CHAPTER 3
VAPOUR COMPRESSION SYSTEM

3.1 Introduction

From the inception of the refrigeration machine in 1755, a number of attempts were made for mechanical refrigeration by using air, water and ether etc as refrigerants. The vapour compression refrigeration and vapour absorption refrigeration systems were developed around 1870. The refrigeration system were also used for providing cooling and humidification for summer comfort (air conditioning)

3.2 Theoretical Cycle Analysis

The simple vapour compression refrigeration cycle is shown in Fig. 3.1, nowadays, this system is used almost everywhere and is the most popular in the refrigeration system. It consists of four essential parts 1.Compressor, 2.Condenser, 3.Expansion Valve, and 4.Evaporator. Compressor is said to the heart of the vapour compression system compresses the vapour refrigerant from the evaporator pressure(Pe) to the condenser pressure (Pc), so that vapour can be condensed at the corresponding saturation temperature (tc), the condenser rejects the heat of refrigerant to the surrounding either by water or air which is act as cooling medium. Hence the phase transfer takes place from vapour refrigerant to liquid refrigerant enters in to the expansion valve. The expansion valve, also known as the throttle valve, expands the liquid refrigerants from high pressure liquid refrigerant to low pressure liquid refrigerant. Finally, liquid refrigerant enters in the evaporator. The evaporation is achieved in coils of low pressure and temperature, where cooling effect is produced by absorbing heat from the cooling space, the refrigerant phase transfer occurs from liquid refrigerant to vapour refrigerant, only pure vapour the goes back to the compressor completing the cycle [105].

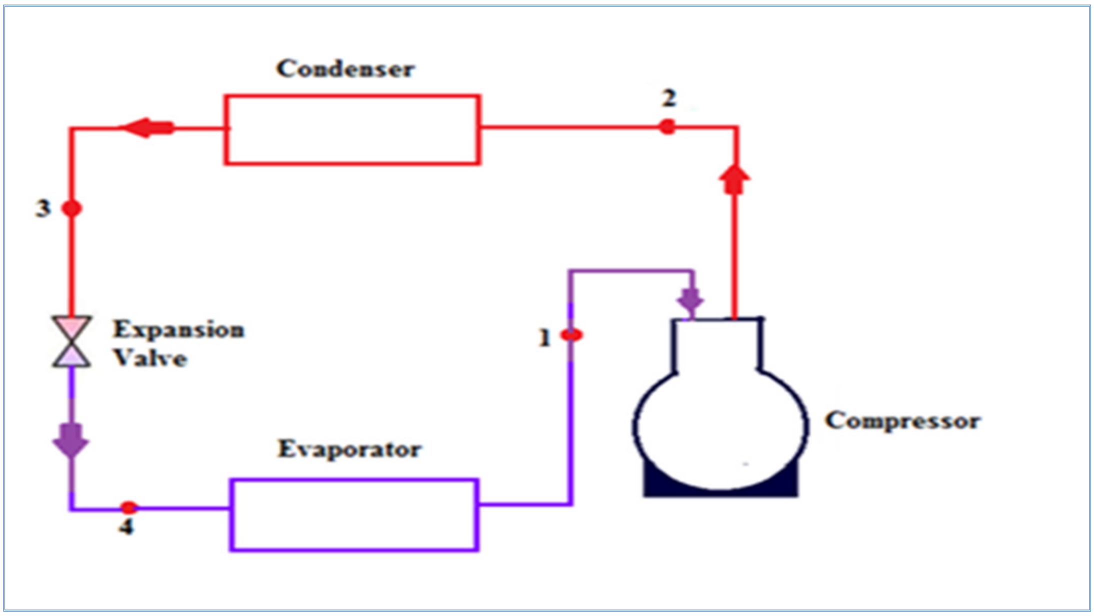

Fig. 3.1 Simple vapour compression refrigeration cycle

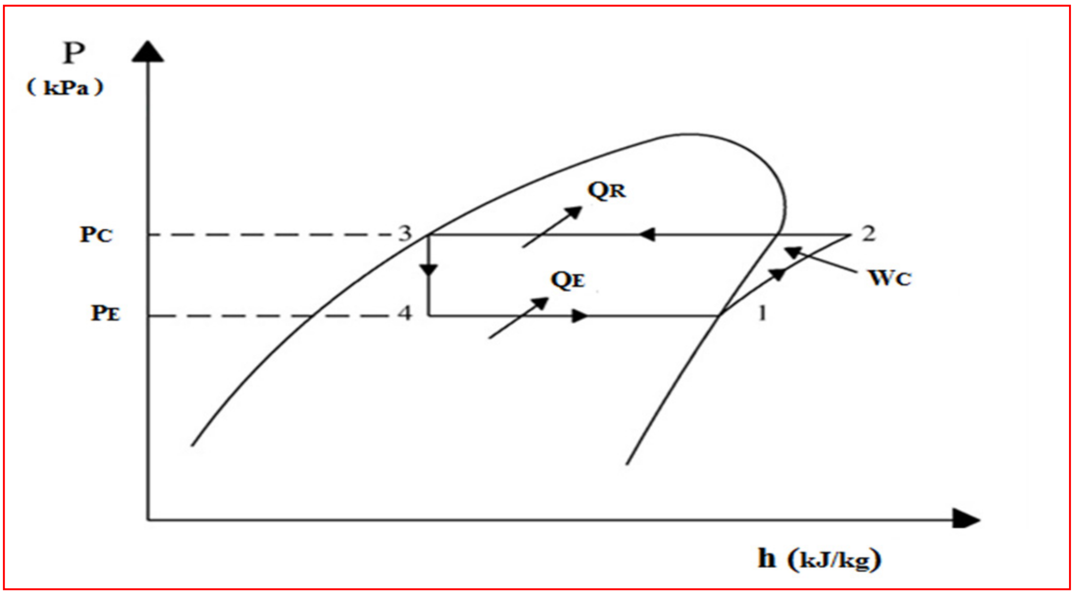

Fig. 3.2 P-h Diagram for refrigeration cycle

As shown in Fig. 3.2, the P-h diagram (Moeller diagram) for refrigeration cycle with four basic processes are frequently used in the analysis of Vapour Compression Refrigeration cycle, process 1to 2 is Compression, process 2 to 3 heat rejection in the Condenser, process 3 to 4 Expansion (Throttling) and process 4 to 1 is Evaporation i.e. heat absorbed in the evaporator. The performance characteristics are can be computed for Compressor work (Wc), Refrigeration Effect (Q_E) and Coefficient of Performance (COP).

The Performance of a Refrigerator is expressed by the ratio of amount of heat taken by the cold body to the amount of work supplied by the compressor; this ratio is called Coefficient of performance. The system performance is calculated as follows [18 &20].

