CHAPTER THREE

(a). The refrigerating Agent

This is the substance employed as the heat absorber or cooling agent, and is called the refrigerant.

All cooling processes may be classified as either sensible or latent according to the effect the absorbed heat has upon the refrigerant.When the absorbed heat causes an increase in the temperature of the refrigerant, then it is sensible cooling process; whereas when the absorbed heat causes a change in the physical state of the refrigerant (either melting or vaporizing), then it is latent cooling process.

Some useful terms

(b). The terms that are frequently used in Refrigeration and Air conditional operations.

i. Sensible Heat: This is heat addition to or removed from a substance which causes a change in temperature in the substance.

ii. Specific Heat Capacity: This is the amount of heat added or released to change the temperature of 1kg of the substance by 1'c. Different substance require different amounts of heat per unit mass to cause there change in temperature.

iii. Latent Heat: "This is heat, which brings about a change of state with no change in temperature.

iv. All pure substances are to change their state i.e. from solid to liquid, from liquid to gas and vice-versa.

v. Saturation Temperature: The temperature at which a fluid will change from liquid phase to vapour phase or, conversely, from the vapour phase to the liquid phase.

vi. Liquid at this temperature is called a saturated liquid, while a vapour at this temperature is called a saturated vapour. For a given pressure, the saturation temperature is the maximum temperature the liquid can have and the minimum temperature that vapour can have.

vii. Superheated Vapour: This is a vapour at any temperature above the saturation temperature corresponding to its pressure.

viii. Sub cooled Liquid: If after condensation, the resulting liquid is cooled so that its temperature is reduced below the saturation temperature, it is sub cooled.

ix. Critical Temperature: The temperature of a gas may be raised to a point such that it cannot become saturated regardless of the amount of pressure applied. The critical temperature of any gas is the highest temperature that the gas can have and still be condensable by the application of pressure.

x. Critical Pressure: Critical pressure is the lowest pressure at which a substance can exist in the liquid state at its critical temperature; that is, it is the saturation pressure at the critical temperature.

xi. Condensation: Condensation of vapour may be accomplished in several ways:

  i. By extracting heat from vapour;
  ii. By increasing the pressure of the vapour.
  iii. By some combination of these two methods.

b. Refrigerant: It is the working medium used in refrigeration systems is called the refrigerant. It is the heat carrying medium, which during the refrigerating cycle (i.e. compression, condensation, expansion and evaporation) it absorbs heat from a low temperature system and discard the absorbed heat to a higher temperature system. The natural ice, the mixture of ice and salt were the first refrigerants, later ether, NH_3, SO_2, methyl chloride and CO_2 came into use as refrigerants, in compression cycle refrigeration machines, most of the early refrigerants have been discarded for safety reasons, and lack of thermal or chemical stability. In the present days refrigerants such as halo-carbon and hydro-carbon compounds are used for air conditioning and refrigeration applications. The suitability of a particular refrigerant for a certain application is determined by its cost, thermodynamic, physical, chemical and other various practical factors and properties. There is no single refrigerant that is suitable for all applications, hence no refrigerant. A certain refrigerant may be preferred for a particular application because of its advantages for that purposes, nevertheless it still has some disadvantages when viewed with a different perspective. Therefore when choosing a refrigerant for an application the one that has greater advantages and less disadvantages will be preferred.

c. Desirable properties of a Refrigerant

We have earlier stated that no refrigerant is an ideal refrigerant; nevertheless we accept the refrigerant with the following properties to be ideal:

- Low boiling point, high latent heat of vaporisation, low specific heat of liquid low specific volume of vapour, non-corrosive to metal, non-flammable and non-explosive, non-toxic, low cost, easy to be liquefied at moderate pressure and temperature, easy to locate leaks by odour or suitable indicators, and mixes well with oil.
- The standard comparison of refrigerants, as used in the refrigeration industry, is based on an evaporating temperature 0f -15^0c and a condensing temperature of $+30^0$c

Classification of the desirable properties or characteristics of Refrigerant:
(i) Thermodynamics (ii) Physical and chemical, (iii) safety groups.

i. Thermodynamic characteristics:

(a) High latent enthalpy of vaporization: this ensures a large refrigerating effect per unit mass of the refrigerant circulated in a small capacity system, too low of a flow rate may actually lead to problems.

(b) Low freezing temperatures: otherwise large amounts of power will be required for compression.

(c) Positive evaporating pressure: pressure in the evaporator should be above atmospheric pressure to prevent air from leaking into the system.

(d) Relatively low condensing pressure: to prevent expensive piping and equipment.

ii. Physical and chemical characteristics:

(a) High dielectric strength of vapour: this permits the use of hermetically sealed compressors where vapour may come in contact with motor windings.

(b) Good heat transfer characteristics: Thermo physical properties are required that high heat transfer coefficient can be obtained. This includes properties such as density, heat, viscosity, and thermal conductivity.

(c) Satisfactory oil solubility: a system must be designed with oil solubility characteristics in mind, so that if oil is dissolved in the refrigerant or vice versa, it will not affect lubrication and heat transfer characteristics and also will not lead to oil logging in the evaporator.

(d) Low water solubility: this characteristic is essential because water in a refrigerant can lead to corrosion or freeze up in the expansion devices.

(e) Inertness and stability: the refrigerant must not react with materials it will contact and its own chemical make-up must not change with time.

iii. Safety:

(a) Non-flammability: refrigerant should not burn or aid combustion when mixed with air.

(b) Non-toxicity: it should not be toxic to humans either directly or indirectly through foodstuffs.

