Natubhai V. Patel College of Pure & Applied Sciences
S. Y. B.Sc. Semester-4
Industrial chemistry/ IC (Vocational)
**USO4CICV01/US04CICH02: Chemical Plant Utilities**
UNIT – 2

SYLLABUS

Fuels-Classification, Advantages and disadvantages, Analysis of fuels, heating media
Air- Specification for industrial uses of air. Industrial applications of CO_2, O_2, N_2 and H_2

2.0 INTRODUCTION

      Fuel is a combustible substance, containing carbon as main constituent, which on proper burning gives **large amount of heat,** which can be used economically for domestic and industrial purposes. Wood, charcoal, coal, kerosene, petrol, diesel, producer gas, oil gas, etc. are some of the fuels.

      During the process of combustion of a fuel (like coal), the atoms of carbon, hydrogen, etc. combine with oxygen with the simultaneous liberation of heat at a rapid rate. This energy is liberated due to the "rearrangement of valence elections" in these atoms, resulting in the formation of new compounds (like CO_2, H_2O, etc.). These new compounds have less energy (or heat content) in them and, therefore, the energy (or heat) released during the combustion process is the **difference** in the energy of the reactants (C, H, and O of fuel) and that of the products formed.

Fuel   + O_2 $\longrightarrow$ Products   +   Heat

More heat   Lesser heat energy content
energy content
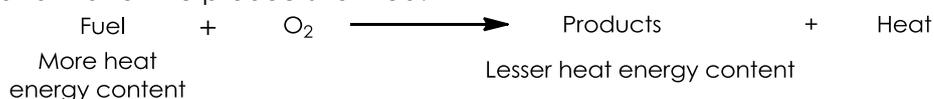
      The primary or main sources of fuels are coals and petroleum oils, the amounts of which are dwindling day-by-day. These are stored fuels available in earth's crust and are, generally, called **'fossil fuels'.**

2.1 CLASSIFICATION OF FUELS

2.1.1 According to Occurrence (and preparation)
      (a) Natural or primary fuels, which are found in nature **as such,** e.g., wood, peat, coal, petroleum, natural gas, etc.
      (b) Artificial or secondary fuels are those which are **prepared** form the primary fuels. For example, charcoal, coke, kerosene oil, diesel oil, petrol, coal gas, oil gas, producer gas, blast furnace gas, etc.
2.1.2 According to the state of aggregation
 (a) Solid fuels; **(b)** liquid fuels, and **(c)** gaseous fuels.
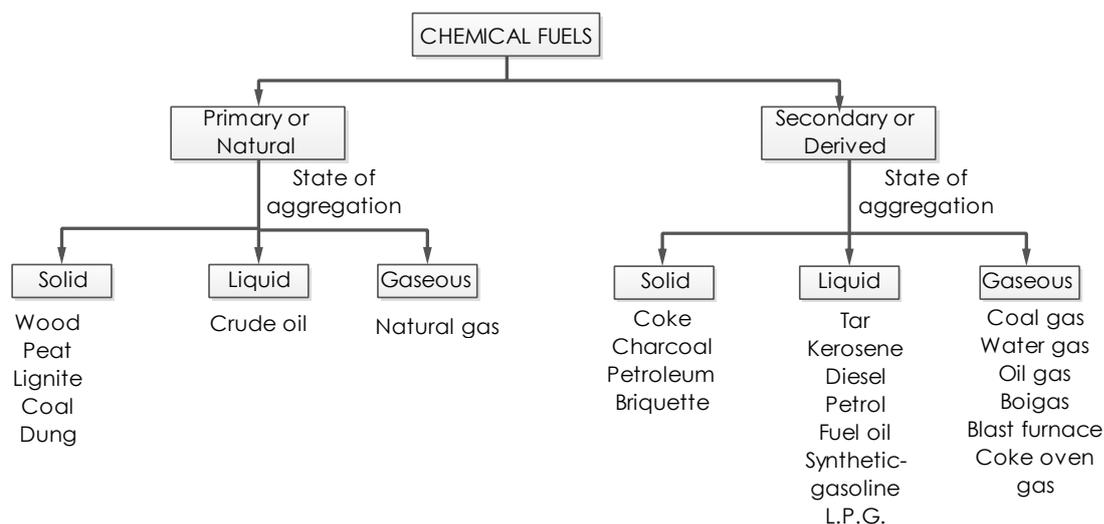
2.2 UNITS OF HEAT

2.2.1 Calorie
Calorie is the amount of heat required to raise the temperature of one gram of water through one degree Centigrade (15-16^{0}C).

