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Fuels

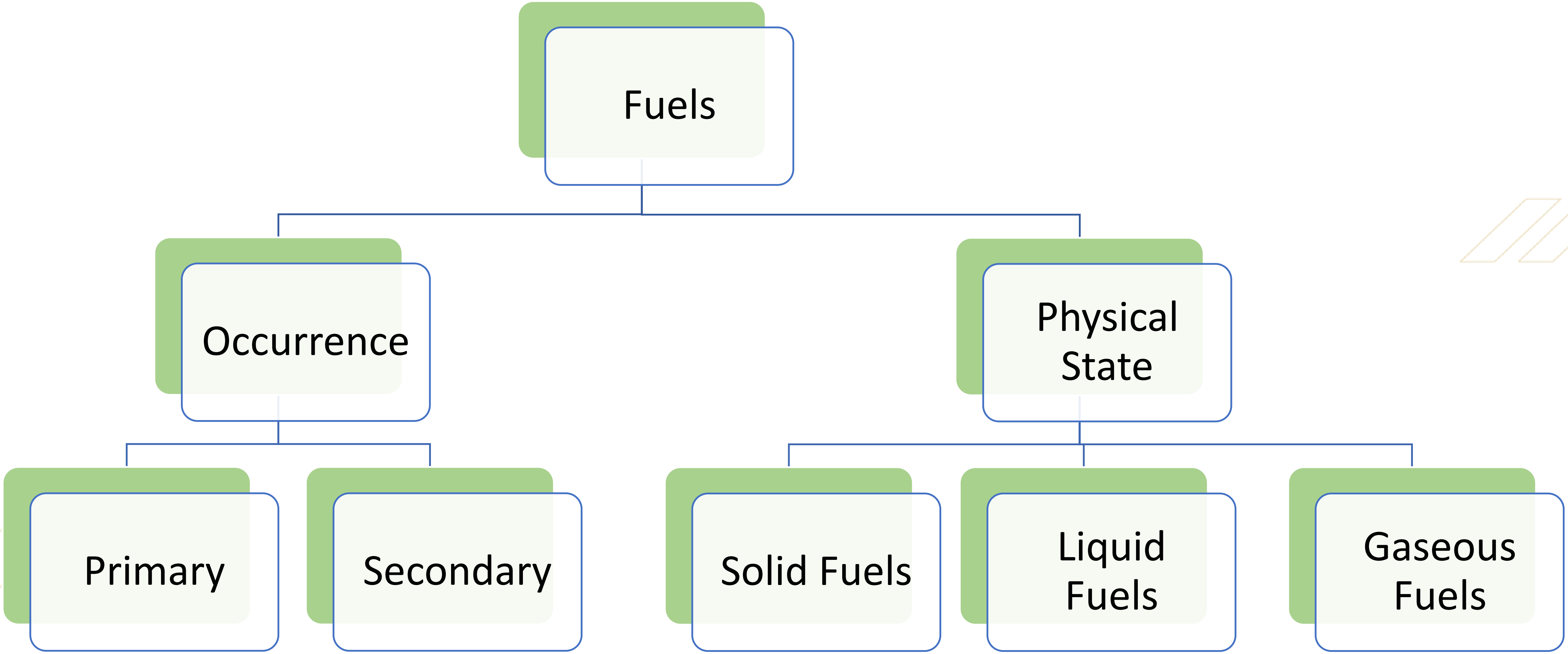
What is a Fuel?

- Any source of heat energy is called a fuel.
- The term fuel is applied to a combustible substance which on burning in presence of oxygen produces a large amount of heat that can be used economically for domestic and industrial purposes. For e.g. wood, charcoal, coal, kerosene etc.
- Combustion of these fuels is used as a source of heat and power.

Fuels are called as Chemical Fuels

During combustion of these fuels, a chemical reaction involving the breakage of bonds of reactants and formation of new bonds in the products takes place ,which is accompanied by a large amount of heat. Hence, these fuels are termed as **Chemical Fuels.**

Classification of Fuels



On the basis of Occurrence

A) **Primary Fuels:** Fuels which occur in nature as such are called primary fuels. These can be used either without processing or after little processing which does not change the chemical composition of the fuel. Examples: wood, peat, coal, petroleum.

