FUEL AND COMBUSTION

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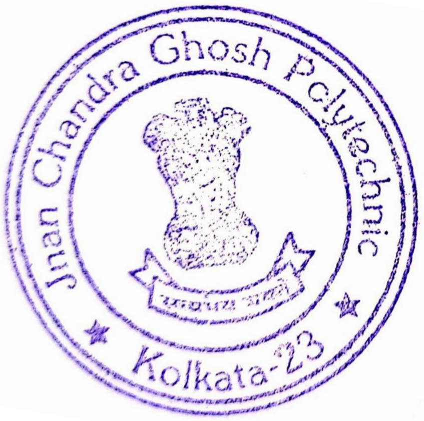
Fuels and combustion

Introduction, Characteristics of a good fuel, Classification of fuels, Calorific Value, Types & Determination of calorific value using bomb Calorimeter (Numerical Problems), LPG, CNG, Producer gas, Water gas, Biodiesel, Gasohol, Disohol, Analysis of Coal (Proximate and Ultimate Analysis).



Introduction

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

For example, wood, coal, kerosene, petrol, diesel and water gas.

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

Combustion reaction of a fuel can be represented as follows

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

Classification of fuel

- **Fuel**
  - **Primary or natural fuel**
    - **Solid** (wood, coal)
    - **Liquid** (petroleum)
    - **Gaseous** (Natural gas)
  - **Secondary or Artificial fuel**
    - **Solid** (Charcoal)
    - **Liquid** (petrol)
    - **Gas** (coal gas)

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

Calorific value

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

Gross or Higher calorific value (G.C.V or H.C.V): It is the total quantity of heat liberated when one unit of fuel is burnt completely and products of combustion has been cooled to room temperature.

Net or Lower calorific value (N.C.V or L.C.V)): It is the total quantity of heat liberated when one unit of fuel is burnt completely and products of combustion has been permitted to escape.

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

Latent heat of steam= 537 cal/gm

Units of Calorific value

Units of calorific value	**Solid fuel**	**Liquid fuel**	**Gaseous fuel**
CGS method	cal/g	cal/g	cal/cm^3
MKS method	Kcal/Kg	Kcal/Kg	Kcal/m^3
FPS method	B.Th.U/Ib	B.Th.U/Ib	BTU/ft^3
SI method	Joule/Kg	Joule/Kg	Joule/m^3

1 Kcal/kg= 1.8 B.Th.U/Ib
1 Kcal/m^3 = 0.1077 B.Th.U/ft^3

Characteristic of good fuel

A good fuel should have

- high calorific value
- moderate ignition temperature
- low moisture content
- low non combustible matter content
- low cost and easy availability
- easy to transport and storage cost should be low
- products of combustion should not be harmful.
- burn in air without much smoke
- combustion should be easily controllable.

Theoretical calculation of calorific value using Dulongs formula

H.C.V= $[8080C + 34500(H-O/8) + 2240\,S]/100 \quad kcal/kg$

Where,

C= % of carbon in the fuel

H= % of hydrogen in the fuel

O= % of oxygen in the fuel

S= % of sulphur in the fuel

And

Calorific value of carbon= 8080 kcal/kg

Calorific value of hydrogen= 34500 kcal/kg

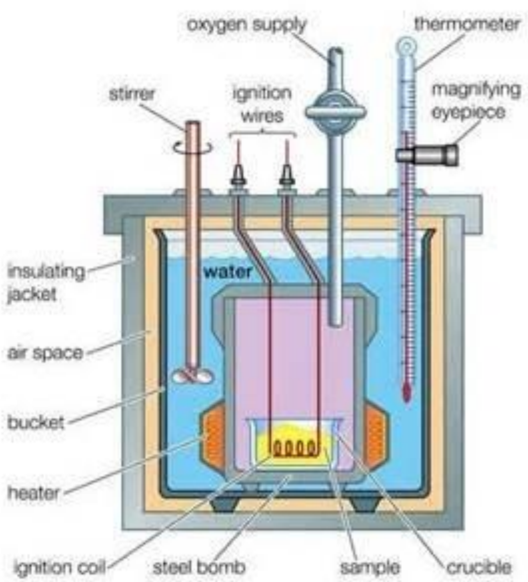
Calorific value of sulphur= 2240 kcal/kg

