UNIT-III

FUEL

A fuel is any combustible substance that containing carbon as the main constituent which on proper burning gives large amount of heat that can be used economically.

OR

A substance used to produce energy is called fuel.

eg. Kerosene, wood, petrol, coal, diesel and water gas.

Combustion is a high-temperature exothermic chemical reaction in which substance combines with oxygen producing heat, light and flame.

Combustion reaction of fuel can be represented as fallows

$$C_nH_{2n+2} \longrightarrow CO_2(g) + H_2O(g) + heat$$

Fig. Fuel

Calorific value:

Calorific value of fuel is the total quantity of heat liberated when one unit of fuel is burnt completely.

OR

Total amount of heat liberated when unit mass or unit volume of a fuel is completely burnt in presence of excess supply of oxygen.

Gross calorific value (G.C.V) or higher calorific value (H.C.V):

It is total quantity of heat liberated when one unit of fuel is burnt completely and the product of combustion has been cooled to room temperature. It is also called higher calorific value (H.C.V).

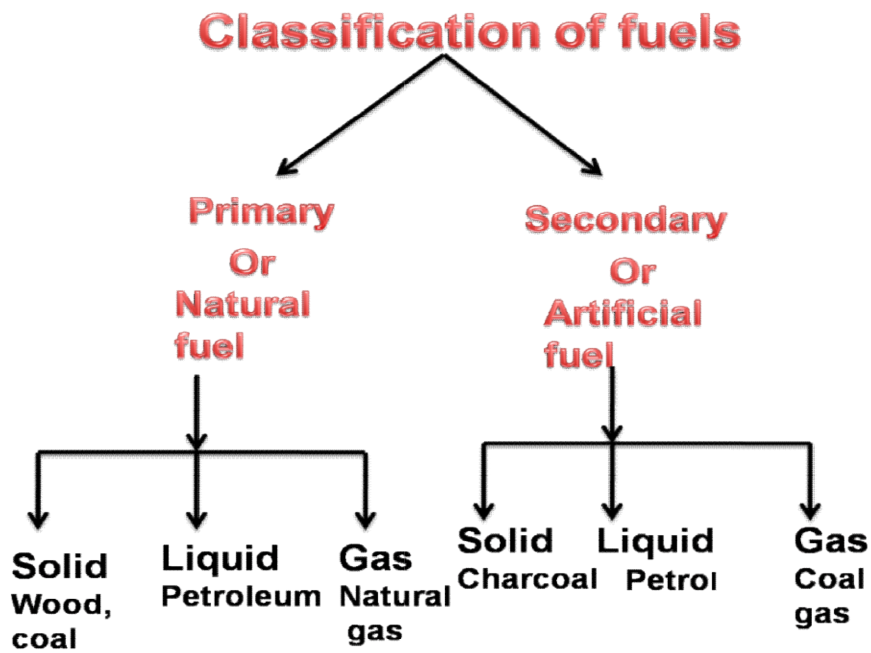
Net calorific value (N.C.V) or Lower calorific value (L.C.V):

It is total quantity of heat liberated when one unit of fuel is burnt completely and the product of combustion has been permitted to escape. It is also called Lower calorific value (L.C.V).

Characteristics of good fuel:

A Good fuel should have

- It should possess high calorific value.
- It should have proper ignition temperature. The ignition temperature of the fuel should neither be too low nor too high.
- It should not produce poisonous products during combustion. In other words, it should not cause pollution o combustion.
- It should have moderate rate of combustion.
- Combustion should be easily controllable i.e., combustion of fuel should be easy to start or stop as and when required.
- It should not leave behind much ash on combustion.
- It should be easily available in plenty.
- It should have low moisture content.
- It should be cheap.
- It should be easy to handle and transport.



Primary fuels are found in nature whereas secondary fuels are prepared from Primary fuel by processing them in a number of ways.