The work done during the isentropic compression per kg of refrigerant is given by

$$Wc = m_r (h_2 - h_1) \quad \text{------------------------------} \quad (3.1)$$

The refrigerant effect or heat absorbed or extracted by the liquid-vapour refrigerant during evaporation per kg of refrigerant is given by

$$Q_E = m_r (h_1 - h_4) \quad \text{------------------------------} \quad (3.2)$$

The Coefficient of performance (C.O.P.) is the ratio of heat extracted in the refrigerator to work done on the refrigerator.

$$COP = \text{Refrigeration Effect/ Work Done} \quad \text{--------------} \quad (3.3)$$

$$COP = \frac{h1-h4}{h2-h1} \quad \text{--} \quad (3.4)$$

$$\text{Pressure ratio} = \frac{Pc}{pe} \quad \text{-------------------------------} \quad (3.5)$$

$$\text{Energy Efficiency Ratio (EER)} = 3.5 * COP \quad \text{---------------} \quad (3.6)$$

$$\text{Capacity of the system} = 1\ TR = 3.5\ kW \quad \text{------------------} \quad (3.7)$$

$$\text{Heat Rejected in the Condenser} = m_r * (h_2 - h_3) \quad \text{-------------} \quad (3.8)$$

Heat Absorbed in the Evaporator = m_r ($h_1 - h_4$) ---------- (3.9)

Where,

h_1 and h2 are Enthalpies of Refrigerant at the inlet and outlet of compressor (kJ/kg).

$h_3 = h_4$ are Enthalpies of Refrigerant at the inlet and outlet of expansion valve (kJ/kg).

For the air conditioning system of 1 TR capacity, with the following operating conditions the Performance of the system can be computed as:

The operating conditions have been chosen for condenser temperature of 54.5˚C and evaporator temperature 7.2˚C for selected three different types refrigerants (R22, R32 and R410A) in vapour compression cycle [17].

For the theoretical analysis, the vapour refrigerant is in dry saturated condition at the beginning of the compression, using P-h chart of R22 (Appendix-E) the following properties obtained are.

Enthalpy of the refrigerant at entry to compressor is h_1 = 395 kJ/kg

Enthalpy of the refrigerant at the at outlet of the compressor is h_2 =435 kJ/kg

Enthalpy of refrigerant at outlet of the expansion valve $h_3 = h_4$ = 252 kJ/kg

Pressure at the in the evaporator = 6.26 bar

Pressure in the condenser = 21.51 bar

From the equation (3.4),

$$\text{COP} = \frac{h1-h4}{\text{h2}-\text{h1}}$$

$$\text{COP} = \frac{395-256}{435-395} = 3.4$$

$$\text{Pressure ratio} = \frac{Pc}{\text{pe}} = 3.43$$

Energy Efficiency Ratio (EER) =3.5 * COP

= 12.49

Capacity of the system = 1 TR = 3.5 kW

The net refrigeration effect = m_r * (h_1-h_4) = 3.5 kW

Mass flow rate of refrigerant = 3.5/ (h_1 –h_4)

Mass flow rate of refrigerant = 0.0244 kg/s

Compression work = m_r *(h_2 –h_1)

=0.0244 *(h_2 –h_1)

=0.976 kW

Heat rejected in the condenser = m_r * (h_2 –h_3)

= 4.27 kW

Heat absorbed in the evaporator = m_r (h_1 – h_4)

=3.29 kW

By using P-h chart of R410A (Appendix-F) the following properties obtained are

Enthalpy of the refrigerant at entry to compressor is h_1 = 405 kJ/kg

Enthalpy of the refrigerant at the at outlet of the compressor is h_2 =440 kJ/kg

Enthalpy of refrigerant at outlet of the expansion valve h_3 =h_4 = 290kJ/kg

Pressure at the in the evaporator = 10bar

Pressure in the condenser = 33.92bar

From the equation (3.4),

COP $= \frac{h1-h4}{\mathrm{h2-h1}}$

COP $= \frac{405-290}{440-405}$ = 3.28

Pressure ratio $= \frac{Pc}{\mathrm{pe}}$ = 3.31

Energy Efficiency Ratio (EER) =3.5 * COP

= 11.76

Capacity of the system = 1 TR

= 3.5 kW

The net refrigeration effect = $m_r * (h_1 - h_4) = 3.5$ kW

Mass flow rate of refrigerant = $3.5/ (h_1 - h_4)$

Mass flow rate of refrigerant = 0.0304kg/s

Compression work = $m_r *(h_2 - h_1)$

$=0.0304*(h_2 - h_1)$

=1.064 kW

Heat rejected in the condenser = $m_r * (h_2 - h_3)$

= 4.56kW

Heat absorbed in the evaporator = $m_r (h_1 - h_4)$

=3.5 kW

By using P-h chart of R32 (Appendix-G) the following properties obtained are

Enthalpy of the refrigerant at entry to compressor is $h_1 = 500$ kJ/kg

Enthalpy of the refrigerant at the at outlet of the compressor is $h_2 = 555$ kJ/kg

Enthalpy of refrigerant at outlet of the expansion valve $h_3 = h_4 = 315$ kJ/kg

Pressure at the in the evaporator = 10.1 bar

Pressure in the condenser = 34.1 bar

From the equation (3.4),

COP $= \frac{h1 - h4}{\mathrm{h2 - h1}}$

COP $= \frac{500 - 315}{555 - 500} = 3.36$

Pressure ratio $= \frac{Pc}{pe}$ = 3.37

Energy Efficiency Ratio (EER) =3.5 * COP

= 11.76

Capacity of the system = 1 TR = 3.5 kW

The net refrigeration effect $= m_r * (h_1 - h_4)$

= 3.5 kW

Mass flow rate of refrigerant $= 3.5/(h_1 - h_4)$

Mass flow rate of refrigerant = 0.0189 kg/s

Compression work $= m_r * (h_2 - h_1)$

$= 0.0189 * (h_2 - h_1)$

=1.03 kW

Heat rejected in the condenser $= m_r * (h_2 - h_3)$

= 4.53kW

Heat absorbed in the evaporator $= m_r (h_1 - h_4)$

=3.49 kW

The refrigeration capacity by of refrigeration is its cooling capacity or heat transfer rate that it can provide for cooling. The SI unit for the heat transfer rate is kW, however, the refrigeration capacity is still measured in “Ton of Refrigeration (TR)”.One ton of refrigeration is equivalent to 3.5kW, and i.e. the heat is removed from the substance to produce cooling effect.

The system thermodynamic performance parameters are measured in terms of COP, where as the system appliance rating is measured in Energy Efficiency Ratio (EER).It is ratio between net cooling capacities (Btu/hr) to the total electrical input (W) under designed operating conditions.

The relation between Coefficient of performance (COP) and Energy Efficiency Ratio (EER) can be written as EER = 3.5 X COP [9].

3.2.1 Effect of super heating and sub-cooling

The performance vapour compression refrigeration system is mainly depends on following two important processes:

1. Superheating of vapour refrigerant and
2. Sub-cooling of liquid refrigerant

Superheating and sub –cooling process will influence the cooling capacity and compressor work. Fig. 3.3 & Fig 3.4 shows the effect of super heating and sub cooling in the vapour compression cycle the vapour leaving the evaporator is usually at temperature lower than the temperature of the surrounding, hence it is desirable superheat the vapour before its entry into the compressor. Superheating increases the refrigerating effect and amount of work supplied to the compressor. Since the increase in refrigerating effect is less as compared to the increase in work supplied, the net effect of superheating is to reduce COP.

The higher the sub-cooling the higher is the efficiency [3&16] the degree of this sub cooling depends on size of condenser, ambient conditions and refrigerant used. The greatest amount of heat is transferred during the change of state. If the refrigerant after condensation process $2\text{-}3^1$ is cooled below saturation temperature $T_3{}^1$ by throttling before expansion, then the process is called sub cooling or under cooling it is done along the saturated liquid line Sub cooling increases the refrigerating effect per kg of refrigerant circulated[81]. Since refrigerant effect is more; the amount of refrigerant circulated can be reduced.

