**Chapter-1 (FUNDAMENTALS OF REFRIGERATION)**

* 1. **Introduction to refrigeration and air conditioning:**

The knowledge of refrigeration and air conditioning can be traced as far as some of the earliest civilizations. The ancient Chinease were aware of the fact that ice made their beverages colder and tastier during hot month of summer. Thus they cut large pieces of ice during the winter and store them in straw for later use. Similarly, the early Egyptians who had no ice on their land, used a different method to cool their drinking water. They knew that if damped this knowledge was used to solve their problems.

They took porous pots, filled them with water and placed them on the roof tops on the sun set. A little water would seep through the porous walls of the pots and the night breeze of the desert would evaporate the moisture. Thus evaporation was used to make the water cooler.

* 1. **Meaning of refrigeration effect:**

The meaning of refrigeration can be defined as the process of removing heat from a substance to be cooled and passing it on to some other substance under controlled conditions. It also includes the process of lowering and maintaining the temperature of a cooled body below the general temperature of its surroundings. In nut shell, the refrigeration means the continued extraction of heat from a cooled body whose temperature is already below the temperature of its surroundings.

* **Refrigeration:** *it is the process for producing cold and protecting our food against spoilage so that perishable food stuffs can be preserved in original state for a certain period.*
* **Air conditioning:** *it is the process of cooling/heating, cleaning and circulating the air after controlling the moisture content in it.*

**1.2.1 Domestic and commercial applications of refrigeration and air condition:**

1. Airplanes 5. Dairies
2. Auditorium 6.Cold drinks
3. Automobiles 7.Breweries
4. Bakeries 8.Computer center
5. Cinemas 10. Cold storage
	1. **Units of Refrigeration**

The practical unit of refrigeration is expressed in terms of ton of refrigeration abbreviated as TR. A ton of refrigeration is defined as the amount of refrigeration effect produced by the uniform melting of one ton (2000lbs) of ice from and at **0**$°∁$ in 24hours.

**1.3.1 S.I. SYSTEM**

In SI system, the weight of one ton of ice is taken as 907.18kg and the latent heat of fusion of ice is 334.9kj/kg. Therefore in SI system the value is ;

 Ton of refrigeration = 907.18kg × 334.9 kJ/kg

 =$ \frac{303814.582}{24}$ = 12658.94 kJ/hour

 = $\frac{303814.582}{24×60}$ = 12658.94 kJ/min. $≅$ 211 kJ/min.

 =$ \frac{ 303814.582}{24×60×60}$ = 3.516 kJ/sec.

 = 3.516 kW

Thus, this rate of cooling means one ton refrigeration.

 Hence, 1 ton refrigeration = 211 kJ/min

 = 3.516 kW

**1.4 COP (COEFFICIENT OF PERFORMANCE)**

The performance of refrigeration machine is expressed by a term called co-efficient of performance.

 It is defined as the ratio between the refrigerating effect in the evaporator to the work input ***i.e.*** heat equivalent of work supplied to the refrigerating machine.

 Let, N = Net refrigerating or cooling effect in kJ/s

 W = Work input to the machine in kJ/s

 K= Coefficient of performance of the machine.

 COP$=\frac{Refrigeration effect}{Workdone}$

 K$=\frac{N}{W}$

**1.5 Methods Of Refrigeration**

There are many methods ofrefrigeration but commonly used are given below ;

1. Ice refrigeration
2. Dry ice refrigeration
3. Air expansion refrigeration
4. Evaporative refrigeration
5. Vapour compression refrigeration
6. Vapour absorption refrigeration
7. Steam jet refrigeration
8. Gas throttling refrigeration
9. Liquid gas refrigeration

10.Thermo-electric refrigeration

**1.5.1 ICE Refrigeration**

This is the oldest method to produce cooling effect and still used for many applications for which other methods of refrigeration are not suitable. The ice can be natural or artificial. We know that the latent heat of ice is 335kj/kg. Thus, when 1kg of ice is placed in an enclosed space, it will start melting at atmospheric pressure by absorbing heat equivalent to its latent heat from the surrounding walls and changing into **0**$°∁$ water. This process results in lowering down the temperature of the enclosed space. A simple ice refrigerator is as shown in fig. 1.2.

