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LECTURE NOTES

ON

REFRIGERATION AND AIR CONDITIONING

DIPLOMA 5th SEMESTER

COMPILED BY

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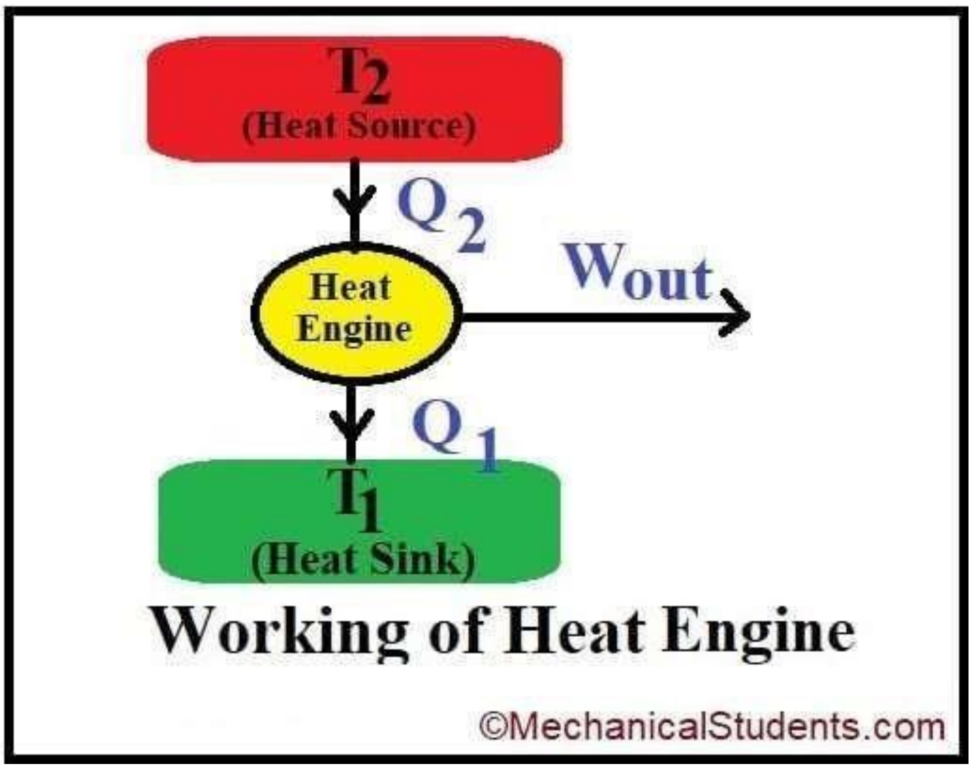
Refrigeration and Air Conditioning:

Refrigeration is defined as the process of achieving and maintaining a temperature below that of the surroundings. The aim is to cool some product or space to the required temperature.

Air Conditioning refers to the treatment of air and to simultaneously control its temperature, moisture content, cleanliness, odour and circulation, as required by occupants, a process, or products in the space.

Difference between a Refrigerator, Heat Pump, and Heat Engine

A heat engine is a system that converts Thermal energy into Mechanical Energy.



