84 = 13010.16 cal/g
5. 0.72 g of fuel containing 80% carbon when burnt in a bomb calorimeter increased the temperature of water from 27.3°C to 29.1°C. If the calorimeter contains 250g of water and if its water equivalent is 150g, Calculate the HCV of fuel.

   Ans: HCV = (250+150)(1.8)/0.72 = 1000 cal/g