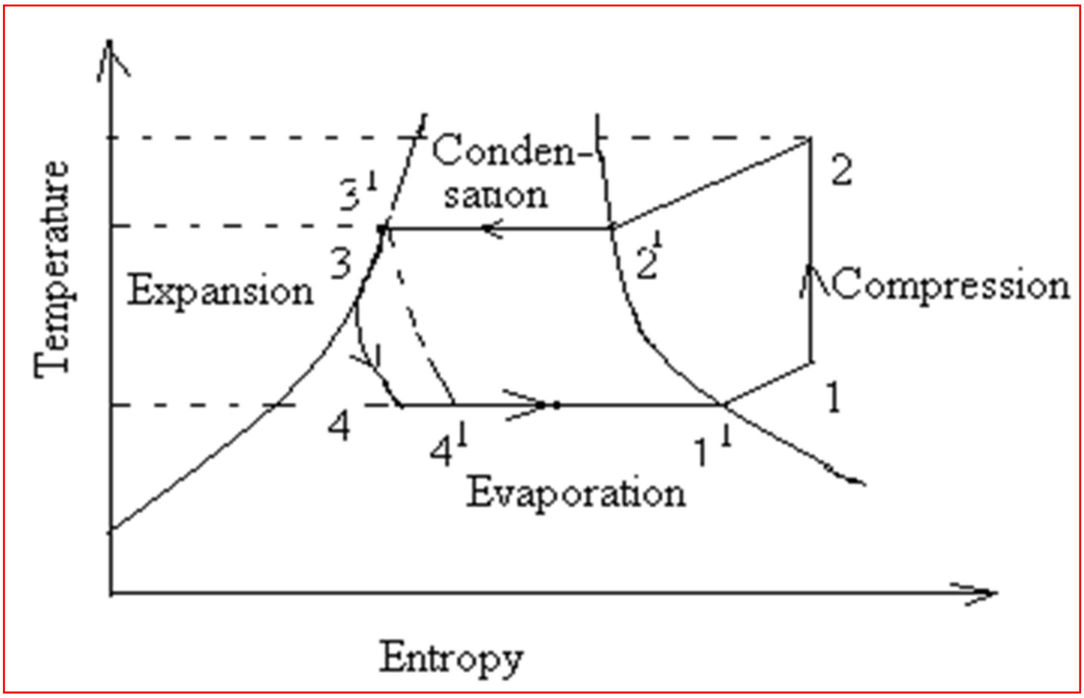

Fig. 3.3 T-s plot with Sub-cooling and Super heating

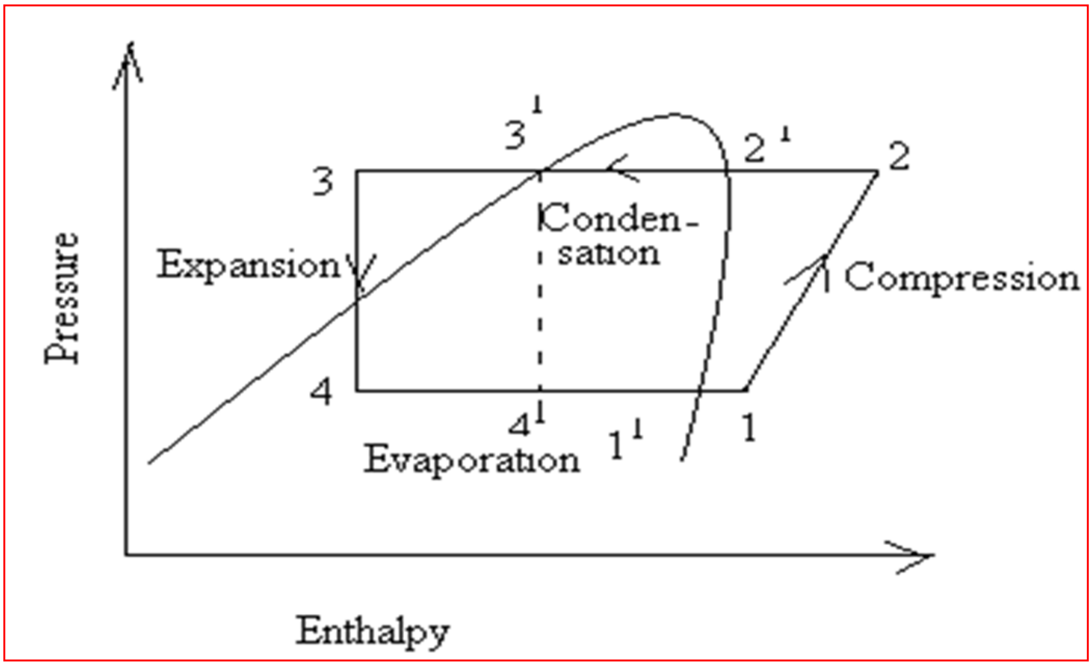

Fig. 3.4 P-h Plot with Sub-Cooling and super heating

As the mass flow rate of the refrigerant is less, the volume of vapour handled by the compressor is less per "TR". Although the work of compression does not change with sub cooling the COP is improved as net refrigerating effect is higher. As the mass flow rate per ton of refrigerant is less, the power input per ton of refrigeration is less. Sub Cooling is achieved by two methods: (1) By using a liquid suction heat exchanger and (2) By using a sub cooler piped in series or parallel with condenser. It must be observed that the superheating and sub-cooling is done for practical reasons.

3.2.2 Effect of suction and discharge pressure

As shown in Fig.3.5 and Fig. 3.6, the suction and discharge pressures are effect the refrigeration cycle, if the suction pressure decreases, there will be decrease in refrigeration effect from (h_1 - h_4) to (h_1^1 - h_4) and increase the work of compression from (h_2 - h_1) to (h_2^1 - h_1^1). Since the COP of system is the ratio between net refrigeration to work of compression, there the decrease in suction pressure, the COP decreases ultimately the refrigeration capacity decreases and the cost of refrigeration increases. If the condenser pressures increases the compressor work increases from (h_2-h_1) to (h_2^1 -h_1) and the refrigeration effect decreases from (h_1-h_4) to (h_1-h_4^1) hence the coefficient of performance decreases. The condenser will operate at higher pressure, hence the condenser must be strong to withstand higher pressures which increases the initial cost of the system.