 Ice is kept above the tray in the baffle. Material to be cooled is placed in the refrigerated space. When air comes in contact with ice, it becomes cool and heavy and starts flowing downward, cooling the material on the way by absorbing its heat, becomes light and then rises up, this is how the convection current are formed and the air circulates in the refrigerator automatically till whole of the ice placed above the tray melts away. The process is non-continuous because the ice is to be fed after each melts who have refrigeration effect. Thus in the ice refrigerator, the minimum temperature obtained is **0**$°∁$**.**

**1.5.2 Dry Ice Refrigeration**

In thismethod, in place of ice, dry ice **i.e.** solid carbon dioxide is used. During the phase change, it does not enter into liquid state and thus under sublimation change of state occurs from solid to vapour, absorbing heat equivalent to its latent heat of evaporation. It evaporates at **-78**$°∁$ at standard atmospheric pressure. So this method of refrigeration can produce much low temperature than ice refrigeration and is specially used during air transportation were perishable food stuffs are preserved by placing dry ice on the top or at sides of cartoon containing eatables to keep them in frozen condition.

**1.5.3 Evaporative Refrigeration**

Whenever any liquid evaporates, absorption of heat takes place from surroundings which is equivalent to its latent heat of evaporation. In this way, the temperature of the surroundings is decreased i.e. during summer night, an earthen pitcher or jar filled with water and placed in open air, cools the water due to evaporation. A small amount of water comes out through pores and evaporates due to the dry condition of air around the pitcher. This small amount of water takes heat from the remaining water to evaporate and thuswater in the pitcher or jar gets cooled. This method was adopted by ancient Egyptians to cool the water. Similarly, many other examples of evaporation cooling can be quoted.

 **1.** The cooling effect of fanning on a hot day is due to the evaporation of perspiration.

 **2.** In summer, after taking bath we feel cold due to the evaporation of water drops on our body.

 **3.** When a drop of petrol or spirit is put on the palm, it evaporates and absorbs heat from the skin and we feel cold.

**1.6 Introduction To Air Refrigeration System**

Air refrigeration system is one the oldest systems of cooling where air is used as a working substance. In those days, this system was universally employed due to safe properties, cheapness and availability of air as a natural gift. Later on, it became obsolete because of low coefficient of performance, high operating cost, low heat carrying capacity, non change of phase throughout the cycle and large volume to handle to produce a given amount of refrigeration effect. It has, conditioning and thus air refrigeration system has proved quite effective due to the availability of high pressure rammed air with low equipment weight.

**Advantages and Disadvantages of Air Refrigeration System**

**ADVANTAGES:**

1. The refrigeration ‘air’ is non-poisonous, harmless, easily and abundantly available. In case of leakage, there is no danger of any kind.
2. No separate mechanical and electrical power is required to operate the system which makes is highly reliable, especially for aircraft refrigeration.

(iii) The system is highly useful for aircraft refrigeration because of its light weight and less space requirements.

(iv) Air refrigeration system can be used for liquefying the gases.

**DISADVANTAGES:**

1. It has very low coefficient of performance.
2. It has high operating cost.

(iii)It requires a large volume of air to be handled for each ton of refrigeration. This results in greater size of compressor and expander.

(iv)It has low heat carrying capacity.

(v)Since air has poor conductivity and during air refrigeration cycle, there is no change of phase in air. Therefore, cooling is produced only be taking sensible heat which requires a wide range of temperature.

**1.7 REVERSED CARNOT CYCLE**

 Reversed carnot cycle falls under air refrigeration system. A machine working on reversed carnot cycle will function as a refrigerator. During one cycle of operation, there are two adiabatic and two isothermal processes. During adiabatic process, the adiabatic portion of the stroke will need very high speed and during.

 Isothermal process, the isothermal portion of the stroke will require very low speed. Thus the variation of speed in the same stroke is not practicable. Therefore the production of such a machine in actual practice cannot be made to work on this cycle but has great theoretical importance making it a worthwhile study. Fig. 1.12 (a) & (b) shows the P-V and T-S diagram of the cycle.

 Starting from point ***a***, the clearance volume of the cycle is full of air, the air expands adiabatically to point ***d***, causing the temperature to fall from $T\_{1}$to$T\_{2}$. The air then expands from ***d*** to ***c*** isothermally and the cold body is brought in contact to be cooled, doing work and taking an equivalent amount of heat at temperature $T\_{2}$**.** Now the body is removed and the air is compressed from ***c*** to ***b*** adiabatically by external power and the temperature rises from $T\_{2}$ to $ T\_{1}$. The final operation of the cycle ***ba*** is the isothermal compression during which heat is rejected to the hot body at temperature $T\_{1}$.