Fuels

Fuels are two types:

- Natural or Primary fuels
- Artificial or Secondary fuels

Natural or Primary fuels:

Those fuels which occur naturally are called natural or primary fuels e.g wood, coal, petroleum, natural gas. These are further classified as

- Solid fuels, e.g., coal, wood, cattle dung etc.
- Liquid fuels, e.g., crude oil, petroleum etc.
- Gaseous fuels, e.g., natural gas

Artificial or Secondary fuels:

- Solid fuels, e.g., coke, charcoal, coal etc.
- Liquid fuels, e.g., tar, kerosene, diesel, petrol, gasoline etc.
- Gaseous fuels, e.g., coal gas, water gas, oil gas etc.

Comparison between Solid, Liquid and Gaseous fuels

Solid fuels

Advantages:

- They are easy to transport.
- They are easy to store without any hazard of spontaneous explosion.
- Cost of production of solid fuels is low.

- They posses moderate ignition temperature.

Disadvantages

- Their ash content is high.
- Their thermal efficiency is low, because large part of heat energy is wasted during combustion.
- Cost of handling is high.
- Calorific value is low.

Liquid fuels

Advantages:

- They burn without forming dust, ash etc.
- They posses high calorific value per unit mass than solid fuels.
- They easy to transport through pipes.
- They can be stored without any loss.
- They require less excess of air for complete combustion
- It can be use as internal combustion fuels.

Disadvantages:

- The cost of liquid fuel is much relatively higher as compared to solid fuels.

- There is a greater risk of fire hazards, particularly in case of a highly inflammable and volatile liquid fuel.
- Choking of sprayers (during liquid fuel combustion) is drawback of oil firing.
- Specially constructed burners and spraying apparatus are required.

Gaseous fuels

Advantages:

- They have high heat content.
- They can be conveyed easily through pipelines to actual place of requirement, there by minimum labour cost in transportation.
- They do not require any special burners.
- They have high calorific value.
- They burn in slight excess of air supply.

Disadvantages:

- Large storage tank are required for them.
- They are most costly as compared to solid and liquid fuels.

- They are highly inflammable, so chances of fire hazards are high in their use.

QUESITIONS

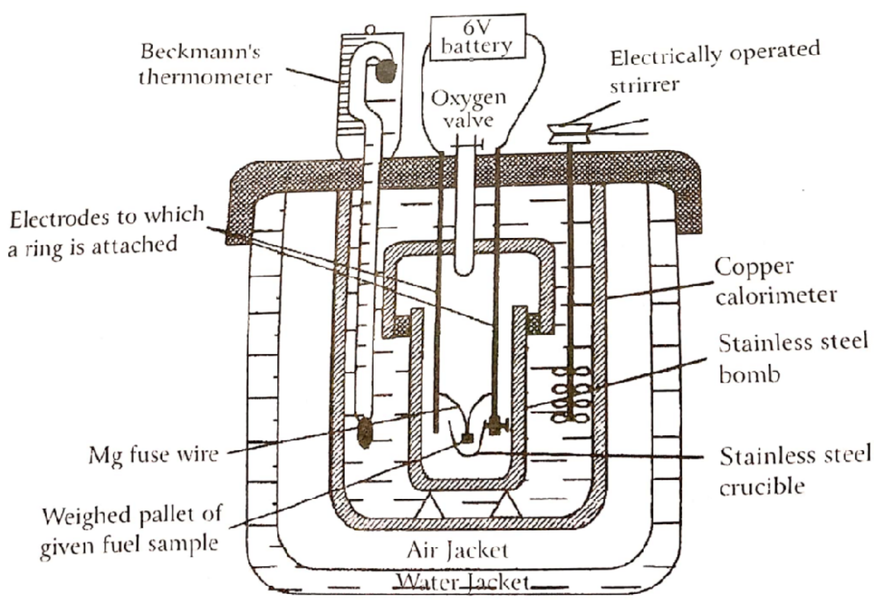
1) What is the difference between gross and net calorific value?
2) When 0.94g of a fuel burnt completely in excess of oxygen the rise in temperature of water in a calorimeter containing 1400g of water was 2.5^0C.Calculate the H.C.V. of the fuel if the water equivalent of calorimeter, etc.,is 150g.
3) What are the characteristics of good fuel?
4) What are the types of fuels?
5) What is advantage and disadvantage of liquid fuels?

Determination of Calorific Value Using Bomb Calorimeter

Bomb calorimeter is used to find the calorific value of solid and liquid fuels.