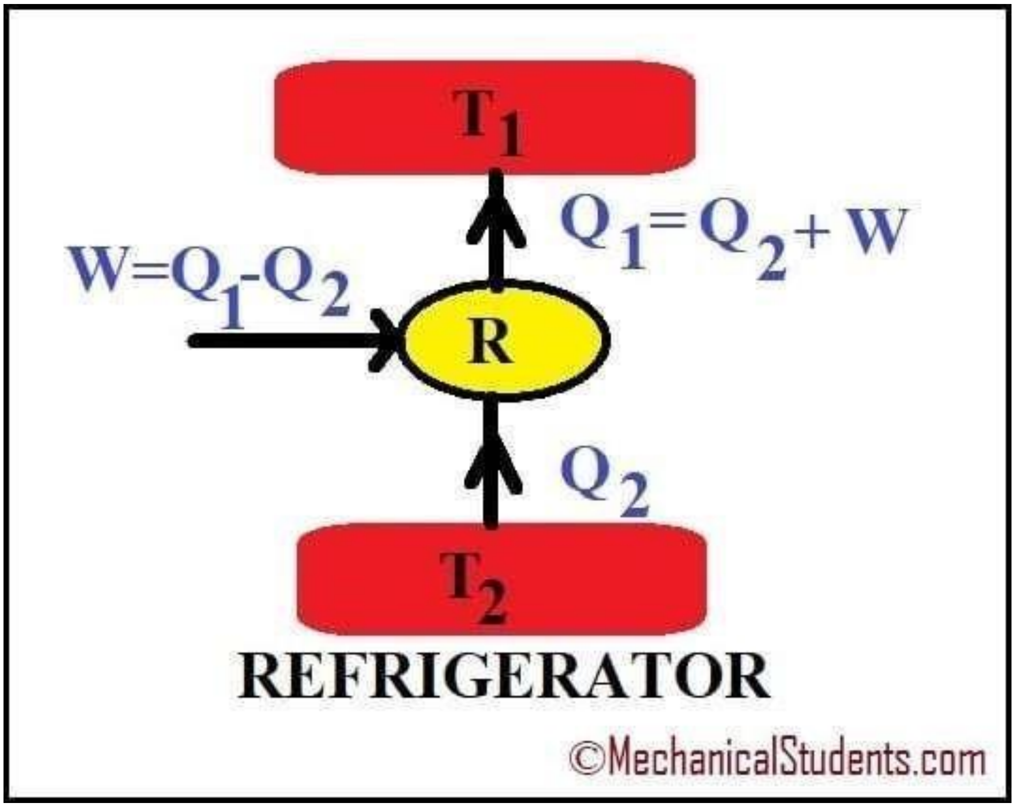
In a heat engine, the heat supplied to the engine is converted into useful work. If Q2 is the heat supplied to the engine and Q1 is the heat rejected from the heat engine, then the network done by the engine is given by

We = Q2-Q1

So the performance of the engine or Efficiency is given by

Generally, Efficiency is calculated as = We/Q

A refrigerator is a reversed heat engine, where heat is pumped from low temperature (cold body--> Q1) to high temperature (hot body-->Q2)

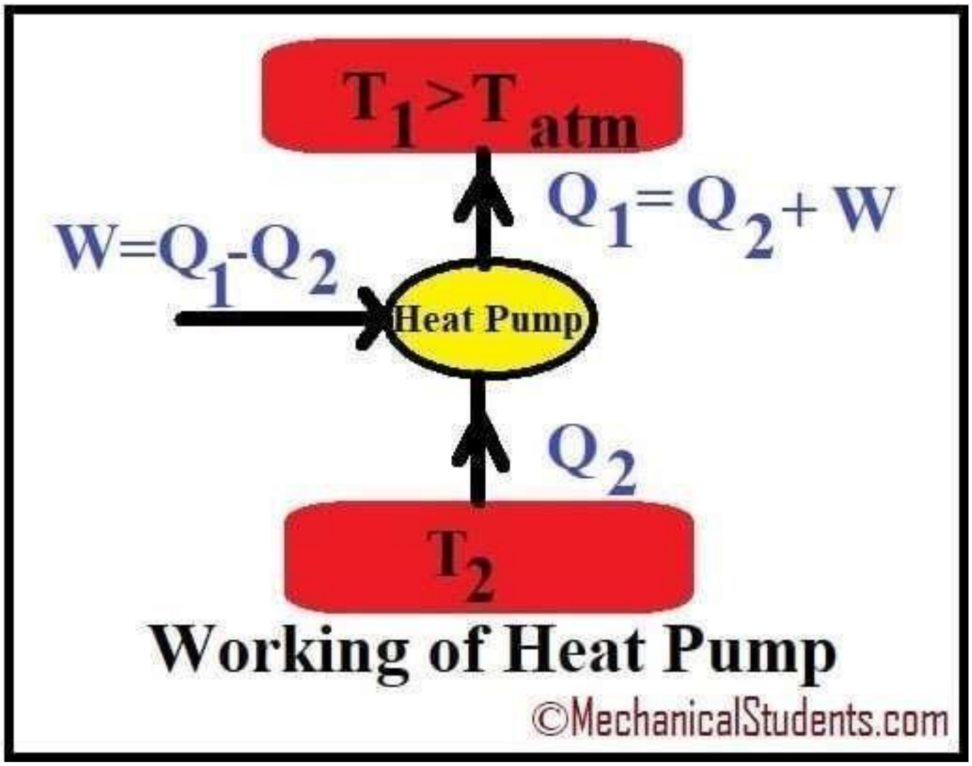


So, Work WR is required to be done on the system.