 The coefficient of performance is calculated from the **T-S** diagram.

 The heat extracted from the cold body is given by the area ***c d e f*** and the work done by

***a d c b.***

 Therefore, coefficient of performance (COP) = $\frac{Heat extracted from the cod body }{Work done}$

 $= \frac{Area cdef}{Area cdcb}$

 $=\frac{T\_{2} × dc}{(T\_{1 }-T\_{2})dc}=\frac{T\_{2}}{T\_{1-}T\_{2}}$

**Chapter-2 (VAPOUR COMPRESSION SYSTEM)**

**2.1 Introduction**

 A vapour compression refrigeration system is an improvement over air refrigeration system in which low vapour refrigerant from the evaporator is changed into high pressure vapour refrigerant in the compressor. Different refrigerants are used for different purposes. The refrigerant is circulated throughout the system in the air tight and leak proof mechanism without leaving the system. Alternatively, the refrigerant condenses and evaporates during the cycle. During evaporation, the refrigerant absorbs its latent heat from the evaporator, while during condensing, it gives out its latent heat to the surroundings. Therefore, the vapour compression refrigeration system may be called the latent pump system as it pumps the latent heat from low temperature to high temperature. Now vapour compression system is much used for all purpose refrigeration from smallest domestic refrigeration to a big air conditioning plant.

**2.2 PRINCIPLE**

 The principle of vapour compression refrigeration system is based upon the fact that *evaporation causes cooling*. Whenever evaporation takes place of a liquid, it gives cooling effect. For example, in a refrigerating machine, the liquid is evaporated in a part called evaporator. During evaporation, the liquid takes the latent heat from the substance to be cooled and produces cooling.

**2.3 Function of vapour compression system**

 In vapour compression system, a change in the state of vapour is called a process. When the system repeates over and over again these processes, the repetition is called a cycle. Thus the compression cycle is the compression of the refrigerant by the compressor during which the refrigerant absorbs heat from one place and releases it to an other place. Therefore in vapour compression system, there are four fundamental function required to complete one cycle these four functions are;

1. Compression
2. Condensation

(iii) Expansion and

(iv) Vapourisation

The above four functions are shown in the flow diagram (Fig. 21) to complete one cycle.

1. **Compression:** the function of compressor is to maintain the flow of the refrigerant in the system. It sucks the low pressure and low temperature refrigerant from the evaporator, compresses it by raising its pressure and temperature until the vapor temperature is greater than the condenser temperature. The cooling media of compressor is air or water.
2. **Condensation:** in the condenser, latent heat of vapourisation is removed from the high pressure and high temperature vapours. The vapours are condensed into high pressure liquid. The high pressure and low temperature vapours are collected into the receiver tank until needed to flow ahead.

**(iii) Expansion:** from the receiver tank, the liquid refrigerant passes through the expansion valve. The expansion valve control the flow of liquid refrigerant to the evaporator. It is the dividing point between the high pressure and low pressure side of the system. When the high pressure liquid refrigerant passes through the expansion valve, some of flashes into vapor and cools the remaining liquid to a low temperature of about **-10**$°∁$**.**

**(iv) Vapourisation: the low temperature** and low pressure liquid enters the evaporator. It absorb heat from the surroundings and changes into vapour from, after absorbing latent heat of vapourisation. The low pressure and low temperature vapours formed in the evaporator are sucked back by the compressor, completing the function of one cycle and compression refrigeration system.

**2.4** **PARTS AND NECESSITY OF VAPOUR COMPRESSION SYSTEM**

**2.4.1 Necessity of vapour compression refrigeration system**

 There are four necessities of vapour compression refrigeration system;

1. The compressor to establish the two pressure levels *i.e.* low pressure and high pressure. This is necessary for the function of system.
2. A condenser to reject heat from the system.
3. An expansion valve to regulate the flow of the refrigerant.
4. An evaporator to absorb heat from the system.

In addition to the above, suction line, discharge line, liquid line and receiver tank are also necessary to form a closed circuit through which he refrigerant flows while completing a cycle of vapour compressor refrigeration system.