B) **Secondary Fuels:** The fuels which are derived from the primary fuels by further chemical processing are called secondary fuels. Example Coke, charcoal, kerosene, coal gas, producer gas, etc.

On the Basis of Physical State

1. **Solid Fuels**: The ones which are solid in nature. E.g. Wood, peat, lignite, coke, charcoal.

2. **Liquid Fuels**: The ones which are liquid in nature. E.g. Crude oil, Petrol, LPG.

3. **Gaseous Fuels**: The ones which are gaseous in nature E.g. Natural gas, water gas.

Calorific Value

- Each fuel releases its own set of energy i.e. all of them do not release the same amount of energy upon combustion. The energy produced by combustion of one kg of fuel is known as its **calorific value**.
- It is defined as the total quantity of the heat liberated when a unit mass of a fuel is burnt completely.
- It judges the efficiency of the fuel.
- Higher the C.V., Greater is the efficiency of the fuel.
- The calorific value is an important characteristic of the fuel. The unit of measurement of the calorific value is the same as the energy.
- Thus, we can differentiate different fuels on the basis of their calorific value for their efficient usage. Furthermore, each of them has a different cost with respect to another. Some are cheaper while others are expensive.

Units of Calorific Value

The quantity of heat can be measured in the following units:

1) **Calorie:** It is defined as the amount of heat required to raise the temperature of 1 gram of water through 1 degree centigrade.

1 calorie = 4.185 Joules = 4.185 x 10^7 ergs

2) **Kilocalorie:** This represents the unit of heat in MKS system. It is defined as the amount of heat required to raise the temperature of one kilogram of water through 1 degree centigrade.

1 Kilocalorie = 1000 cal

Units of Calorific Value

3) **British Thermal Units (BTU):** It is defined as the amount of heat required to raise the temperature of 1 pound of water through 1 degree Fahrenheit.

1 BTU = 0.252 kcal

1 kcal = 3.968 BTU

4) **Centigrade Heat Unit (C.H.U):** It is defined as the amount of heat required to raise the temperature of 1 pound of water through 1 degree centigrade.

1 kcal = 3.968 BTU

1 kcal = 2.2 CHU

Units of the calorific value for solid, liquid and gaseous fuels are given below:

For solid and liquid fuels the following units are used like calories/gm , kcal/Kg and BTU/ lb.

For gaseous fuels ,the following units are used like calories/cm^3, kcal/m^3 and BTU / ft^3

Types of Calorific Value

Calorific value is of two types:

1. Gross Calorific Value (GCV)- also called as **Higher Calorific Value (HCV)**
2. Net Calorific Value (NCV)- also called as **Lower Calorific Value (LCV)**

Gross Calorific Value

It is the total amount of heat generated when a unit quantity of fuel is completely burnt in oxygen and the products of combustion are cooled down to the room temperature.

Usually, all the fuels have sufficient amount of hydrogen. The hydrogen present during combustion is converted into steam. As the products of combustion are cooled down to room temperature, the steam gets condensed into water and latent heat is evolved. Thus in the determination of gross calorific value , this latent heat also gets included in the measured heat. Therefore, **gross calorific value** is also called the **higher calorific value.**

NET Calorific Value

It is defined as the net heat produced when a unit quantity of fuel is completely burnt and the products of combustion are allowed to escape.

When a fuel is burnt, the water vapour, formed due to the presence of hydrogen in the fuel, are not condensed and escape along with hot combustion gases. Hence, a lesser amount than gross calorific value is available. Therefore, this is called Net Calorific Value.

Calorific Value

LCV = HCV–Latent Heat of water vapours formed

Since 1 Part by weight of hydrogen gives nine parts by weight of water i.e.