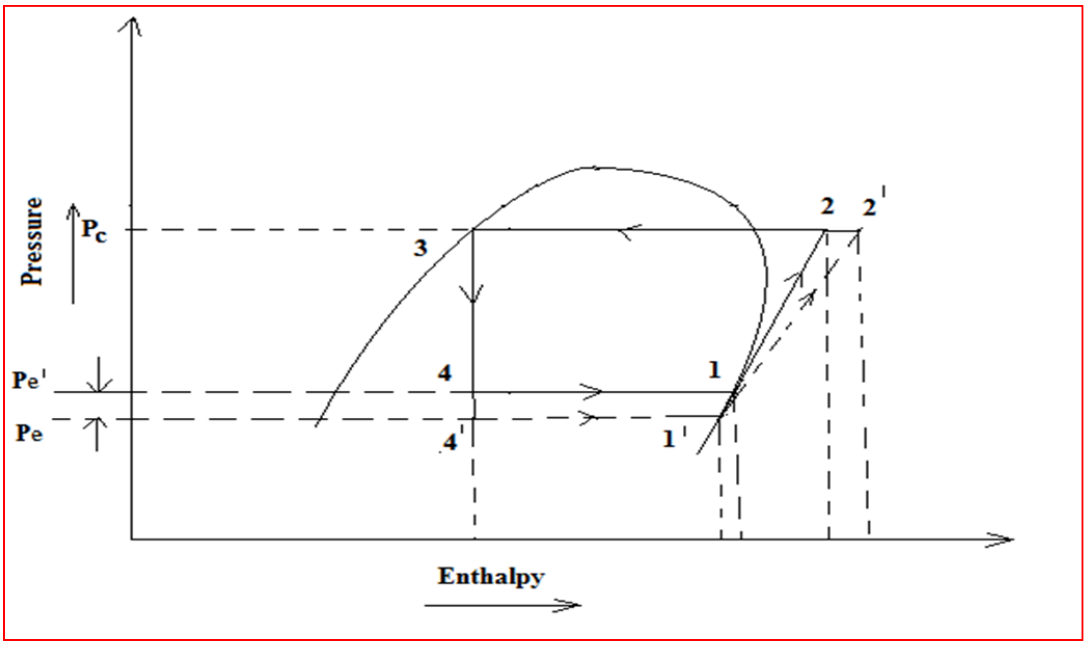

Fig. 3.5 Effect of suction pressure

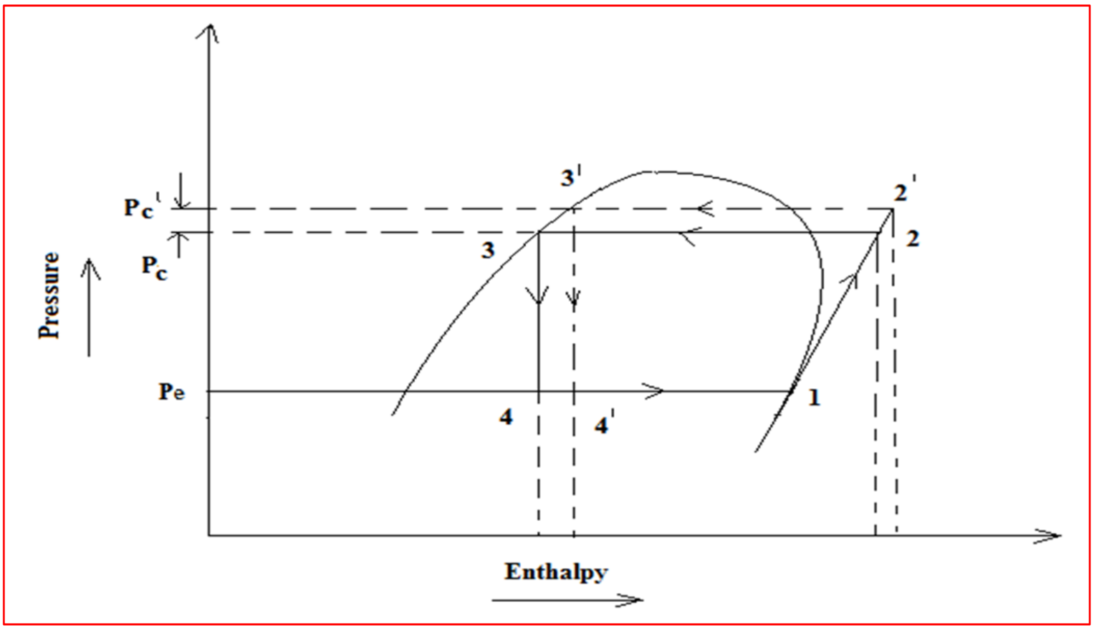

Fig. 3.6 Effect of discharge pressure

3.3 Refrigerant Classification

Refrigerants are working substances or heat- carrying medium in refrigeration system, during a refrigeration cycle heat is absorbed from a low temperature system and rejects the heat to a high temperature system.

Refrigerants can be classified as follows:

(I) On the basis of working principle:

(A) Primary refrigerants and (B) Secondary refrigerants

(A) Primary refrigerants

The refrigerant which directly participate in the refrigeration system and cools the products or substances are called Primary refrigerants. These refrigerants undergo change of phase during heat absorption or heat rejection in the evaporator and condenser..

(B) Secondary refrigerants

This refrigerant does not directly participate in the refrigeration cycle, but is used only as a medium for cooling. This refrigerant first cooled by primary refrigerants and then cools the substance which is to be maintained at lower temperatures. Examples are H_2O, Brine and calcium chloride solutions.

Qualities of secondary refrigerants:

- Remain liquid state under all working conditions
- Non corrosive when in contact with metal
- High specific heat and
- Undergo no change when in contact with refrigerants or other gases.

(II) On the basis of nature of the refrigerants:

(A) Natural Refrigerants and (B) Artificial or synthetic refrigerants

(III) On the basis of safety:

(A) Safety refrigerants and (B) Flammable refrigerants

(IV) On the basis of chemical composition

(A)Halocarbon refrigerants, (B) Hydrocarbon refrigerants,

(C)Inorganic refrigerants and (D) Mixture refrigerants

The Halocarbon compound refrigerants were invented and developed by Charles Kettering and Dr.Thomas Migely in 1928.the American society of Heating, refrigeration and Air-Conditioning Engineers (ASHRAE) identifies 42 halocarbon compounds as refrigerants [14, 66 &72]. These refrigerants are sold in the market under trade names as Freon, Genetron, Isotron and arcton.

The Hydro-carbon refrigerants are highly flammable and explosive, most of the organic compounds are considered as refrigerants under this group. Many hydrocarbon refrigerants are successfully used as refrigerants in industrial and commercial installations.Inorganic refrigerants were extensively used before the introduction of hydrocarbon refrigerants. These refrigerants are still in use due to their inherent thermodynamic and physical properties. Mixture refrigerants comprise multiple components with different volatilities when used in refrigeration systems; R410a is azeotropic mixture of HFC-32and HFC-125 in proportion of 50/50 % by weight [30].

(V) On the basis of Mixtures:

There are three categories of mixtures; these are the alternative solution for the problems of limited available of pure and natural refrigerants.

- Azeotropes
- Near-Azeotropes

- Zeotropes

Azeotropes are the stable mixture refrigerants, these behaves as single component at a given concentration i.e. whose vapour and liquid phases retain identical over a wide range temperatures.

Near-azeotrope is also mixture refrigerants with only small difference (2-10K) in liquid to vapour composition exist in equilibrium conditions. The third type of mixture refrigerants are posses' large amount temperature and compositions of individual phase during evaporation.

Based on the knowledge, some of the commonly used refrigerants used for refrigeration and air conditioning are given as follows with their chemical name, chemical formula and the number.

Methane Series:

CHFC ------------------R22 ------------------------------Monochlore difluoro methane

HFC ------------------R32 -----------------------------Difluoro methane

Ethane Series:

CHFC-------------------R123 ($CHCL_2 – CF_3$) -------------Dichloro trifluro ethane

HFC -------------------R125 ($CHF_2 –CF_3$) ----------------Pentafluoro ethane

HFC---------------------R134a (CH_2F-CF_3) ----------------Tetrafluoro ethane

HFC --------------------R143a ($CH_3 –CF_3$) ------------------Trifluro ehane

HFC---------------------R152a (CH_3-CHF_2) -----------------Difluro ethane

Propane Series:

HFC--------------------R245fa ($C_3H_3F_3$) ------------------Pentafluoro propane

HC------------------------R290 (C_3H_8) ------------------Propane

Butane Series:

HC --------------------------R600a---- (C_4H_{10}) --------------Isobutane

Zeotropic Blends:

HFC ------------------------R407A [R125/143a/134a (44/52/4)]

HFC ------------------------R407C [R32/125/134a (23/25/52)]

HFC -------------------------R410A [R32/125(50/50)]

Azeotropic Blends:

HFC ------------------------R507A [R125/143a (50/50)]

Inorganic refrigerants:

(NH3) -----------------------R717----------------------------Ammonia

(H_2O) -----------------------R718----------------------------Water

(CO_2) ---------------------- R744--------------------------- Carbon dioxide.