WR = Q2-Q1

The performance of a refrigerator is the "ratio of the amount of heat taken from the Cold body Q1 to the amount of work to be done on the system WR.

Any refrigerating system is a heat pump, which extracts heat from a cold body and delivers it to a hot body.



Thus there is no difference in the operation cycle of a refrigerator and a heat pump.

- The main difference between them is in their operating temperatures.
- A refrigerator works between cold body temperature (T1) and atmospheric temp (Ta) whereas the heat pump operates between hot body temp (T2) and the atmospheric temperature (Ta).
- A refrigerator used for cooling in summer can be used as a heat pump for heating in the winter season.
- so Wp = Q2-Q1

Performance of refrigerator and heat pump

COP(Coefficient of performance)

COP is defined as the relationship between the power (kW) that is drawn out of the heat pump as cooling or heat, and the power (kW) that is supplied to the compressor.

the C.O.P is the reciprocal of efficiency and is given as

(C.O.P)R = Q1/ WR = Q1 / (Q2-Q1) ------------ for refrigerator

(C.O.P)hp = Q2/ WR = Q2 / (Q2-Q1)----------- for heat pump

Refrigerator	Heat Pump	Heat Engine

A refrigerator is a reversed heat engine, where heat is pumped from a body at low temperature to a body at high temperature.	Any refrigerating system is a heat pump, which extracts heat from a cold body and delivers it to a hot body.	A heat engine is a system which converts Thermal energy into Mechanical Energy.
The network done by the refrigerator is given by WR= Q2-Q1	The network done by the heat pump is given by Wp= Q2-Q1	The network done by the engine is given We= Q2-Q1
The C.O.P. of Refrigerator is (C.O.P)R = Q1/ WR = Q1 / (Q2-Q1)	The C.O.P. of heat pump is (C.O.P)hp = Q2/ WR = Q2 / (Q2-Q1)	The C.O.P. of heat engine is (C.O.P)e= (Q2-Q1)/Q2

Unit of refrigeration

Rating for Refrigeration indicates the rate of removal heat. The unit of refrigeration is expressed in terms of ton of refrigeration (TR). One ton of refrigeration is defined as the amount of refrigeration effect (heat transfer rate) produced during uniform melting of one ton (1000kg) of ice at 0°C to the water at the 0°C in 24 hours.

Calculation for one ton of refrigeration

Latent heat of ice is 335KJ/kg (heat absorbed during melting of one kg ice)
1 Ton of refrigeration, 1TR= 1000*335 in 24 hours

$$=(1000\times335)/(24\times60) \text{ in one minute}$$
$$= 232.6 \text{ kJ/min}$$

Theoretically one Ton of refrigeration taken as 232.6kJ/min, in actual practice, it is taken as 210kJ/min.
1 ton of refrigeration approximately equal to 3.5kW.

Lecture note

Sub-Refrigeration and air conditioning

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Air Refrigerator Working On Bell-Coleman Cycle with PV and TS Diagram (Reversed Brayton or Joule Cycle)