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$$

Therefore, LCV= HCV - Weight of hydrogen x 9 x Latent heat of steam

= HCV – Weight of hydrogen x 9 x 587

Determination of the Calorific Value

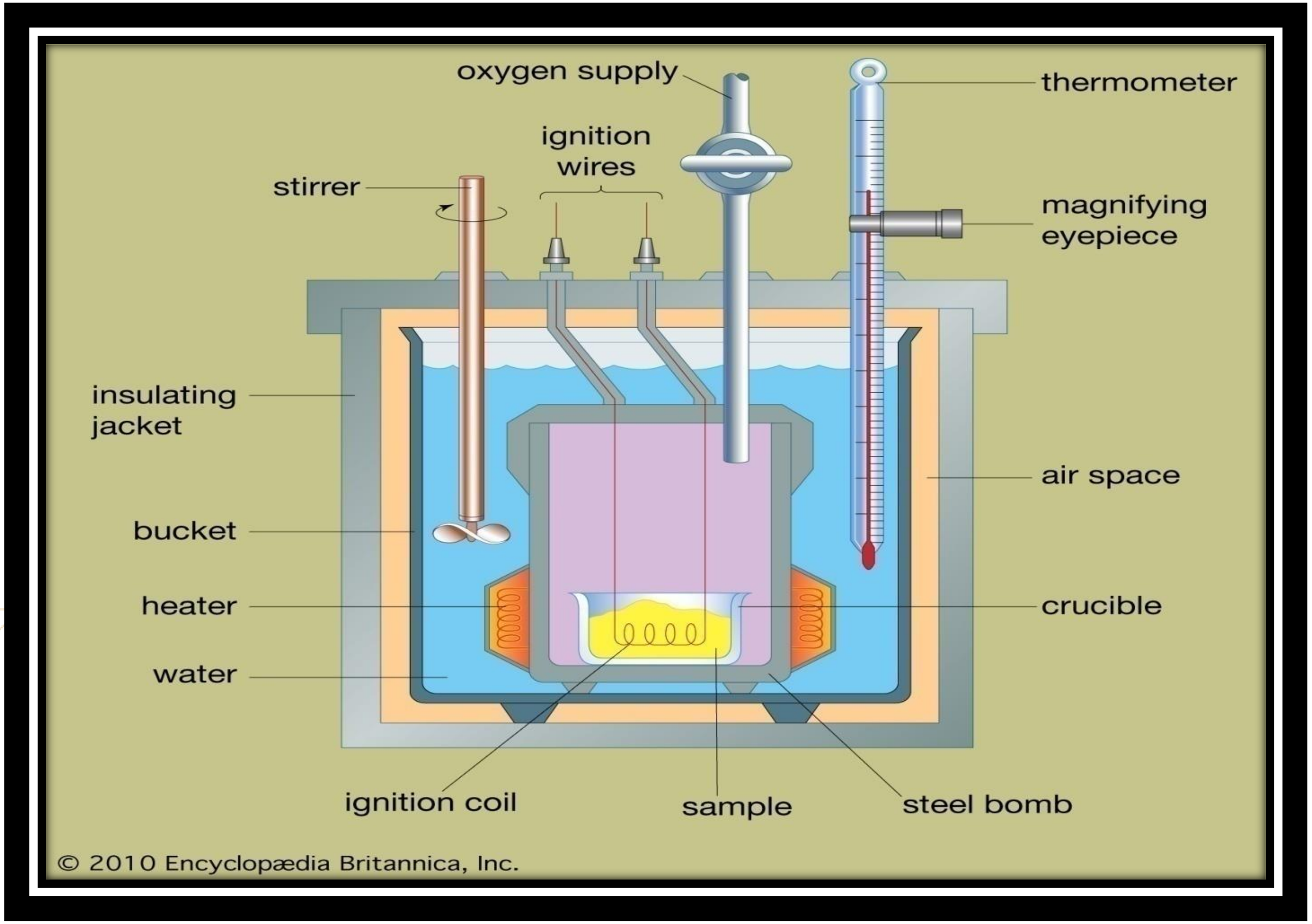
1) Solid and Non-volatile Fuels

The calorific value of solid and non-volatile fuels is determined by Bomb Calorimeter.

Principle of Bomb Calorimeter: A known amount of the fuel is burnt in excess of oxygen and the heat liberated is transferred to a known amount of water. The calorific value of the fuel is then determined by applying the principle of calorimetry i.e.

Heat Gained = Heat Lost

Bomb Calorimeter



Construction of Bomb Calorimeter

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Bomb calorimeter consists of the following parts:

- **Steel bomb:** Steel bomb consists of a strong cylindrical container made up of stainless steel which is capable of withstanding pressure of at least 50 atmospheres. The bomb is generally provided with a gas-tight screw cap or lid. The lid in turn is provided with two holes for electrodes and one oxygen inlet valve. A small ring is fitted to one of the electrodes which act as a support for silica crucible.
- The bomb is placed in a copper calorimeter containing a known amount of water. The calorimeter is provided with an electrical stirrer and a Beckmann thermometer
- The copper calorimeter is surrounded by the air jacket and water jacket to prevent any loss of heat due to radiation.
- A crucible is made up of nickel, or fused silica which contains the fuel. The crucible is placed inside the ring attached to one of the electrodes

Working of Bomb Calorimeter

A known amount of the given fuel (about 0.5-1 g) is taken in the silica crucible supported over the ring.