The only refrigerant that is currently being used for methane series is R22.The refrigerant being currently used from ethane series are R134a, R123.R152a is also being used in Europe.

3.4 Properties of Refrigerants

An ideal refrigerant should give a good coefficient of performance and also safe to use while operating between the pressures. There is no ideal refrigerant which can be used under all operating conditions. The characteristics of some refrigerants make them suitable for use with reciprocating compressor and other refrigerants are best suited to centrifugal compressor or rotary compressor. Therefore in order to select a correct refrigerant, it is necessary that it should satisfy those properties which make it ideal to use for the particular application [62].

The properties of refrigerants are essential in determining its use for a particular application. There are three groups of properties,

(I). Thermodynamic properties of refrigerants,

(II). Chemical properties of refrigerants and

(III). Physical properties of refrigerants

(I) Thermodynamic properties of refrigerants:

1. Boiling point temperature:
   - Low boiling temperature at atmospheric pressure is desirable. It increases the capacity of plant
2. Freezing point temperature:
   - The freezing point should be low to prevent the refrigerant which will leads to choking of valves etc
3. Evaporator and condenser pressures:
   - The evaporative pressure and condenser pressure should be positive i.e., above the atmospheric pressure in order to avoid air leakage into the system
4. Critical temperature and pressure:
   - Critical temperature for a refrigerant should be high to prevent excessive power consumption
   - Critical pressure should be low so as to give low pressure
5. Latent heat of vaporisation:
   - Latent heat of vaporization should be large to minimize the quantity of refrigerant used
6. Coefficient of performance:

- High COP is desirable to reduce the running cost

7. Specific volume:

- Low specific volume reduces the size of the compressor

8. Power requirement:

- Power require should be low as possible
- Increases the system coefficient of performance

(II) Chemical properties of refrigerants:

- Non flammable and non-explosive
- Non-poisonous, non-toxic and no effecting food stuffs
- Should not have any disagreeable odor
- Should not have any corrosion action on the parts of the system

(III) Physical properties of refrigerants:

1. Stability and inertness:

- An ideal refrigerant should not decompose at any temperature of refrigeration system.
- It should not form higher boiling point liquids or solid substance through polymerization

2. Corrosive property:

- An ideal refrigerant should not corrode with metals

3. Viscosity:

- Low viscosity is desirable for better heat transfer and low pumping power

4. Leakage tendency:

- Leakage tendency of a refrigerant should be low to prevent loss of refrigerant

5. Dielectric strength:

- Dielectric strength for a refrigerant is desirable to prevent electric motor directly exposed to the refrigerant

6. Thermal conductivity:

- High thermal conductivity of a refrigerant is desirable because it reduces the flow rate of refrigerant for a given capacity

7. Cost:

- The cost of the refrigerant should be low
- It vary depending upon the capacity of refrigerating system

The characteristics of some refrigerants make them suitable for use with reciprocating compressor and other refrigerants are best suited to rotary or centrifugal compressor. Therefore in order to select a correct refrigerant, it is necessary that it should satisfy those properties which make it ideal to be used for the particular application. High flammable refrigerants have bigger risk, the refrigerant R-410A is comes under class 1, Non-Flammable refrigerant and R-32 is comes under class A2L low flammable refrigerant with low burning velocity category which has been classified by ASHRAE 34 standards.

3.5 Refrigerant Designation

There are large numbers of refrigerants and many of the refrigerants have large chemical formulas, which become very difficult to express and remember their name sometimes. Kettering and Migley introduced a classification to express all the refrigerants by a very common notation called R (m-1) (n+1) (q).American Society of Heating, Refrigeration and Air –conditioning Engineer (ASHRAE) had been adopting the nomenclature. The general chemical formula for the refrigerants is given as CmHnClpFq in which n + p + q = 2(m+1)

m : number of carbon atoms→ (m -1)

n : number of hydrogen atoms →(n +1)

p : number chlorine atoms

q : number halogen atoms like fluorine / bromine / iodine.

As shown above the number for the particular refrigerant is given by R(m-1)(n+1)(q)

Example :(I) Dichloro-Monochloro –Methane

The chemical formula→$CHClF_2$

R → Refrigerant

m→ 1

n→1

P→1 and

q→2

n + p + q = 2 (m+1)

1+1+2 =2(1+1)

4=4

It satisfies the balance equation so that the chemical formula is correct. The Designation for the above refrigerant stands that: R (1-1) (1+1)2 =R_{22}

Example (II) :(I) Difluoro –Methane

The chemical formula→CH_2F_2

R → Refrigerant

m→ 1

n→2 and

q→2

n + p + q = 2 (m+1)

2+0+2 =2(1+1)

4 = 4

It satisfies the balance equation so that the chemical formula is correct. The Designation for the above refrigerant stands that: R (1-1) (2+1)2 = R_{32}

The nomenclature for other refrigerants which do not fall under the halocarbon category, is as follows

(i) Cyclic organic compounds with four carbon atoms are numbered using digit 300 series after R.

Example: R316→Trochloro Hexafluoro cyclobutane ($C_2C_{l3}F_6$)

R318→Octafluoro cyclobutane (C_4F_8)

(ii) Azeotropes are numbered with digits 500 series after R.

Example: R500 → (CCl_2F_2 / CH_3CHF_2)

R501 → ($CHCLF_2$ / $CClF_2CF_3$)

(iii) Zeotroes are numbered with digits 400 series after R

Example: R407C→R32+R125+R134a (23% +25% +52%)

R410A→ R125+R32 (50% /+50%)

(iv) Certain organic compounds are given with digits 600 series

Example: R600a→C_4H_{10}

The subscript 'a' denotes as an isomer i.e. these compounds have same chemical formula and same atomic weight but different chemical structure.

(v) Propane series Refrigerants

Example: R290→C_3H_8 (Propane)

(vi) Inorganic Refrigerants

Example: R717→NH_3, Ammonia
R718→H_2O, Water

Table 3.1 shows the different thermodynamic properties, there no ideal refrigerant which can be used under all operating conditions. The characteristics of some refrigerants make them suitable for use with rotary compressor, and other refrigerants are best suited to reciprocating compressors. Therefore in order to select better suitable refrigerant, it is necessary that refrigerant should satisfy those properties make it ideal to be used for the particular applications [101&86]. In the Refrigeration Cycle the evaporator temperature is assumed to enter at -15°C (saturated vapour) and Condenser temperature is assumed as 30°C.The theoretical comparison of refrigerant R22, R410A and R32 of various properties and Performance parameters affecting COP for air conditioning system.