2.2.2 Kilocalorie
Kilocalorie (or Kilogram centigrade units) is equal to 1,000 calories. This is the unit of metric system and may be defined as 'the quantity of heat required to raise the temperature of one kilogram of water through one degree Centigrade. Thus

1 kcal = 1,000cal

2.2.3 British thermal unit (B.T.U.)
BTU is defined as "the quantity of heat required to raise the temperature of one pound of water through one degree Fahrenheit (60-61^{0}F). This is the English system unit.

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

or   1 kcal = 3.968 B.T.U.

2.2.4 Centigrade heat unit (C. H. U.)
CHU is "the quantity of heat required to raise the temperature of 1 pound of water through one degree Centigrade." Thus

1 kcal = 3.968 B.T.U. = 2.2 C.H.U.

2.3 CALORIFIC VALUE

Calorific value of a fuel is "the total quantity of heat liberated, when a unit mass (or volume) of the fuel is burnt completely"

2.3.1 Higher or gross calorific value
Usually, all fuels contain some hydrogen and when the calorific value of hydrogen-containing fuel is determined experimentally, the hydrogen is converted into steam. If the products of combustion are condensed to the room temperature (15^{0}C or 60^{0}F), the latent heat of condensation of steam also gets included in the measured heat, which is then called "higher or gross calorific value".

So, **gross** or **higher calorific value (HCV)** is "the total amount of heat produced, when unit mass / volume of the fuel have been burnt completely and the products of combustion have been cooled to room temperature" (i.e., 15^{0}C or 60^{0}F).

2.3.2 Lower or net calorific value
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".

Alternatively, **net or lower calorific value (LCV)**
= HCV - Latent heat of water vapour formed
= HCV - Mass of hydrogen x 9 x Latent heat of steam

because 1 part by mass of hydrogen produces 9 parts by mass of water. The latent heat of steam is 587 kcal/kg or 1,060BTU/lb. of water vapour formed at room temperature (i.e., 15^{0}C).

2.3.3 Units of calorific value
The calorific value is, generally, expressed in calorie/gram (cal/g) or kilocalorie/kg {kcal/kg) or British thermal unit/lb. (B.T.U/lb.) in case of solid or liquid fuel. In case of gaseous fuels, the units used are kilocalorie/cubic metre (kcal/m^3) or B.T.U./cubic feet (B.T.U./ft^3).

$$\left.\begin{array}{l} 1 kcal / kg = 1.8 x B.Th.U ./ lb \\ 1 kcal / m^3 = 0.1077 x B.Th.U ./ ft^3 \\ 1.B.Th.u./ ft^3 = 9.3 kcal / m^3 \end{array}\right\} \quad ....(1)$$

2.4 CHARACTERISTICS OF A GOOD FUEL

> **High calorific value**

A fuel should possess high calorific value, since the amount of heat liberated and temperature attained thereby depends upon the calorific value of fuel.

> **Moderate ignition temperature**

Ignition temperature is the lowest temperature to which the fuel must be pre-heated so that it starts burning smoothly. Low ignition temperature is dangerous for storage and transport of fuel, since it can cause fire hazards. On the other hand, high ignition temperature causes difficulty in kindling (or igniting) the fuel, but the fuel is safe during storage, handling and transport. Hence, an ideal fuel should have "moderate" ignition temperature.

> **Low moisture content**

The moisture content of the fuel reduces the heating value and involves in a loss of money, because it is paid for at the same rate as the fuel. Hence, fuel should have low moisture content.

> **Low non-combustible matter content**

After combustion, the non-combustible matter remains, generally, in the form of ash or clinker. The non-combustible matter also reduces the heating value, besides additional cost of storage, handling and disposal of the waste products produced. Each per cent of non-combustible matter in fuel means a heat loss of about 1.5%. Hence, a fuel should have low content of non-combustible matter.

> **Moderate velocity of combustion**

If the rate of combustion is low, then the required high temperature may not be possible, because a part of the heat liberated may get radiated, instead of raising the temperature. On the other hand, too high combustion rates are also not required.

> **Products of combustion should not be harmful**

Fuel, on burning, should not give out objectionable and harmful gases. In other words, the gaseous products of combustion should not pollute the atmosphere. CO, SO_2, H_2S, PH_3, etc., are some of the harmful gases.

> **Low cost**

A good fuel should be readily available in bulk at a cheap rate.