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

$= [H.C.V - 9H \times 537/100]\,kcal/kg$

$= [H.C.V - 0.09H \times 537]\,kcal/kg$

Bomb Calorimeter for determination of calorific value of solid and liquid fuel



Principle: When a certain weighed quantity of a fuel is burnt in a calorimeter, the heat given out is used up in heating the calorimeter and the water inside the calorimeter. If we equate the heat given out by the fuel to the heat taken up by the calorimeter and the water, the calorific value of a fuel can be determined.

Construction and working principle of Bomb calorimeter

It consist of a stainless steel bomb in which combustion of fuel is made to take place.

A known mass of the given fuel is taken in nickel crucible supported over a ring inside the steel bomb which is connected with two electrodes. The bomb lid is tightly screwed and filled with O_2 upto 25 atm. The bomb is then lowered into the copper calorimeter containing known mass of water.

The water is stirred with the help of mechanical stirrer and the initial temp is recorded. The electrodes are then connected to 6 volt battery and the circuit is completed. Uniform stirring of water is continued and the maximum temp is recorded.

Calculation of Bomb Calorimeter

Let, X= mass in gm of the fuel sample

W= mass of water in calorimeter

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

t_1= Initial temp of water in calorimeter

t_2= Final temp of water in calorimeter

C= calorific value of the fuel

Now,

Heat liberated by the fuel = Heat taken up by the calorimeter

$$X \times C = (W + w)(t_1 - t_1)$$

$$C = (W + w)(t_1 - t_1)/X$$

$$\text{i.e, } H.C.V = (W + w)(t_1 - t_1)/X$$

Gaseous fuel

1. **Natural gas:** It occurs in nature (mostly found under earth crust along with crude oil) is a mixture of hydrocarbons (80-95% methane and 5-20% ethane and other hydrocarbons.

Calorific value: 12000-14000 kcal/m3

Use: largely used as domestic fuel

A. CNG (Compressed natural gas): It is the natural gas compressed under high pressure.

Use: largely used as alternative fuel for motor vehicles.

B. LNG (Liquefied natural gas): It is the liquefied natural gas by refrigerating natural gas to -260^{o}F.

Use: Since it is more dense than CNG, so is good for large trucks that need to go on long distance.

2.LPG (Liquefied petroleum gas): It is a mixture of hydrocarbons (80-95% proane and 5-20% ethane and other hydrocarbons.

Calorific value: 27800 kcal/m3Use: used as domestic and industrial fuel

Bio fuel

3. Gobar gas or bio gas: Animal dung converted to Bio gas which is a clean fuel. It is a mixture of hydrocarbons (50-60% methane and 30-40% carbon dioxide) and little N_2 and H_2 and traces of H_2S.

Process: A slurry of cow dung and water (1: 1) is put into the plant. Gobar gas is produced by anaerobic bacterial decomposition of the mixture which is drawn through pipes. The residue left is rich in nutrient which can be used as manure.

Calorific value: 1200 kcal/m3

Use: mostly used as domestic fuel (cooking and lighting)

Bio gas can also be generated from animal and plant wastes.

Bio diesel

. **Biodiesel** refers to a vegetable oil - or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, ethyl, or propyl) esters.

Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, soybean oil, animal fat (tallow)) with an alcohol producing fatty acid esters.

Biodiesel is a renewable, clean-burning diesel replacement that is reducing dependence crude petroleum and improving the environment.

Gaseous fuel

4. Water gas: It is mainly a mixture of CO and hydrogen and it is produced by passing alternatively steam and little air through a bed of red hot coke maintained at about 900-1000°C.

At first steam reacts with red hot coke at 900-1000°C to produce CO and H_2.