Bomb Calorimeter

A bomb calorimeter consists of a stainless steel strong cylindrical bomb in which the combustion of fuel takes place. The bomb is covered by a lid, which can be screwed to the body of the bomb so as to make a perfect gas-tight seal. The lid of the bomb is provided with two stainless steel electrodes and an oxygen inlet valve. A small ring is attached to one of the electrodes. This ring supports a nickel or stainless steel crucible. The bomb is placed in copper calorimeters, which is surrounded by an air-jacket and water-jacket to prevent heat losses due to radiation. The copper calorimeter is provided with an electrically operated stirrer and Beckmann's thermometer. Beckmann's thermometer is graduated in $1/100^{th}$ of a degree. It can read accurately temperature difference upto $1/100^{th}$ of a degree.



Bomb calorimeter

Working: A known weight (about 0.5 to 1.0 g) of the given fuel is taken in the clean crucible supported over the ring. A fine wire of magnesium, touching the fuel sample, is then stretched across the electrodes. The bomb lid is tightly screwed and bomb filled with oxygen to 30 atmospheric pressures. The bomb is then lowered into calorimeter, containing a known weight of water. After through stirring, the initial temperature of water is noted. The electrodes are then connected to a battery of 6V and circuit is completed. The sample burns and heat is liberated which is transferred to water. Uniform stirring of water is continued and the maximum temperature attained is noted. The calorific value of the given fuel can be calculated as:

Calculation

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

W = mass of water in the copper calorimeter

w = water equivalent in g of calorimeter, stirrer, thermometer, bomb etc;

t_1 = initial temperature of water in calorimeter

t_2 = final temperature of water in calorimeter

L = Gross calorific value of fuel in cal/g

So, Heat liberated by burning of fuel = $x\,L$

Heat absorbed by water = $[W \times S \times (T_2\text{-}T_1)]$

And Heat absorbed by apparatus = $[W' \times S \times (T_2\text{-}T_1)] = w\,(T_2\text{-}T_1)$

Now, total heat absorbed by water, apparatus, etc. = $(W + w)\,(t_2\text{-}t_1)$

But heat liberated by the fuel = Heat absorbed by water, apparatus, etc.

$$x\,L = (W + w)\,(t_2\text{-}t_1)$$

or H.C.V. of fuel (L) = $(W + w)\,(t_2\text{-}t_1) \div x$ cal/g (or kcal/g)

Note : The water equivalent of the copper calorimeter is determined by burning a fuel of known calorific value such as benzoic acid (H.C.V. = 6,325 kcal/kg) and naphthalene (H.C.V. = 9,688 kcal/kg).

Let H = % of hydrogen in fuel, then:

$1 \times \frac{H}{100}$ g = g of hydrogen present in 1 g fuel.

As all fuels contain some hydrogen and when the calorific value of hydrogen containing fuel is determined experimentally, hydrogen is converted into steam according to

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

Weight of H_2O produced from $\frac{H}{100}$ g H_2 (or 1 g fuel) $\frac{9H}{100}$ g = 0.09 Hg

So, Heat taken by H_2O in forming steam = 0.09 H × 587 cal (latent heat of steam = 587 cal/g)

So, L.C.V. = H.C.V. – Latent heat of water vapour formed

or, L.C.V. = (H.C.V. – 0.09 H × 587) cal/g

Corrections

- ✓ **Cotton Thread Correction** is made by the mass of the dry cotton thread used for firing.
- ✓ **Fuse Wire Correction:** The heat liberated during the determination of calorific value, includes the heat given out by ignition of the fuse wire used. Hence, it must be subtracted from the total value.
- ✓ **Acid Correction:** The fuels containing S and N are oxidized, under high pressure and temperature of ignition, of sulphuric acid and nitric acid respectively.

$$S + H_2 + 2O_2 \longrightarrow H_2SO_4 + \text{heat}$$
$$2N + H_2 + 3O_2 \longrightarrow 2HNO_3 + \text{heat}$$

The above reactions are exothermic in nature. Thus, the measured amount of heat also includes the heat given out during the acid formation. The amount of H_2SO_4 alone is determined by the precipitation (as $BaSO_4$) while the amount of these acids is analysed from washing of bomb by titration.