> **Easy to transport**

Fuel must be easy to handle, store and transport at a low cost. Solid and liquid fuels can easily be transported from one place to another. On the other hand, transportation of gaseous fuels is costly and can even cause fire hazards.

> **Combustion should be easily controllable**

Combustion of the fuel should be easy to start or stop, when required.

> **Should no undergo spontaneous combustion**

Spontaneous ignition can cause fire hazards.

> **Storage cost**

In bulk should be low.

> **High efficiency**

It should burn in air with efficiency, without much smoke.

> **Uniform size**

In case of solid fuel, the size should be uniform so that combustion is regular.

2.5 COMPARISON BETWEEN SOLID, LIQUID AND GASEOUS FUELS

2.5.1 Solid fuels

Advantages
> Easy to transport
> Convenient to store, without any risk of spontaneous explosion
> Low cost of production
> Possess moderate ignition temperatures

Disadvantages
> High ash content

➢ Low thermal efficiency i.e. Large proportion of heat is wasted during combustion
➢ Burn with clinker formation
➢ Combustion operations cannot be controlled easily
➢ High cost of handling
➢ Lower calorific value as compared to that of liquid fuels
➢ Require large excess of air for complete combustion
➢ Cannot be used as internal combustion engine fuels

2.5.2 Liquid fuels
Advantages
➢ Possess higher calorific value per unit mass than solid fuels
➢ Burn without forming dust, ash, clinkers, etc.
➢ Their firing is easier and also fire can be extinguished easily by stopping the liquid fuel supply
➢ Easy to transport through pipes
➢ They can be stored indefinitely, without any loss
➢ The flame produced by burning liquid fuels can easily be controlled by adjusting the liquid fuel supply
➢ Generally, handled by pipes and one man can easily regulate a large number of furnaces simultaneously
➢ Clean in use and economic in labour
➢ Loss of heat to chimney is very low, due to greater cleanliness
➢ Require less excess of air for complete combustion
➢ Require less furnace space for combustion
➢ No wear and tear of grate bars and cleaning of fires, etc., unlike solid fuels.
➢ Can be used as internal combustion fuels
Disadvantages
➢ Higher cost as compared to solid fuels
➢ Costly special storage tanks are required
➢ Higher risk of fire hazards, particularly in case of a highly inflammable and volatile liquid fuel.
➢ They give bad odour
➢ Specially constructed burners and spraying apparatus are required for efficient burning of liquid fuels
➢ Choking of sprayers (during liquid fuel combustion) is a drawback of oil firing

2.5.3 Gaseous fuels
Advantages
➢ Conveyed easily through pipelines to the actual place of need, thereby eliminating manual labour in transportation
➢ Can be lighted at moment's notice
➢ Have high heat content and hence, help us in having higher temperatures
➢ Economy in heat because it can be pre-heated by the heat of hot waste gases
➢ Their combustion can readily be controlled for changes in demand like oxidizing or reducing atmosphere, length of flame, temperature, etc.
➢ Burn without any soot (or smoke) and are ash less, so there is no labour involved in ash handling, etc.
➢ Clean in use
➢ Do not require any special burner
➢ They can be produced by using even the poorest quantity of coal, etc.
➢ Burn without heat loss, due to convection currents
➢ Burn in slight excess of air supply
➢ Free from solid and liquid impurities. Hence, they do not affect the quality of   metal produced, when used as a metallurgical fuel
➢ Complete combustion without pollution is possible, due to uniform mixing of air and fuel
➢ Have high calorific values
➢ Can also be used as internal combustion engine fuels

Disadvantages
➢ Very large storage tanks are needed for them
➢ Highly inflammable, so chances of fire hazards are high in their use
➢ More costly as compared to solid and liquid fuels

Table: 1 Relative merit of solid, liquid and gaseous fuels.

Solid fuels	Liquid fuels	Gaseous fuels
Easily available and cheap.	More costly than solid fuels, but cheap only in the countries of origin.	Except natural gas, other gaseous fuels are costly.
Transport, storage and handling is convenient, without any risk of spontaneous explosion.	Can easily be transported through pipes, but care must be taken to store them in closed containers only.	Must be stored in leak proof voluminous storage tanks and can be distributed through pipelines.
There is least risk of fire hazards.	There is greater risk of fire hazards.	They are highly inflammable, so chances of fire hazards are high in their use.
Combustion is a slow process and its control and stopping is not easy.	Quick combustion takes place; and it can be controlled or stopped, when needed.	Combustion takes place rapidly and more efficiently and greater flexibility in usage is available by controlling air supply.
Labour is required in their storage, transport, etc.	Lesser handling cost is required.	Lesser handling cost is required.
Ash is always produced and its disposal is a problem. Smoke is invariably produced.	No ash problem and burning is clean, but high carbon and aromatic liquid fuels may produce smoke	Neither ash nor smoke is produced.
Cannot be used in Internal combustion engines.	Can be used in internal combustion engines.	Can also be used as internal combustion engine fuels.
Burn in large excess of air.	Burn in slight excess of air.	Also burn in slight excess of air.
W/W calorific value is least.	W/W calorific value is higher.	W/W calorific value is highest.
Their thermal efficiency is least.	Their thermal efficiency is higher than that of solid fuels.	Their thermal efficiency s highest.