Table.3.1 Comparison of properties of selected refrigerants

Refrigerant and their properties	**R22(HCFC)**	**R410A (HFC)**	**R32 (HFC)**
Chemical Name	Monochlorodiflurometh ane	Azeotropic Blend	Difluoro Methane
Chemical formula	$CHClF_2$	R32+R125	CH_2F_2
Molar Mass(g mol^{-1})	86.468	72.585	52.024
Safety Designation	A1	A1	A2
ODP	0.05	0	0
GWP	1700	2100	650
Boiling Point	-41 ° C	-52.7 ° C	-51.75 ° C
Critical Temperature	96 ° C	72 ° C	78° C
Critical Pressure	49.38 bar	49.026 bar	58.3 bar
Critical Density kg/m^3	523.8	553	424
Critical Volume m3/kg	0.001904	0.00205	0.002326
Freezing point ° C	-160	-155	-213
Cop(Te= -15˚C &Tc= +30˚C)	4.66	4.87	4.599
Compression ratio (Pe at -15 ° C and Pc at +30 ° C)	4.05	3.91	3.95
Colour	Light Green	Rose	Clear, Colorless
Flammability	Nil	Nil	Low Flammable
Composition	Single	Mixtures	Single
h_{fg} (kJ/kg at 25 ° C)	180.3	192.6	272.5
Sat. Liquid Density at 25 ° C kg/m^3	1191	1065	961
Sat.Vapour Density at 25 ° C kg/m^3	44.8	64.2	47.2
Atmospheric Life years	15.8	---	7.3
Refrigerant Charge (kg)	0.9	0.85	0.65

Refrigerants are classified by ASHRAE under latest standards -34 as Class 1, 2, 2L, and 3 for their flammability characteristics, and Class A and B for non–toxic characteristics respectively. The specific classification is based on their respective flammability variables such as flame velocity. The flame velocity is the variable used to classify refrigerants between classes 2 and class 2L under which the refrigerant with a flame velocity below 10 cm/s were recently classified as 2L by ASHRAE- Standards-34. R32 can be serving as the initial candidate for new equipment to meet any potential HFC phase down proposals for at least until 2020[12 &72].

3.6 System Design Consideration

A window air conditioner is basically an enclosed assembly designed to be a compact unit primarily for mounting in a window, through the wall. The function of a window mounted room air conditioner is to provide comfort to occupants in the room by circulating clean, cool air.

A complete unit of room air conditioner consists of the refrigeration system, the control system, electrical system, air circulation system ventilation and exhaust system.

The basic components in a window air conditioner are as follows:

1. Compressor which pumps up the low pressure refrigerant from the evaporator to the condenser as super heated vapour at high pressure. Generally the hermitically sealed type of compressors is used for air conditioners.
2. Evaporator is an important device used in low pressure side of the refrigeration system. Evaporator in which heat, from room air is absorbed by the circulating refrigerant and cooled, for recalculating into the room.
3. Condenser in which the refrigerant rejects heat to the atmosphere, absorbed in the evaporator. The phase transfer takes place in the condenser i.e. superheated vapour refrigerant to liquid refrigerant. Air cooled condenser are generally used. It consists of copper tubing through the refrigerant flows.
4. Capillary tube which throttles refrigerant from high pressure liquid to low pressure liquid.

5. Single phase double-ended shaft fan motor on to which impeller and propeller are fitted which draw air onto evaporator and condenser.
6. An air filters which arrests dust from air entering the evaporator.
7. Damper controls for fresh air ventilation and room air exhaust.
8. A set of sheet metal components with thermal insulation wherever necessary.
9. Control panel equipped with controls for operating the unit which includes a room air temperature control device.

Fig. 3.7 shows, the importance of proper system design when hermetic compressors are used on appliances, Compressors cannot over 64 emphasized, because the motor and compressor assembly in the hermetic compressor necessitate holding mechanical, electrical and thermodynamic variables within the limits specified for safe and trouble free operations.

The ultimate effect of refrigeration load is to influence the following parameters

- Suction and Discharge pressure
- Return gas temperature
- Current Drawn
- Motor winding temperature.

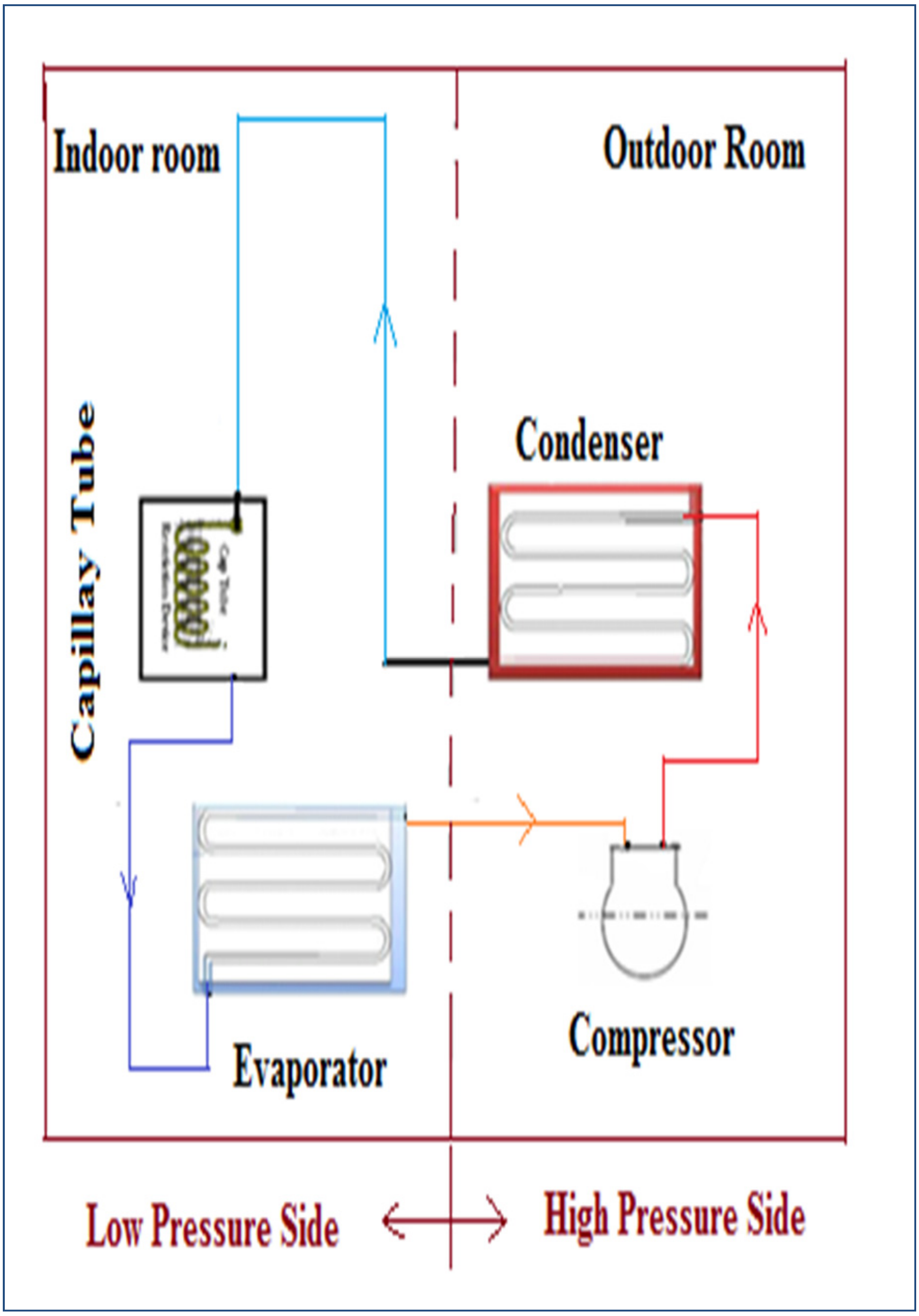

Fig. 3.7 system design considerations

3.6.1 Consideration of critical factors

- Ambient temperature
- Compressor selection
- Air flow over compressor shell
- Condenser design
- Air flow through condenser
- Evaporator design
- Air flow through evaporator
- Selection of refrigerant control device
- Refrigerant used
- Heat exchangers
- Refrigerant piping's.