A piece of fine magnesium wire is tightly stretched across the electrodes, touching the fuel sample. The lid of the bomb is tightly screwed and bomb filled with oxygen at 25 atmospheric pressure.

The bomb is placed inside the copper calorimeter which contains a known amount of water. After thorough stirring , initial temperature of water is noted with the help of Beckmann thermometer, Which can read accurately, temperature difference up to 1/100th of a degree

Working of Bomb Calorimeter

The electrodes are connected to a 6-volt battery and the circuit is completed. The fuel in the crucible burns with the evolution of heat.

The heat produced by burning of a fuel is transferred to water, which is stirred throughout the experiment by the electric stirrer.

Maximum temperature shown by thermometer is recorded. Time taken to cool the water in the calorimeter from maximum temperature to room temperature is also noted.

Calculations

Let , weight of the fuel sample taken = x gm

weight of water in the calorimeter = W gm

Water equivalent of the calorimeter, stirrer, bomb, thermometer= w gm

Initial temperature of water= t_1 degree C

Final temperature of water = t_2 degree C

Higher or gross calorific value= C cal/gm

Heat gained by water= W x Δt x Specific heat of water

Heat gained by water = W (t_2-t_1) x 1 cal

Heat gained by calorimeter = $w(t_2-t_1)$ cal

Heat liberated by the fuel = x C cal

Heat liberated by the fuel = Heat gained by water + Heat gained by calorimeter

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

$$C = (W+w)(t_2-t_1) / x \text{ cal/gm}$$

Calculations

Net Calorific Value

Let the percentage of hydrogen in the fuel = H% or H/100

Weight of water produced from 1 gm of the fuel = 9H/100 gm

(Because 1 gm of hydrogen produces 9 gm of H_2O)

Heat liberated during condensation of steam= 0.09H x 587 cal

Net (Lower) Calorific Value = GCV- Latent heat of water formed

= GCV – 0.09H x 587 cal/gm

Corrections in the Formula

For obtaining the accurate results following corrections are also incorporated

1. **Fuse wire corrections**: As Mg wire is used for ignition, the heat generated by burning of Mg wire is also included in the gross calorific value as measured above. Hence, this amount of heat has to be subtracted from the total value.
2. **Acid Corrections**: During combustion , sulphur and nitrogen present in the fuel are oxidised to their corresponding acids under high pressure & temperature. Since the reactions are exothermic in nature, the heat liberated is not obtained in the practical use of coal, because SO_2 and N_2 pass into the atmosphere. Therefore ,the heat liberated needs to be subtracted.

Corrections in the Formula

3. **Cooling Corrections**: Heating & cooling are simultaneous processes. As the temperature rises above the room temperature, there will be loss of heat due to radiation , and the highest temperature recorded will be slightly less than that obtained. Therefore, this temperature of cooling correction needs to be added.

Therefore, the formula becomes:

$C = (W+w)(t_2-t_1+\text{Cooling correction}) - (\text{Acid + fuse corrections})$ / Mass of the fuel

Numerical on Calorimeters

Q1. The following data were obtained in a bomb calorimeter experiment.

Weight of coal burnt = 0.994 g

Weight of water in calorimeter= 2592g

Weight of bomb, calorimeter = 3940g

Rise in temperature of water= 2.732 degree Celsius

Mean specific heat of the apparatus =0.098

Find the gross calorific value of the fuel. If the fuel contains 8% hydrogen, calculate its lower calorific value. [Latent Heat of steam = 587 cal/g]

Numerical on Calorimeters

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Q2. A sample of coal contains 92% C, 5% H and 3% ash. When the coal was tested for its calorific value in the bomb calorimeter, the following results were obtained:

Weight of the coal burnt=0.95g

Weight of water taken= 700g

Water equivalent of bomb and calorimeter=2000g

Increase in temperature=2.48°C

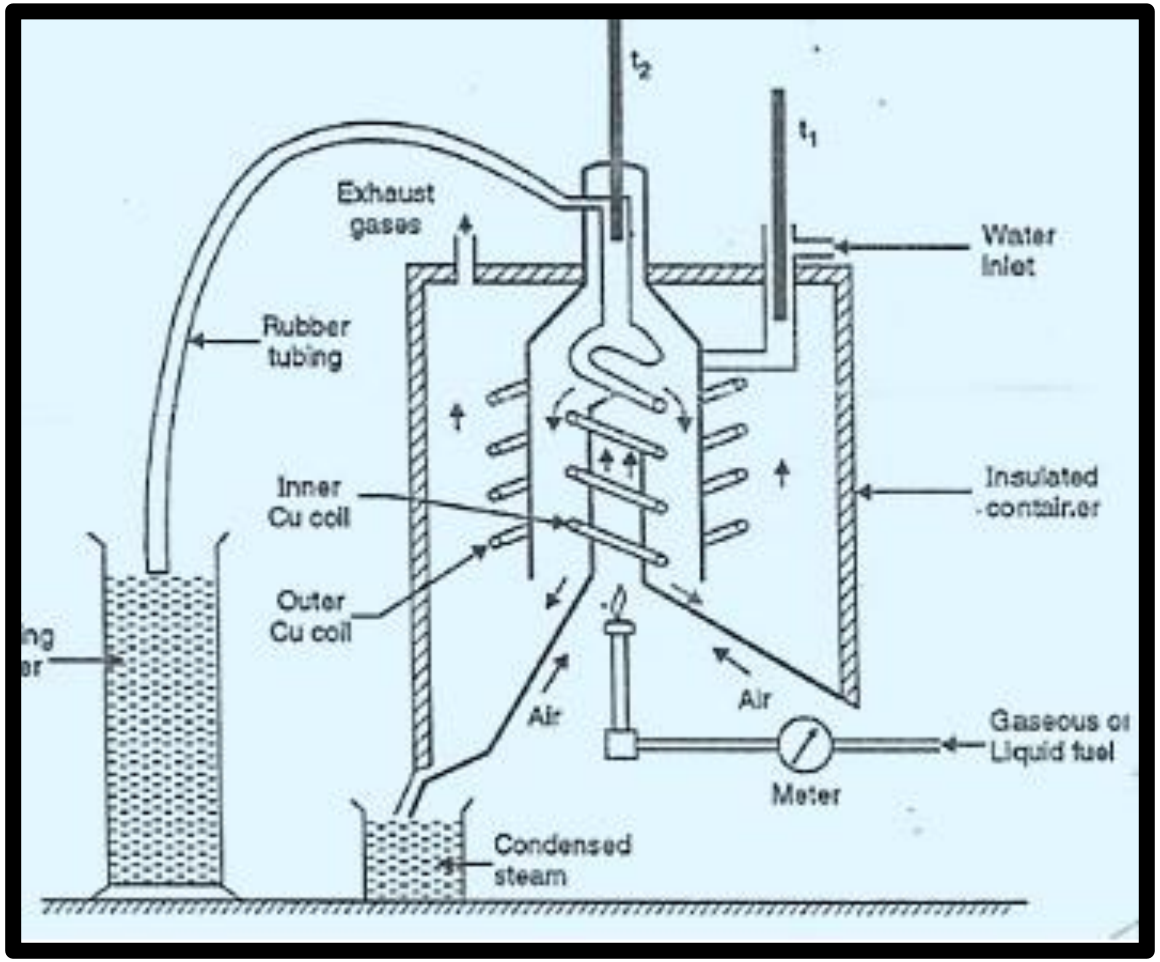
Acid correction = 60.0 Cal, Cooling Correction = 0.02° C

Fuse Wire correction = 10.0 Cal.

Calculate the NVC & GCV. Given latent heat of steam is 587 cal/g

Boy's Gas Calorimeter

2) **Gaseous and volatile liquid fuels**: The calorific value of gaseous and volatile liquid fuels is determined by Boy`s Gas Calorimeter.