2.6 BOMB CALORIMETER

This apparatus is used to find the calorific value of solid and liquid fuels.
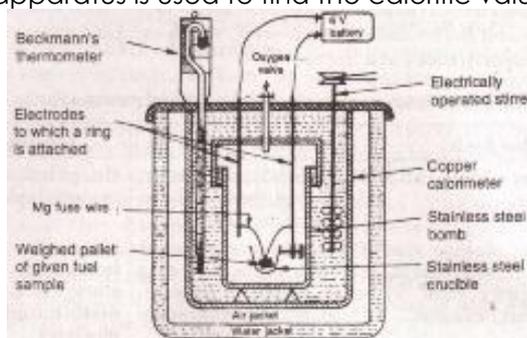
Figure: 1 Bomb calorimeter

2.6.1 Construction

It consists of a strong cylindrical stainless steel bomb in which the combustion of fuel is made to take place. The bomb has a lid, which can be screwed to the body of bomb so as to make a perfect gas-tight seal. The lid is provided with two stainless steel electrodes and an oxygen inlet valve. To one of the electrodes, a small ring is attached.

In this ring, a nickel or stainless steel crucible can be supported. 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 calorimeter is provided with an electrically operated stirrer and Beckmann's thermometer, which can read accurately temperature difference up to 1/100th of a degree.

2.6.2 Working

A known mass (about 0.5 to 1.0 g) of the given fuel is taken in clean crucible. The crucible is then supported over the ring. A fine magnesium wire, touching the fuel sample, is then stretched across the electrodes. The bomb lid is tightly screwed and bomb filled with oxygen to 25atm pressure. The bomb is then lowered into copper calorimeter, containing a known mass of water. The stirrer is worked and initial temperature of the water is noted- The electrodes are then connected to 6-volt battery and circuit completed. The sample burns and heat is liberated. Uniform stirring of water is continued and the maximum temperature attained is recorded.

2.6.3 Calculation

Let x = mass in g of fuel sample taken in crucible; W = mass of water in the 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 = higher calorific value in fuel in cal/g.

∴ Heat liberated by burning of fuel =x L and

Heat absorbed by water and apparatus $= (W + w)(t_2 - t_1)$

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

∴ $xL = (W + w)(t_2 - t_1)$

or HCV of fuel (L) $= \dfrac{(W + w)(t_2 - t_1)}{x}$ cal/g(or kcal/kg)   ....(2)

Note: The water equivalent of the calorimeter is determined by burning a fuel of known, calorific value and using the above equation. The fuels used for this purpose are benzoic acid (HCV = 6,325 kcal/kg) and naphthalene (HCV = 9,688 kcal/kg).

If H = percentage of hydrogen in fuel, then

$\dfrac{9H}{100}$ g = Mass of H_2O from 1 g of fuel = 0.09H g

∴   Heat taken by water in forming steam

= 0.09 H X 587cal   (∴ Latent heat of steam = 587cal/g)

LCV = HCV - Latent heat of water formed

= (L - 0.09 H X 587)cal/g (or kcal/kg)   ....(3)

2.6.4 Corrections

To get more accurate results, the following corrections are applied;

➢ **Fuse wire connection**

The heat liberated, as measured above, includes the heat given out by ignition of the fuse wire used.

➢ **Acid correction**

Fuels containing S and N are oxidised, under high pressure and temperature of ignition, to H_2SO_4 and HNO_3 respectively.

S + 2H + 2O_2 $\longrightarrow$ H_2SO_4 + Heat

2N + 2H + 3O_2 $\longrightarrow$ 2HNO_3 + Heat

Formations of these acids are exothermic reactions. So, the measured heat also includes the heat given out during the acid formation. The amount of these acids is analysed from washings of bomb by titration; while H_2SO_4 alone is determined by precipitation as $BaSO_4$. The correction for 1 mg of S is 2.25cal; while for 1 mL of N/10 HNO_3 formed is 1.43 cal.