**2.5 DRY, WET AND SUPERHEATED COMPRESSION**

**2.5.1. When the vapour is dry and saturated at the end of compression**

 Refrigerating effect, R.E. = Area 1 – 4 – e – f

 = $h\_{1}$ –$ h\_{4} $per kg of refrigerant

 **=**$ h\_{1}$ $- h\_{f3}$ ($∴h\_{4}= h\_{f3} )$

 $∴$ Coefficient of performance, COP = $\frac{RE}{W}$ = $\frac{N}{W}$

**2.5.2. When the vapour is wet at the end of compression**

**2.5.3. When the vapour is super heated at the end of compression**

**2.5.3.1. When the vapour is super heated before compression**

**2.5.3.2. When the refrigerant is subcooled or under cooled before throttling**

**2.6 Enthalpy**

Enthalpy is one of the fundamental quantities which occurs invariably in thermodynamics. It is the sum of internal energy and the pressure volume product. This sum is called enthalpy and is expressed in heat units. Symbolically, it is represented as :

 **H = U** **+** $ \frac{PV}{J}$

Where, **H** is the enthalpy i.e. total heat.

 **U** is total internal energy in heat units.

 and $\frac{PV}{J} $is the work expressed in heat units.

**2.7 Entropy**

The term entropy means transformation. It is an important thermodynamics property of a working substance introduced by clausius during the analysis of second law of thermodynamics. The entropy of a working substance increases with the addition of heat decreases with removal of heat. In reversible process over a small range of temperature, the increase or decrease of entropy, when multiplied by the absolute temperature, gives the heat absorbed or rejected by the working substance is given as ;

 $dQ=$$T dS$

 Or $dS =$$\frac{dQ}{T}$

 Where $dQ$ is the heat absorbed.

 $ T$ is the absolute temperature and

 $dS$ is the increase in entropy.

**2.8 Actual vapour compression system**

The actual vapour compression cycle in the vapour compression system differs from the theoretical cycle in many ways because of the following reasons;

1. The compression process is assumed to be isentropic (i.e. reverse adiabatic) in a theoretical cycle which in reality is not there due to the friction and other losses.
2. Transfer of heat between the refrigerant and cylinder walls is assumed to be nil theoretically but in actual practice, the cylinder wall is hotter than the incoming gas from the evaporator and colder than the compressed gas discharged to the condenser.
3. Pressure drop in the evaporator and condenser is assumed to be nil in theoretical cycle of operation but in actual practice, the pressure of the refrigerant drops is those components because of the friction.
4. Both the suction and discharge valve of the compressor are actuated by pressure difference and thus the actual suction pressure inside the compressor is slightly below the evaporator and the discharge pressure is above of condenser.
5. Theoretically the cool refrigerant enters the evaporator and dry saturated vapours travel to the compressor. But in actual practice by using heat exchanger sub cooling of the liquid and super heating of the vapour is a normal occurance.

**Chapter-3 (REFRIGERANTS)**

**3.1 Function of refrigerant**

The function of a refrigerant is to remove heat from within a refrigerated space. The refrigerant pickup heat from a place where it is not required and rejects to a place where it is not objectionable. The function of the refrigerant is performed by absorbing heat at low temperature through expansion or vapourisation and rejection is by condensation at higher temperature and pressure. For the proper function of refrigeration system, a particular refrigerant is selected for a particular application taking into consideration its desirable and indesirable properties.

**3.2 Classification of refrigerants**

The refrigerant may be classified into two main groups according to their manner of absorption or extraction of heat from the substance to be refrigerated.

1. **Primary refrigerant**
2. **Secondary refrigerant**

**3.2.1Primary refrigerants**

 The refrigerant which directly take part in the refrigeration system and cool substance by absorption of latent heat are called primary refrigerants.

 e.g. = ammonia, carbon dioxide, sulphur dioxide, methyl chloride, methylene chloride, fluorinated hydrocarbons.

**3.2.2Secondary refrigerants**

 The refrigerants which are first cooled by primary refrigerants and then used for pulling substances by absorption of sensible heat are called secondary refrigerants.

e.g. air, water, calcium chloride brine, sodium chloride brine and similar other non freezing solution.