$C + H_2O \longrightarrow CO + H_2$ -29 kcal (endothermic reaction)

This reaction is endothermic and temerature of the bed of coke falls. In order to raise the coke bed temperature to 1000°C, the supply of steam is temporarily cut off and air is blown when the following exothermic reactions took place.

$C + O_2 \longrightarrow CO_2$ + 97 kcal (exothermic reaction)

$2C + O_2 \longrightarrow 2CO$ + 59 kcal (exothermic reaction)

Composition: H_2 =50% ; CO= 40%, N_2 and CO_2 = 4% each

Calorific value: 2800 kcal/m3

Use: used as industrial fuel

Gaseous fuel

5. Producer gas: It is mainly a mixture of CO and nitrogen and it is produced by passing air over white hot coke bed maintained at about 1000-1400^{o}C.

$2C + O_2 \longrightarrow 2CO$ + 59 kcal (exothermic reaction)

$C + O_2 \longrightarrow CO_2$ + 97 kcal (exothermic reaction)

Carbon dioxide formed is reduced to CO by heated coke.

$CO_2 + C \longrightarrow 2CO$ -39 kcal (endothermic reaction)
This reaction is endothermic and temperature of the coke bed is maintained at 1000-1400^{o}C.

Composition: N_2 =50% ; CO= 30%, H_2 =4%, and rest CO_2 , CH4 etc.
Calorific value: 1300 kcal/m3
Use: used as industrial fuel (for heating of open hearth furnaces in steel and metallurgy).

Gaseous fuel

5. Coal gas: It is obtained by destructive distillation of coal.

Destructive distillation is a process by which a substance is Heated strongly in absence of air thereby separating volatile and nonvolatile content.

Coal $\longrightarrow$ Coal gas + Coke (residue)

Destructive distillation of coal (at 1200°C) afforded coal gas and as a residue coke is obtained.

Composition (By volume):

H_2 =50% ; CH_4= 30%, CO =8%, (these are combustible, heat producing and non illuminant gas)

C_2H_4, C_2H_2, C_6H_6 =3%, (illuminant gas)

N_2, O_2, CO_2 ------- 5% (as inert diluents)

Calorific value: 4900 kcal/m3

Use: used as domestic and industrial fuel

Fossil fuel

They are formed by bacterial decomposition of plants and animals (buried on earth million years ago) in presence of heat and under pressure of earth.

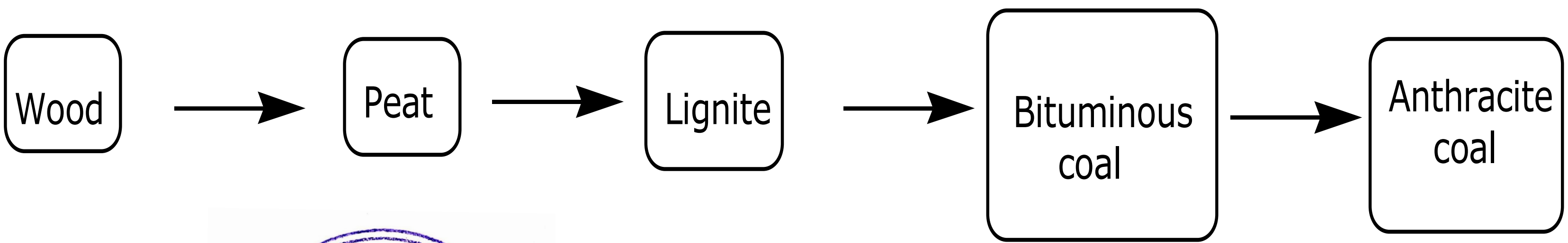
They are available on earth crust.

For eg. Coal, petroleum and natural gas.

Classification of coal

Coal is a primary solid fuel which occurs in nature in very impure form of carbon. It is a fossil fuel.

Wood, peat, lignite, bituminous and anthracite are the different stages in the conversion of wood to coal. Carbon content is highest in anthracite coal.