➢ **Cooling correction**

Time taken to cool the water in calorimeter from maximum temperature to room temperature is noted. From the rate of cooling (7minute) and the actual time taken for cooling (t minutes), the cooling correction of $dtxt$ is added to the rise in temperature.

$$\therefore \quad L = \frac{(W+w)(t_2 - t_1 + cooling\,correction) - [Acid + fu\sec orrections]}{Mass\,of\,fuel\,(x)} \quad ....(4)$$

2.7 HEATING AND COOLING METHODS AND MEDIUMS

Let us assume that we have a vessel containing a system to which heat is to be added or from which heat is to be removed. Since the question of whether the process is one of heating or cooling is in principle merely a question of the direction of the temperature difference, no distinction need be made and we shall generally refer to the processes as if they were heating processes, whereas in some cases actual applications may be cases of cooling. The system under consideration may be one in which a chemical reaction is occurring, or it may be a purely physical process such as vaporization. We are concerned here only with the methods available for the transfer of the desired amount of thermal energy at a suitable rate. We shall consider briefly, from the standpoint of general principles only, the following heating methods and mediums:

- Hot water
- Steam
- Hot oil
- Organic vapours
- Mercury
- Fused salts
- Flue gases
- Electrical heating

It is well to recall at the start that the ultimate sources of all energy for heating are (1) fuels and (2) water power (excluding minor items such as direct use of solar energy, of wind and tide power, and a few others). The first six mediums listed are really only indirect ways of heating by means of flue gases or by radiation, which derive their energy directly from the two fundamental sources just mentioned. Heat must first be transferred to these mediums either by conduction or convection from hot gases or by radiation from hot surfaces. The main reason for the indirect method is that closer control of the temperature in the system being heated is thereby attained, and this is often vital to the success of the process. One of the most important considerations in connection with any heating method, and in fact the chief one to concern us here, is the temperature level at which the energy can be made available for transfer. Obviously, it must be greater than that of the substance being heated; the difference in temperature is, for purposes of general discussion, conveniently referred to as the "thermal head" or "potential." The available potential is directly related not only to the rate of transfer but also in many cases to the thermal efficiency. This term refers to the fraction of the available energy in a medium that gets transferred to the desired system. If the medium transferring heat is a gas, the potential decreases as heat is transferred and this limits the fraction of the energy that can be made available. For example, if a process were to be carried out at 2000^0F and the heating medium were a flue gas at 2200^0F, only about 10% of the available energy in the gases could be utilized directly. In a continuous process, some of the energy otherwise wasted in the exhaust gases might be transferred to materials entering the system, thus increasing the thermal efficiency. On the other hand, if the medium is a saturated vapour, a large proportion of the energy is available at a constant potential, which is advantageous from the standpoint both of thermal efficiency and of temperature control.

Hot water has certain limited uses as a heating medium, being particularly useful in the range between 100 and 212^0F for the heating of sensitive materials that must not be heated above a given temperature limit in this range. Saturated steam is the most desirable heating medium in the range from 212 to 600^0F. It is simple to use and control, clean, and easily available and gives uniform temperature over the entire surface and high rates of heat transfer. The temperature is readily controlled at a given point by control of the pressure since it is used as a saturated vapour. In this very fact also lies the chief disadvantage of steam, viz., that high temperatures can be attained only by concomitant high pressures. The following figures taken from steam tables give an idea of the temperatures possible with

steam at various pressures.

Gauge pressure, lb./sq.in.	Temperature	
	⁰F.	⁰C
250	406	208
800	518	270
1,400	587	308
2,000	636	335
3,200 (critical)	705	373

The critical temperature would be the absolute upper limit but not a practicable temperature at the present time for several reasons. Boilers for 1,400 lb. pressure are in use, but in general only much lower pressures would be available in most chemical plants, so that the practical limit for steam heating is nearer 400 to 450⁰F. The use of the higher pressures greatly increases the difficulties in the construction of heating surfaces, especially of the jacket type, and at high pressures the steam must be used in a coil of pipe or tubing. The Thermo coil (trade name of a commercial product) is an interesting combination of a jacket and a coil, in that the coil carrying the high-pressure steam is cast integral with the walls of the vessel to be heated. Superheated steam can be obtained at the higher temperatures without the corresponding pressures, but it is of little use as a heating medium since one loses the two big advantages of saturated steam, *viz.*, uniformity of temperature and high transfer rate. One must also bear in mind that at temperatures of 900⁰F and higher the chemical reaction between water vapour and iron surfaces becomes appreciable. In small installations it is sometimes convenient to boost the available steam pressure by means of a reciprocating compressor. As was shown in Chap. VI the compression of saturated steam gives superheated steam, which has just been shown to be undesirable as a heating medium. The compression should therefore be followed by a de-superheating step. This is readily accomplished by contacting the steam with liquid water.