Compressors are designed for operating at normal ambient temperature and adverse conditions up to 46˚C.

3.7 Selection of Compressor

The compressors are normally classified as under:

a) High Back Pressure units Rating at +7.2˚C Evaporator temperature [HBP]

b) Medium Back Pressure units Rating at -6.7˚C Evaporator temperature [MBP]

c) Low Back Pressure units Rating at -23.3˚C Evaporator temperature [LBP]

It is important to ensure that the compressor is selected on the basis of the operating back pressure, which in turn directly related to the cooling coil operating temperatures. High back pressure compressors should never be used on the low temperature applications, since the cooling of the motor windings depend both on gas temperature and amount of refrigerant circulated through the compressor. The high back pressure compressors would have inadequate refrigerant flow over the motor winding to bring about the desired cooling. Low back pressure applications may also require high torque motor to cope with the higher differential pressures.

3.8 Selection of Condenser

Condensers are basically heat exchangers in which the refrigerant undergoes a phase change. In refrigeration system condenser is used in high pressure side. Its major function is to remove heat of hot vapour refrigerant which is discharged from the compressor. In condensers the refrigerant vapour condenses by rejecting heat to an external fluid, which acts as a heat sink [23 &48]. The condenser should be designed to dissipate the sum of the heat absorbed by the evaporator and the work of compression and also to provide adequate sub cooling to the liquid refrigerant in order to improve the cycle efficiency. The design of condenser should be a compromise between economy and safe operating pressures.

The following important factors affecting the condenser capacity:

(i) Type of material

(ii) Surface area, and

(iii) Temperature difference

According to condensing medium and application the condensers can be classified as:

(i) Air cooled condenser

(ii) Water cooled condenser, and

(iii) Evaporative condenser.

The selection of condenser depends upon the capacity of the refrigerating system, the type of refrigerant used and the type of cooling medium available.

3.9 Expansion Device

All vapour compression refrigeration system uses expansion device (throttling device) like, Automatic expansion Valve, Thermostatic expansion valve and Capillary tube. Capillary tube is the most popular refrigerant control device used in small refrigerating system. There are several formulas for calculating capillary tube bore and lengths, but the finer adjustments are made by trying on the system. Capillary tube (diameter and length) influences the refrigerant flow and characteristics. The tube diameter range from 0.5 mm to 2.25 mm and the length ranges from 0.5m to 6 m. It is installed in the liquid line before between the condenser and the evaporator. A fine mesh screen is provided at the inlet of the tube in order to protect it from contaminants. A small filter drier is used on some systems to provide additional freeze up application. The following important advantages of capillary tube over other expansion deviser are:

1) The cost of capillary tube is less than all other forms of expansion valves.

2) When the compressor stops, the refrigerant continues to flow into the evaporator and equalises the pressure between the high side and low sides of the system. This considerably decreases the starting load on the condenser. Thus a low starting torque motor can be used to drive the compressor.

3) Since the refrigerant charge in a capillary tube system is critical, therefore no receiver is necessary.Problems from the blockage in the capillary tube results in lower injection of refrigerant into the evaporator, so there will be less cooling. Typically this problem can be solved by changing a new capillary tube.

3.9.1 Selection of capillary tube

For any new system, the capillary length and diameter have to be selected based on the compressor and capillary tube balance point at the desired evaporator temperature. When the liquid refrigerant from the condenser enters the capillary tube the frictional resistance offered by a small diameter tube, the pressure drops. Since the frictional resistance is directly proportional to the length and inversely proportional to the diameter, therefore longer the capillary tube and smaller it's inside diameter, greater is the pressure drop created in the refrigerant flow.

Fig. 3.8 shows a capillary tube is a narrow bore tube of constant diameter; its function is to reduce pressure in the refrigeration system. The Pressure and Temperature distribution along typical capillary length a capillary has been suitably sized for a particular mass flow of refrigerant with the liquid seal at its inlet, "If due to some unbalance in system, the evaporator. In other words, greater pressure difference between the condenser and the evaporator is needed for a given flow rate of a refrigerant. The diameter and the length of a capillary tube once selected for a given set of conditions and load cannot operate efficiently at other conditions.

The compressor and capillary tube , under steady state must be arrive at some suction and discharge pressures , which allows the same mass flow rate through the compressor and capillary tube , this state the balance point. Load increases it will need more refrigerant, on the other hand, if the evaporator load is less, it will need less refrigerant. In both situations because of variation in the suction and discharge pressures, the corresponding pressure drop across the capillary will change and only the necessary amount of liquid will be transferred from condenser to evaporator"[11]. It has been established that properly sized capillary automatically compensates for load variations in the systems over a reasonably wide range of operation.

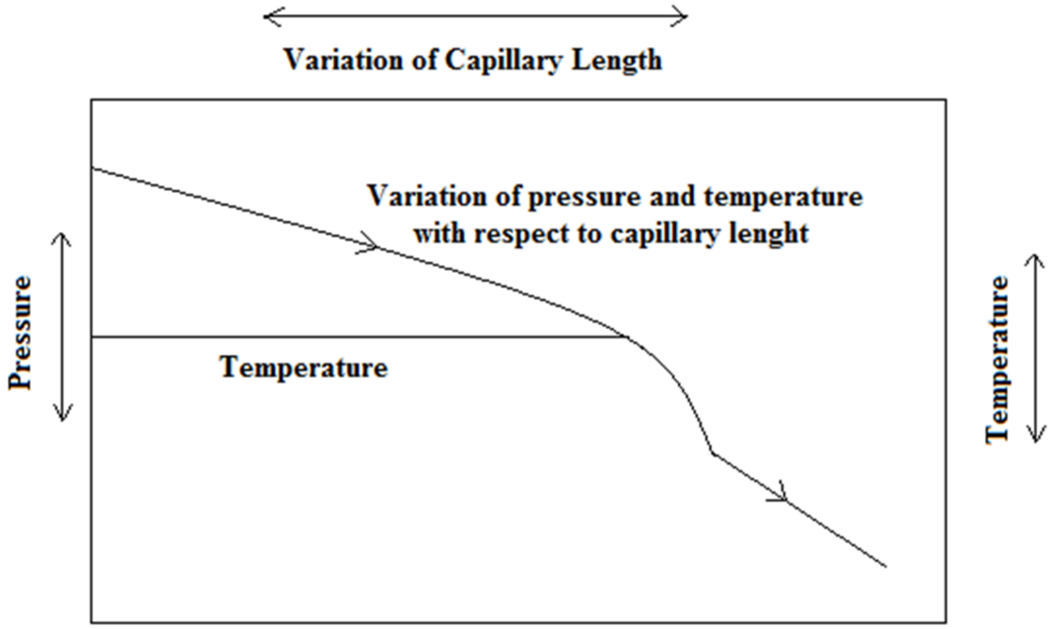

Fig. 3.8 Pressure and temperature distribution along typical capillary length

3.9.2 Balance point between capillary tube and compressor

The capillary tube and the compressor must arrive some suction and discharge pressures under steady state to allow the same mass flow rate through the compressor and capillary tube. This condition is generally known as balance point. At this point the evaporator and condenser pressures are the saturation pressures at the corresponding evaporator and condenser temperatures.