**3.2.1.1Classification of primary refrigerants**:

1. Halo-carbon refrigerants
2. Azeotrope refrigerant
3. Hydro-carbon refrigerant
4. Inorganic refrigerant
5. Unsaturated organic refrigerant

**3.3 PROPERTIES OF R-17, R-22, R-134 (a), C**$O\_{2}$**,R-11, R-12, R-502**

* **R-717, Ammonia (N**$H\_{3}$**)**

 Ammonia is a chemical compound of nitrogen and hydrogen i.e. in one molecule, it consists one atom of nitrogen and three atoms of hydrogen.

* Ammonia is highly toxic, flammable and food destroying.
* It is the cheapest and easily available refrigerant is extensively used in ice plants, large cold storages and skating rings etc.
* Its boiling point is $-33.3^{0}C$ at atmospheric pressure and melting from solid is $-78^{0}C$.
* It has latent heat value at $-15^{0}C$ as 1315 kJ/kg.
* The condenser pressure at $30^{0}C$ is 10.78 bar.
* It becomes flammable when mixed with air and if and if 16 to 20% of gas by volume is mixed with air, it becomes an explosive mixture.
* **R-22, Freon 22 (CH** $CIF\_{2}$**) Mono chloro-difluoro Methane**
* It is non-toxic non flamable and has sweet ordour.
* THE BOILING POINT OFR-22 is $-41^{0}C$ at atmospheric pressure.
* The latent heat value is 216.5 kJ/kg at $-41^{0}C$.
* The normal head pressure at $30^{0}C$ is 10.88 bar at high side and 1.92 bar at $-15^{0}C$ at low side.

The leak detection can be checked with soap solution, halide torch or electronic detector.

* **R-134 (a) Hydro Fluoro Carbon (HCF)**
* It is composed of two carbon, two hydrogen and four fluorine atoms.
* The boiling point of R-134 (a) is $-26.16^{0}C$.
* It critical temperature is $101.1^{0}C$.
* The critical pressure is 41 bar abs.
* Its latent heat of vapourisation at $-15^{0}C$ is 205.2 kJ/kg
* Saturated vapour density at $-25^{0}C$ is 88.11 kg/$m^{3}$

**3.4 PROPERTIES OF IDEAL REFRIGERANT**

1. It should have low boiling point.
2. Its freezing point should be lower than any temperature to be maintained in the refrigerating system.
3. It should be easy to liquefy at moderate temperature and pressure.
4. It should have high latent heat valve.
5. It should be safe to handle.
6. It should be poisonous.
7. it should be non explosive.
8. It should be non corrosive to metals.
9. It should be non-flammable.
10. It should be non-toxic.
11. It should have no effect of moisture.
12. It should be well mixable with oil.
13. It should be easy to detect the leakage.
14. It should be able to withstand operating temperature and pressure.
15. It should be easily available.

**3.5Thermodynamic and thermo-physical properties**

1. **Suction pressure**: at a given evaporator temperature, the sutaration pressure should be above atmospheric for prevention of air or moisture ingress into the system and ease of leak detection. Higher suction pressure is better as it leads to smaller compressor displacement.
2. **Discharge pressure:** at a given condenser temperature, the discharge pressure should be as small as possible to allow light-weight construction of compressor and condenser etc.
3. **Pressure ratio:** it should as small as possible for high volumetric efficiency and low power consumption.
4. **Latent heat of vapourization:** it should be as largeas possible to show that the required mass flow rate per unit cooling capacity is small.
5. **Isentropic index of compression:** it should be as small as possible so that the temperature rise during compression is small.

**3.6Environmental and safety properties**

1. **Toxicity**: ideally, refrigerant used in a refrigeration system should be non-toxic. However all fluids other than air can be called as a toxic as they will cause suffocation when their concentration is large enough. Some fluids are toxic even in small concentrations.
2. **Flammability:** the refrigerant should be preferably be non-flammable and non-explosive for flammable refrigerants special precaution should be taken to avoid accidents
3. **Chemical stability**: the refrigerant should be chemically stable as long as they are inside the refrigerating system.
4. **Miscibility with lubricating oil**: oil separators have to be used if the refrigerant is not miscible with lubricating oil as in case of ammonia. Refrigerant that are completely miscible with oil are desire to handle as in case of R-12. However or refrigerants with limited solubility in case of R-22 special precautions should be taken while designing the system to ensure oil return to the compressor.
5. **Dielectric strength**: this is an important property for system using hermetic comressors. For these system are refrigerants should have high dielectric strength as possible