In the temperature range above that readily attainable with steam and up to about 1000°F., there are three methods (excluding electrical heating for the moment) that are in industrial use where uniform temperatures and close control are needed. These are the circulation of hot oil through jackets or coils, condensation of a saturated organic vapour, and condensation of mercury vapour. The hot-oil system uses a petroleum fraction of high flash point and is mainly useful in the range 350 to 600⁰F, the upper limit being set by decomposition of the oil. The oil is circulated by a pump between the tubular heater, where it is heated by flue gases and the jacket of the vessel to which it delivers heat. Since sensible heat rather than latent heat is being used, the temperature is not uniform over the surface, the amount of variation being a function of the heat load in relation to the rate of oil circulation.

Analogous to the use of steam is the use of the saturated vapour of an organic liquid of higher boiling point than water. In this way one can attain temperatures higher than can be reached with steam and at much lower pressures. There are, however, very few organic compounds that are liquid at room temperature and yet sufficiently stable at elevated temperatures for practical use. The only compounds that have been used commercially to any extent are the aromatic compounds diphenyl and diphenyloxide. Particularly useful is the eutectic mixture of these two known as Dowtherm A containing 73.5 per cent diphenyloxide, which has a freezing point of 53.6⁰F as compared with 80.6 and 156.6⁰F., respectively, for diphenyloxide and diphenyl.

Dowtherm A is useful in the range from 400 to 750⁰F., although above 700⁰F a measurable decomposition occurs and continuous operation above this temperature requires periodic purification of the material and addition of new fluid. Its normal boiling point is 496⁰F, and at the two limiting temperatures given the vapour pressures are 4.1 and 150 lb. per sq. in. abs., respectively. The vapour is produced in a boiler fired with coal, oil, or gas and is used much as steam is used. The chief disadvantages as compared with steam are the lower temperature of decomposition, the lower rate of heat transfer, the fact that it is a combustible material and therefore offers a fire hazard, and the necessity for tighter joints in

the circulating system, since leaks must be kept to a minimum to prevent loss of material. Mercury vapour is usable in the range from 600^0F (vapour pressure about 6 lb. per sq. in. abs.) to 1000^0F (180 lb. per sq. in.), the upper limit being set by the pressure and temperature that available metals will stand. Since mercury is an element, it is absolutely stable to temperature and the question of decomposition does not enter. It has the additional advantages of very high rate of heat transfer and no fire hazard but the disadvantages of high cost, a health hazard unless proper precautions are taken, and the necessity for extreme care in securing a leak- proof system.

The use of fused salts as heat-transfer mediums is old as far as the laboratory is concerned; in relatively small baths for heat-treatment of metals they have been employed for a long time, but large-scale industrial applications are quite new. There are units now in operation with as much as 1,000,000 lb. of salt in the circulating system. The salt used in a number of installations is a mixture known as HTS, consisting of 40 % $NaNO_2$, 7% $NaNO_3$, and 53% KNO_3. It can be used over the range from 300 to 1000^0F or even to 1100^0F in some cases and is particularly useful at temperatures above the upper limit for hot oil and for Dowtherm. Its freezing point is about 290^0F, low enough so that the salt can readily be melted with steam available at most plants. The salt is entirely" stable up to 800^0F; above that a very slow decomposition occurs, which, however, is not serious even up to $1100°F$. The coefficient of heat transfer is very good, values over 2,000 B.t.u. per hr. per sq. ft. per ^0F having been reported. Another advantage of this medium is that it is used at substantially atmospheric pressure and since it has no vapour pressure the pressure does not change as the temperature level is changed. For a considerable amount of information on the properties of HTS, the reader is referred to a paper by Kirst, Nagle, and Castner. It is interesting to note, in passing, that the main application of this medium at the present time is as a cooling agent in the Houdry process of catalytic cracking.