Construction of Boy's Calorimeter

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It consists of the following parts:

- A gas burner in which a known volume of gas at a known pressure is burnt at a uniform rate. The volume of the gas is measured by a meter fitted near the inlet of the gas.
- The burner is surrounded by a chimney/ combustion chamber, which has a copper tubing inside as well as outside. Through this copper coil, water at a constant rate is flowing. Water enters from the top of the outer coil, passes through the outer coils, moves to the Bottom of the chimney and then moves upwards through the inner coils, and exit from the top.
- The thermometers t_1 and t_2 are fitted to note the temperature of incoming, outgoing water respectively.
- A container is provided for collecting water which is formed due to the condensation of steam produced during combustion. The whole assembly is enclosed in an insulated chamber.

Working of Boy's Calorimeter

Burning of fuel and circulation of water are continued for about 15 minutes for initial warming up period.

When the calorimeter gets warmed, the rate of flow is so adjusted that the water leaves the apparatus nearly at atmospheric pressure

Heat produced by burning of gaseous fuels is transferred to water in the copper coil and the steam formed inside the chimney during combustion gets condensed to water which is collected. The following readings are noted, when the conditions become steady:

Working of Boy's Calorimeter

- Volume of gas burnt at a given temperature and pressure in time t, this volume is converted to STP.
- Weight of water is passed through the coil in the same time t.
- Temperature of incoming and outgoing water.
- Weight of water condensed during this time.

Calculations

Let ,

Volume of the gas burnt at STP in a certain time t = Vm^3

Weight of water passed through the coil in time t = W kg

Weight of water condensed during this time = m

Temperature of incoming water = T_1

Temperature of outgoing water = T_2

Rise in temperature = T_2-T_1

Gross Calorific value = C

Heat absorbed by the circulating water = W(T_2-T_1)

Calculations

Heat produced by combustion of fuel = VC

Heat Lost = Heat Gained

$$VC = W\,(T_2 - T_1)$$

Gross Calorific Value (C) = W (T2-T1)/V

Net Calorific Value

Weight of water condensed per m^3 of gas = m/V kg

Latent heat of steam per m^3 of gas= m x 587/ V kcal

So, Net calorific value = GCV – m/V x 587 kcal/m^3

Theoretical Calculations of C.V.

- Theoretically, the calorific value of a fuel can be calculated if the percentages of the constituent elements are known. According to **Dulong's**, the calorific value of a fuel is the sum of the calorific values of its constituents.
- The calorific value of C, H, and S are found to be 8080, 34500 and 2240 kcal/kg respectively.

  Therefore the formula becomes,

  GCV= 1/100 {8080 C + 34,500 $(H - \frac{O}{8})$ + 2,240 S} kcal/kg

Theoretical Calculations of C.V.

Q. Why is it (H-O/8) instead of H?

If Oxygen is present in the fuel , it combines with hydrogen to form H_2O. Thus the hydrogen in the combined form is not available for combustion and is called **fixed hydrogen**.

Amount of hydrogen available for combustion = Total mass of hydrogen-hydrogen combined with oxygen

8 parts by weight of oxygen combined with 1 part by weight of hydrogen to form water i.e. For every 8 parts of oxygen, 1 part of hydrogen gets fixed.

Therefore, Amount of hydrogen available for combustion = Total mass of hydrogen – 1/8 mass of oxygen in the fuel

= H – O/8

The **Net calorific value** will be N**CV = [HCV – 9H/100 x 587] kcal/kg**

= [HCV – 0.09H x 587] kcal/kg

Numerical on Calorimeters

Q1. During the determination of C.V. of a gaseous fuel by Boy`s Calorimeter, the following results were recorded.

Volume of gaseous fuel burnt at NTP = 0.098m^3

Weight of the water used for cooling the combustion products= 50kg

Weight of the steam condensed =0.051Kg

Temperature of the inlet water=26.1^oC

Temperature of the outlet water= 46.5^o C

Determine the Gross and Net Calorific value.

Numerical on Calorimeters

Q2. Calculate the gross and net calorific value of a coal sample having the following composition.

C:82%, H_2: 8%, O_2:5% , S= 2.5%, N_2: 1.4% and ash: 2.1%.

Q3. A coal has the following composition by weight:

C=92%, O=2.0% ,S=0.5%, N=0.5% and ash=1.5%.

Net calorific value of the coal was found to be 9.430kcal/kg. Calculate the percentage of hydrogen and GCV.