The correction for each ml of $\frac{N}{10}$ H_2SO_4 and $\frac{N}{10}$ HNO_3, 3.6 and 1.43 cal respectively must be substracted.

- ✓ **Cooling Correction:** The time taken to cool the water in copper calorimeter from maximum temperature to room temperature is recorded. From the rate of cooling (dt°/min) and the actual time taken for cooling (t min), the cooling correction (dt × t) is added to the increase the temperature.

$$\therefore \quad L = \frac{[(W + w)\,(t_2 - t_1 + \text{cooling correction})] - (\text{ACID} + \text{FUSE correction})}{\text{Mass of fuel sample } (x)}$$

Numerical problem:

1. **On burning 0.72 g of a solid fuel in a Bomb calorimeter, the temperature of 250 g of water is increased from 27.3°C to 29.1°C. If the water equivalent is 150 g, calculate the HCV of the fuel.**

Sol:

x = 0.72 g

W = 250 g

T_1 = 27.3°C

T_2 = 29.1°C

w = 150 g

HCV of fuel = (W + w) (T_2- T_1) ÷ x cal/g

= (250 + 150) (29.1- 27.3) ÷ 0.72

= 1000 cal/g

2. In an experiment in a Bomb calorimeter, a solid fuel of 0.90 g is burnt. It is observed that increase of temperature is 3.8^{o}C of 4000 g of water. The fuel contains 1% of H. calculate the HCV and LCV value (equivalent weight of water = 385 g and latent heat of steam = 587 cal/g).

Sol:

Weight of fuel (x) = 0.90 g

Weight of water (W) = 4000 g

Equivalent weight of water (w) = 385 g

Rise in temperature (T_2-T_1) = 3.8^{o}C

Percentage of carbon = 1%

Latent heat of steam = 587 cal/g

HCV = (W + w) (T_2- T_1) ÷ cal/g

= (4000 + 385) (3.8) ÷ 0.90 cal/g

= 18514.5 cal/g

LCV = (HCV – 0.09 H × 587)

= 18514.5 – 0.09 × 1 × 587

= 18461.6 cal/g

3. **A sample of coal contains: C = 83%, H = 6% and ash 1%.**

   The following data were obtained when the above coal was tested in a bomb calorimeter:

   Weight of coal burnt = 0.92 g

   Weight of water taken = 550 g

   Water equivalent of calorimeter = 2,200 g

   Rise in temperature = 2.42^{o}C

   Fuse wire correction = 10.0 cal

   Acid correction = 50.0 cal

   Calculate the gross and net calorific values of coal, assuming that the latent heat of condensation of steam is 580 cal/g.

Sol: Weight of coal sample (x) = 0.92 g

Weight of water (W) = 550 g

Water equation of calorimeter (w) = 2200 g

Rise in temperature (T_2-T_1) = 2.42^{o}C

Fuse wire correction = 10.0 cal

Acid correction = 50.0 cal

Latent heat of steam = 580 cal/g.

% of H = 6 %

$$\text{H.C.V.} = \frac{(W+w)\,(T_2-T_1) - [\text{Acid + Fuse corrections}]}{x}$$

= (550 + 2200) × 2.42 – [50 +10] ÷ 0.92 g

= **7,168.5 cal/g**

N.C.V. = (G.C.V. – 0.09 H × latent heat of steam)

= (7,168.5 – 0.09 × 6 × 580) cal/g

= **6,855.3 cal/g**

QUESTIONS

1. Describe the method of determination of calorific value of a solid fuel by bomb calorimeter.
2. What is calorific value of a fuel? Differentiate HCV from LCV.
3. Calculate the gross and net calorific value of a coal sample from the following data obtained from a bomb calorimeter. Weight of coal 0.73 gm, weight of water in the calorimeter 1500 gm, water equivalent of calorimeter 470 gm initial temp 25.0^{0}C, and final temp, 28^{0}C, percentage of hydrogen in coal 2.5%, latent heat of steam 587 cal/gm.
4. Define calorific values of a fuel. Distinguish gross and net calorific value.