Since practically all energy transferred as heat is originally derived from the chemical energy of a fuel, the most direct method of heat transfer is to use the products of combustion of the fuel. The maximum temperature attainable by combustion products varies with a number of factors such as the nature of the fuel and amount of excess air used; the upper limit with air is of the order of 4000^0F, and the practical limit for commonly used fuels is generally less than 3000^0F. Higher temperatures may be obtained by burning the fuel with oxygen, but at the present time this is applied only on a small scale for the welding and cutting of metals. The chief disadvantages of heat transfer from products of combustion are poor control of temperature, fouling of heating surfaces, and the large volume of gas to be handled because of its low heat capacity. Kirst, Nagle, and Castner' presented a calculation to compare air at 3 atm. abs. with HTS as a heat-transfer fluid. It was assumed that each fluid was to be circulated in 1-in. pipes with a 50^0F allowable drop in temperature and the same pressure drop due to flow. The results showed that HTS had 485 times the heat-carrying capacity of the air and would require only 1/1,700 as much power for circulation. Furthermore, the heat-transfer coefficient for the salt was 30 times that of the air.

In spite of the disadvantages of direct-fired heating, it remains the only means of transferring heat at temperatures above 1100^0F, with the exception of limited uses of electrical heating.

Electrical heating involves the direct conversion of electrical energy into other forms of energy that can be transferred as heat and that we have classified together under the general head of thermal energy. From the first law, 1 kw.-hr. of electrical energy will produce 3,412 B.t.u. of thermal energy. There are three general ways of effecting the conversion. (1) by resistance, (2) by electric arc, and (3) by induction. The material to be heated may act as the resistance itself; the heat is thus generated directly at the point it is to be applied, and no transfer problem exists. In other cases, special resistors, such as wires of chromium alloys or carbon or carborundum shapes, may be used, and the heat developed in the resistor is transferred to the point of application by radiation and/or convection. The rate of heating by resistance is given by the simple relation

$q = 3.412 I^2 R$

where,   q = rate of heat evolution, B.t.u. per hr.

I = mean current, amp.

R = resistance, ohms.

A form of electric resistance heating usually called "infrared radiant heating" has become of considerable industrial importance in recent years for the drying and baking of coatings and finishes. The heat is generated by electric currents in filaments operating at relatively low temperatures (less than 2500°K.) and by suitable reflection the infrared radiation from the filaments is directed on to the surface where the heat is to be applied. The radiant energy striking the surface is largely absorbed (the degree of absorption depending on the nature of the surface) and converted to thermal energy.

In the induction method, the material to be heated or a container for it acts as the secondary in a step-down transformer the primary of which is a coil of wire to which an alternating current is applied; the low-voltage eddy currents generated in the material or its container are entirely converted to heat. The frequency of the alternating current used is low for a magnetic material and much higher (of the order of 10,000 cycles per second) for nonmagnetic conductors. Recently, an electric heating method applicable to non-conducting materials has been developed that may solve many difficult heating problems. Unlike the previous induction methods, it does not use the transformer principle but makes the material to be heated the dielectric of a condenser in an ultra-high-frequency circuit. The molecular distortion produced by the rapid alternation of the electric field in the dielectric generates heat. Frequencies of the order of 10^6 to 10^7 cycles per second are used.

In the arc method, an electric arc is struck between two electrodes, usually carbon, after which the electrodes may be separated and the arc maintained owing to the passage of the current through vapours produced from the electrodes. The material to be heated is placed in the path of the arc or in close proximity to it.

The only limit set to the temperatures attainable by electric heating is that due to the materials used for resistors or electrodes. The highest temperature attainable in industry is that of the carbon arc (about SGOCC.); this upper limit is presumably fixed by the boiling point of carbon. Consequently, electrical heating is preeminent in the field of very high temperatures such as the manufacture of synthetic abrasives and calcium carbide. It is also used over the whole temperature range in competition with other heating methods because of certain advantages, which may be enumerated as follows:

➢ Heat can be applied directly where required, often without necessity for transfer.
➢ Ease of control.
➢ Cleanliness.
➢ Convenience in location and compactness.
➢ Control of furnace atmosphere.
➢ High thermal efficiency (in general, the only reason this is not 100 per cent is because of heat loss to the surroundings by radiation and convection).

2.8 ANALYSIS OF AIR

Air mainly consist of two gases oxygen and nitrogen, which are practically considered to constitute 1/5 and 4/5 of air by volume respectively. The list of various gases present in air by weight percent is as under

Name of the gas	% by weight in air
Oxygen	20.99
Nitrogen	78.01
Carbon dioxide	0.03 - 0.07
Argon	0.94
Hydrogen	0.01
Neon	0.0015
Helium and Krypton	0.01 - 0.02

Except CO_2 the concentration of all the gases listed above are present in air are constant. However water vapour and traces of ozone and iodine are present in air in variable amounts. Also, composition of air also depends on altitude and distance to sea, in

neighbourhood of industry, built up urban areas, nearby volcanic phenomena. Other gases such as CO, H_2S and NO_2 are also present in air.