A sudden variation in the refrigeration load may change the balance point between the capillary tube and compressor. The capillary tube do not have a accumulator (reservoir) and are the flooded evaporator type system i.e. the evaporator whole surface area is in contact with the liquid refrigerant.

Fig. 3.9 shows the effect of load variation on capillary tube, if the refrigeration load decreases , there is a tendency for the evaporator temperature to decrease, if the refrigeration load increase , there is a tendency for evaporator temperature to increase, for particular condenser temperature. The balance point is shown by point A. If the refrigeration load increases, there is a tendency for the evaporator temperature increases hence the balance point A shifts to point C. At point C the mass flow rate the compressor ($\dot{m}$comp), is seen to more than the capillary tube mass flow rate ($\dot{m}$ cap). In such particular situation, the compressor will draw more and more refrigerant through the evaporator then the capillary tube can be supply to it [53, 57, 66 & 88]. This will lead to starving of evaporator and the evaporator pressure decreases as the compressor tries to evacuate the evaporator.

The corrective process should then start to work as a result of above the liquid refrigerant will back-up in to the condenser, thereby reducing the effective heat transfer surface. The temperature and the condensing pressure will rise; hence an increased pressure differential across the capillary will in turn increase in the feeding rate of the capillary. Consider the load on the cooling coil decreases. Consequently, the evaporator pressure will drop to point B, now the compressor will be pumping out fewer refrigerants than the capillary can feed. It will, therefore, results in flooding of evaporator. Eventually the liquid refrigerant may even enter the compressor and cause slugging or damage. In capillary tube systems use critical charge as a safety measure, only definite amount of refrigerant that is put in the refrigeration system , so that in the eventuality of all of it accumulating in the evaporator, it will just fill the evaporator and never overflow from the evaporator to compressor.

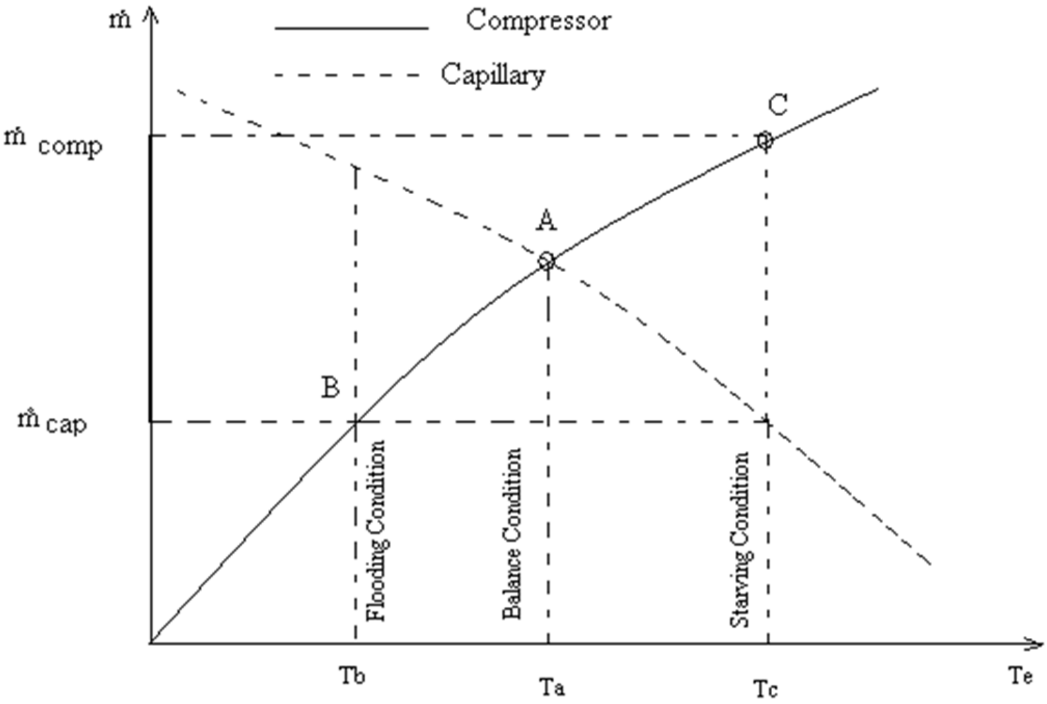

Fig. 3.9 Effect of load variation on capillary tube

3.9.3 Mathematical computation for mass flow rate for balance point

The relation between capillary tub diameter, length and mass flow rate are the important components of system performance. The mass flow rate through the expansion valve can be represented by an algebraic equation in terms of condenser and evaporator temperature. Similarly the mass flow rate through a given compressor can also be represented by an algebraic equation in terms of evaporator and condenser. The balance point of two components can be obtained by simultaneous solutions of two algebraic equations [35].The characteristics of the evaporator temperature, cooling capacity, condenser temperature and mass flow rate through the capillary tube of the system can be computed mathematically as follows:

Mass Flow Rate Equation:

$$m = C_1 + C_2 X\ Te + C_3 X\ T_e^2 + C_4 X\ T_c + C_5 X\ T_c^2 + C_6 X\ T_e\ X\ T_c + C7\ X\ T_e^2\ X\ T_c + C_8\ X\ T_e\ X\ T_c^2 + C_9\ X\ T_e^2\ X\ T_c^2 \text{ ----------------------- } (3.10)$$

Where, Te and Tc are the evaporator and condenser temperatures respectively and the constant C_i can be determined by solving the nine simultaneous equations [88]. The mathematical computation has been described in chapter 4 for different condenser temperature and evaporator temperature.

3.10 Selection Evaporator

The fourth important component in the refrigeration system is the evaporator; the liquid from the expansion valve enters into the evaporator and evaporates the evaporator also known as cooler or freezer. This component is also a heat exchanger like condenser. The evaporator absorbs heat from the surrounding location or medium which is to be cooled passing through the coil. The evaporator must provide required degree of superheating of the refrigerant gas to ensure elimination of liquid refrigerant entering the compressor, liquid refrigerant entry will cause damage to suction valve of compressor.

The evaporator is manufactured in different sizes, shapes and types as per the requirement. The evaporator should normally be sized to ensure the refrigerant returns to the compressor in completely gas state.

There are several ways of classifying the evaporators depending upon the heat transfer process or condition of the heat transfer surface or refrigerant flow.

(i) According to the mode of heat transfer

(a) Forced convection evaporator and

(b) Natural convection evaporator

(ii) According to the type of construction

(a) Plate evaporator

(b) Finned tube evaporator

(c) Bare tube coil evaporator

(d) Shell and tube evaporator

(e) Shell and coil evaporator

(f) Tube in tube evaporator

(iii) According to liquid refrigerant is fed

(a) Flooded evaporator, and

(b) Dry expansion evaporator

The following factors are considered in the design of evaporators:

(i) Heat transfer

(ii) Materials

(iii) Velocity of the refrigerant

(iv) Temperature difference

(v) Contact surface area

The design consideration for the evaporator is frictional losses, quality of refrigerant leaving from the evaporator, avoiding the entry of lubricating oil through the evaporator coil to maintain the evaporator efficiency.