(c) Non-irritability: of the refrigerant means it should not cause irritation to human eyes, nose, lungs or skin.

In addition to the classes of characteristics stated above, it should be relatively low in cost and be easy to detect leaks when arise.

d. Designation System for Refrigerant (Assigning number to each refrigerant)

The ASHRAE designation system has been used in assigning a number to each refrigerant. In this system the halo-carbons and hydrocarbons are designated as follows:

(1) The first digit on the right is the number of fluorine (F) atoms in a molecule.

(2) The second digit from the right is one more than the number of hydrogen (H) atoms in a molecule.

(3) The third digit from the right is one less than the number of carbon (C) atoms, but when the digit is zero, the number is omitted.

Inorganic refrigerants are designated by adding 700 to the molecular weight of the compound. For example water (H2O) has molecular weight of 18 and its ASHRAE designation as a refrigerant is 718. The ASHRAE number designation for dichlorotetra-fluoroethane

(CCIF2CCIF2) can be determined as follows: there are four fluorine atoms, and two carbon atoms per molecule. Thus the ASHRAE designation is:

C	H	F	
(2-1)	(0+1)	(4)	= 114

Thus the refrigerant number of $CCIF_2CCIF_2$ is R-114,

Also, for monochloropenta-fluoroetthane ($CCIF_2CF_3$)

C	H	F	
(2-1)	(0+1)	(5)	= 115

Thus the refrigeration number of $CCIF_2CF_3$ is R-115.

The general chemical formula for the refrigerant (methane or ethane base) is: $C_m H_n Cl_p F_q$.

Table 3. The commonly used halocarbon refrigerants

S/N		Refrigerant number	Chemical name	
1.		R-11	Trichloromonofluoromethane	CCL3F
2.		R-12	Dichlorodifluoromethane	CCL2F2
3.		R-13	Monochlorotrifluoromethane	CCLF3
4.		R-14	Carbontetrafluoride	CF4
5.		R-21	Dichloromonofluoromethane	CHCL2F
6.		R-22	Monochlorodifluoromethane	CHCLF2
7.		R-30	Methylene chloride	CH2CL2
8.		R-40	Methyl chloride	CH3CL
9.		R-100	Ethyl choride	C2H5CL
10.		R-113	Trichlorotrifluoroethane	CCL2FCCLF2
11.		R-114	Dichlorotetrafluoroethane	CCLF2CCLF2
12.		R-115	Monochloropentafluoroethane	CCLF2CF3

Amongst the halo-carbon refrigerants discussed above, only R-11, R-12, and R-22 are the most important and are extensively used nowadays.

Classification of refrigerants: they are broadly divided into (1) primary and (2) secondary refrigerants. Primary refrigerants directly take part in refrigeration system while secondary are first cooled by the primary refrigerants before used for cooling purposes. Primary refrigerants are classified into: (1) halo-carbon, (2) azeotrope (3) inorganic and hydro-carbon refrigerants.

e. **Azeotrope refrigerants:** this refers to a suitable mixture of refrigerants whose vapour and liquid phases retain identical compositions over a wide range of temperatures. However, the mixtures have properties that differ from either of their components.

Table 4. Azeotropic refrigerants, chemical formula and refrigerant numbers

Refrigerant number	Azoetropic mixing refrigerants	Chemical formula
R-500	73.8% R-12 and 26.2% R-152	CCL2F2/CH3CHF2
R-502	48.8% R-22 and 51.2% R-115	CHCLF2/CCLF2CF3
R-503	40.1% R-23 and 59.9% R-13	CHF3/CCLF3
R-504	48.2% R-32 and 51.8% R-115	CH2F2/CCLF2CF3

f. **Inorganic refrigerants**: these refrigerants were exclusively used before the advent of halocarbon refrigerants, and are still used due to their inherent thermodynamic and physical properties.

Table 5. Inorganic refrigerants their chemical names and refrigerant number.

Refrigerants number	Chemical name	Chemical formula
R-17	Ammonia	NH3
R-729	Air	_
R-744	Carbon dioxide	CO2
R-764	Sulphur dioxide	SO2
R-118	Water	H2O

g. **Hydrocarbon refrigerants:** most of these refrigerants are used in industrial and commercial installations. They possess satisfactory thermodynamic properties but are highly flammable and explosive.

Table. 6. Hydrocarbon their chemical names and refrigerant numbers

Refrigerant number	Chemical name	Chemical formula
R-170	Ethane	C2H6
R-290	Propane	C3H3
R-600	Butane	C4H10
R-600a	Isobutene	C4H10
R-1120	Trichloroethylene	C2H4CL3
R-1130	Dichloroethylene	C2H4CL2
R-1150	Ethylene	C2H4
R-1270	propylene	C3H6

Secondary refrigerants-brines: brines are secondary refrigerants and are generally used when temperature are required to be maintained below the freezing point of water i.e. 0°C, then water is commonly used as a secondary refrigerant.

Brine is a solution of salt in water. When salt is mixed in water, it lowers the freezing temperature of the solution (and increases the boiling temperature) because the salt dissolved in water takes off the latent heat from the solution and cools it below the freezing point of water.

The mass of the salt in solution, expressed as the percentage of the mass of the solution is known as concentration of the solution. As the concentration of the solution increases, its freezing point decreases. But when the concentration of the solution is increased beyond a point, the freezing point increases instead of decreasing. The point at which the freezing temperature is minimum, is known as entectic temperature, and at this point the concentration is known as entectic concentration. The brines commonly used are $CaCl_2$, NaCl, glycols such as ethylene glycol, propylene glycol e.t.c.