Classification of coal (contd)

	Wood	**Peat**	**Lignite**	**Bituminous coal**	**Anthracite coal**
% of Moisture content	25	25	20	4	1.5
% of Carbon content	50	57	60-80	83	93.3
% of Hydrogenc ontent	6	5.7	5	5	3
Calorific value (Kcal/kg)	4000-4500	4500-5000	6500- 7000	8100- 8600	8650- 8700

Analysis of coal

Analysis of coal sample is required to access the quality of coal.

(A) Proximate analysis (PA): It is the process of determination of moisture, volatile matter, ash and fixed carbon content.

(B) Ultimate analysis (UA): It is the process of determination of composition of various components of coal which includes the determination of % of C, H, S, N, O and ash content. It is necessary for utilization of coal for industrial purpose.

Proximate Analysis

(1) **Moisture content:** 1 g of finely powdered coal, taken in a crucible, is heated in an electric oven at 105-107oC for 1h. Percentage moisture content can be calculated from the loss of weight.

(2) Volatile matter content: 1 g of finely powdered moisture free coal, taken in a covered crucible, is heated in a muffle furnace at $950^{o}C$ for 7 min. Percentage volatile content can be calculated from the loss of weight.

(3) Ash content: It is the residue obtained after burning of the coal in a muffle furnace under current of air at $700\text{-}750^{o}C$ till a constant weight is obtained.

(2) Fixed carbon content: It is determined indirectly by deducting the sum of total moisture, volatile matter and ash content from 100.

Ultimate Analysis

(1) Determination of % of C & H: This is usually done through a single experiment based on combustion in excess of pure oxygen.

(2) Determination of % of Nitrogen: This is done by Kjeldhal's method where a known weight of the given sample is heatedb with conc. H_2SO_4 in presence of catalytic amount of K_2SO_4 and $HgSO_4$.

(2) Determination of % of S: This is done by heating known weight of the given sample with fuming HNO_3.

Comparison of solid, liquid and gaseous fuel

Solid fuel	Liquid fuel	Gaseous fuel
1. Calorific value: Their calorific value is low.	Their calorific value is high	Their calorific value is highest.
2. **Pollution:** Their ash content is high and they produces lot of smoke on burning.	Their ash content is low and they burn without smoke.	They are almost pollution free; they burn without smoke and ash less.
3. **Ignition temp and fire hazard:** Their possess moderate ignition temperature	Their ignition temp is low so there is a chance of fire hazard.	They have a very low ignition temp so they are highly inflammable and chances of fire hazard is highest.
4. **Cost:** Their production cost is low.	Cost is relatively higher than solid fuel.	They are more costly compare to solid and liquid fuel.

Comparison of solid, liquid and gaseous fuel

Solid fuel	Liquid fuel	Gaseous fuel
5. Transportation: They are easy to transport through normal carriage so cost is low.	They can be transported through pipelines hence it is more costly.	They can be conveyed through pipelines hence costly.
6. **Storage** Their storage needs lot of space but there is no risk.	Costly special storage tank is required for storing and safety precaution has to be taken to prevent fire hazard as most of them are highly inflammable and volatile	They can be compressed in cylinder so storage doesnot need lot of space. Safety precaution has to be taken to prevent fire hazard as they are highly inflammable and volatile.
3. **Mode of operation during combustion:** Their thermal efficiency is low and ignition temperature is high so large proportion of heat is wasted during combustion. They require a large excess of air for complete combustion. But the combustion operation cannot be controlled easily.	Their ignition temp is low so firing is easier and fire can be extinguished by stopping liquid fuel supply. The flame produced by burning can be easily controlled by adjusting fuel supply.	Their ignition temp is lowest so firing is very easy. The flame produced by burning can be easily controlled by adjusting fuel supply.

List of references

Books

1. Engineering Chemistry by **Jain & Jain**

2. A text book of Engineering Chemistry by Shashi Chawla

Links

1. www.**biofuel**stp.eu/spm6/spm6.html
2. www.**biodiesel**.com