2.9 KINETICS AND THEORY OF GASES

According to kinetic theory a gas consists of swiftly moving molecules moving in a haphazard manner. During the movement some molecules collide with one another, some others move away from one another, these phenomena leaving an average distance between the molecules. At lower pressure the average distance is large, and at high pressure the molecules are brought near to one another.

In all the three state of matter, molecules have two tendencies i.e. Attraction tendency and Repulsive tendency. The repulsive tendency is most predominant in gases, and least prominent in solids. While in most of liquids the attractive tendency in molecules is more than the repulsive tendency, so that the molecules remain together, but the attracting tendency is still less than in comparison of solids there so liquid is in fluid state. In the gases as the temperature raises the repulsion tendency increases, and pressure remaining constant the average distance between molecules increases i.e. the volume increases. Hence with fall of temperature the distance diminishes and, the molecules come closer together. Thus it becomes apparent that the average distance of molecules will progressively diminish with fall of temperature, and rise of pressure. Change of average distance of gas is quantitatively expressed by PV/T = constant

2.9.1 Critical temperature

When by decreasing the distance the molecules of a gas are brought close together the gas assumes the liquid form provided the repulsive tendency has been diminished beyond a certain point known as critical temperature which is different for different gases.

Critical temperature is the temperature below which any gas can be liquefied by increasing the pressure. Above the critical temperature any gas cannot be liquefied by compression.

2.9.2 Critical pressure

Above critical temperature the gas will never liquefy under any pressure. The minimum pressure under which gas liquefies at the critical temperature is called as critical pressure.

Therefore air should be cooled at very high pressure and low temperature for cooling purpose. The liquid form is obtained when the kinetic energy and the potential energy of the substance is approximately equal.

The critical temperature and critical pressure of some gases are as follows.

Sr. No.	Gases	Critical temperature (^{0}C)	Critical pressure (atm.)
1.	Ethylene	+9.5	50.65
2.	Methane	-82.85	45.6
3.	Nitrogen	-147.13	33.49
4.	Hydrogen	-239.9	12.8
5.	Oxygen	-118.75	49.7
6.	Acetylene	+35.5	61.55
7.	Ammonia	+132.5	112.3
8.	Carbon monoxide	-138.7	34.6
9.	Carbon dioxide	+31.3	72.9

2.10 APPLICATIONS OF INDUSTRIAL GASES

2.10.1 Oxygen
➢ It is used to produce oxyacetylene flame to cutting and welding the metals
➢ Used in L. D. process for steel production
➢ Used for artificial respiration in case of patients
➢ Used for mountain climbers and high attitude aero planes flights

2.10.2 Nitrogen

- ➢ Used in manufacture of synthetic ammonia, nitric acid
- ➢ Used in manufacture organic nitrates like propellants and explosives,
- ➢ Synthetically produced nitrates are key ingredients of industrial fertilizers
- ➢ Used in producing nitrogen oxide.
- ➢ Applied to create inert atmosphere.

2.10.3 Carbon dioxide

- ➢ As solid CO_2 in refrigeration process
- ➢ Liquid CO_2 is needed in carbonated.
- ➢ Used in creating inert atmosphere.
- ➢ As fire extinguisher
- ➢ Gaseous CO_2 used as a neutralizing agent
- ➢ Gaseous CO_2 is the basic raw material for production of Na_2CO_3, $NaHCO_3$

2.10.4 Hydrogen

- ➢ In fertilizer industries to produce NH_3 which is converted into $(NH_4)_2SO_4$, urea and HNO_3
- ➢ In hydrogenation of oils to make fats or in hardening of fatty oils
- ➢ In hydrogenating coal, low temperature carbonization tar and water gas to produce gasoline
- ➢ In hydrogenating water gas to produce methanol
- ➢ In production of HCI, which is used in large quantity in industries
- ➢ For filling in metrological balloons which are essential for upper air observation to guide the air flights
- ➢ In making oxy-hydrogen flame used for melting of platinum, quartz and in auto welding of lead
- ➢ In producing an inert media and in making tungsten filaments for electric lamps, mixture of nitrogen and hydrogen is used