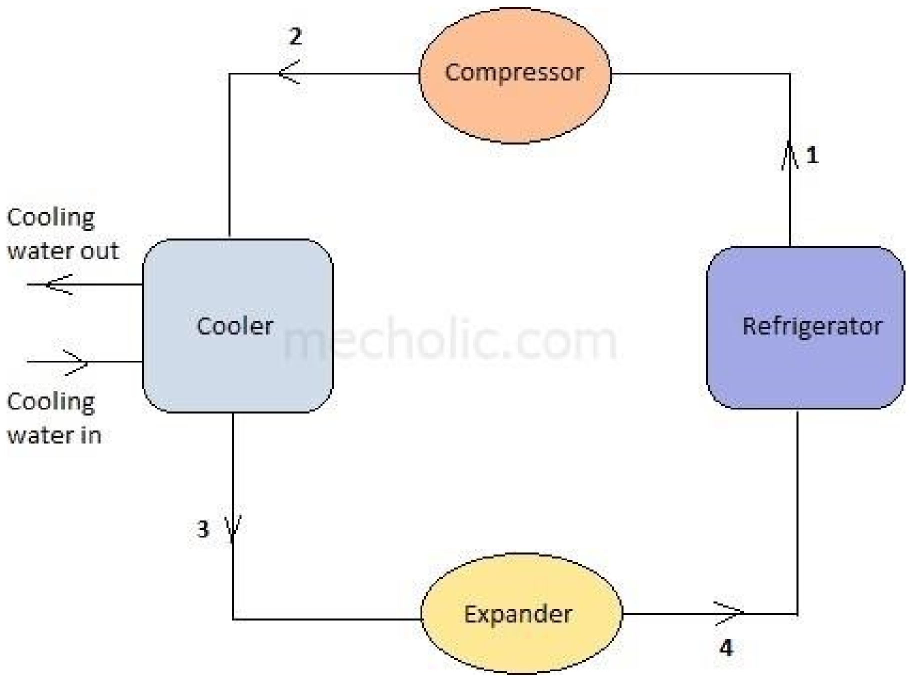
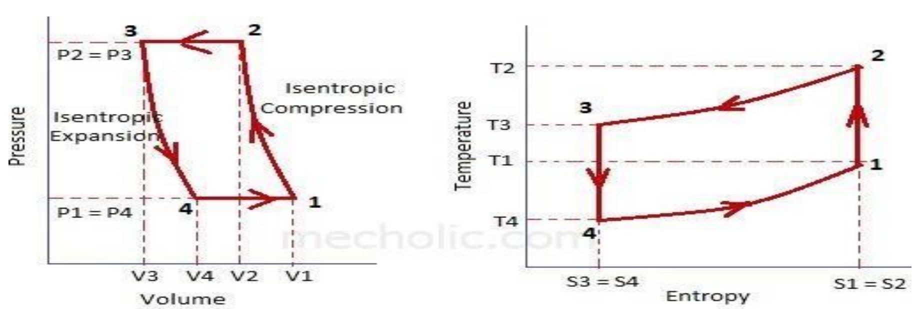
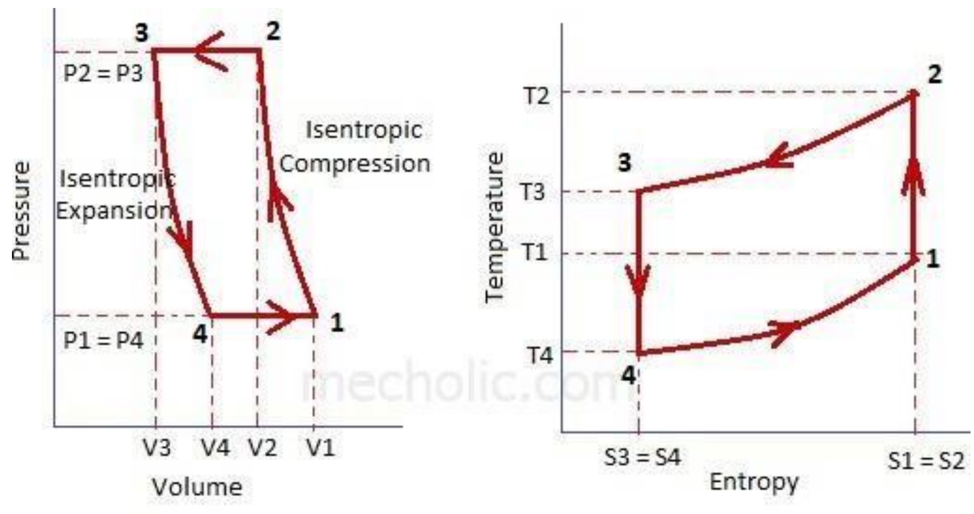


Fig shows a schematic diagram of Bell-Coleman refrigerator (reverse Brayton or joule cycle). This refrigeration system components consists of a compressor, cooler, Expander, and refrigerator. In this process, heat absorption and rejection follows at the constant pressure; the compression and expansion of process are isentropic.

Process in Bell-Coleman refrigeration



(a) P-V Diagram (b) T-S Diagram



(a) P-V Diagram (b) T-S Diagram

Fig show P-V and T-S diagram of bell coleman refrigerator. Here P_1, V_1, T_1, S_1 represents the pressure, volume, temperature, entropy of air respectively at point 1. And so on. It represents the corresponding condition of air when it passed through the component.

1-2: Isentropic Compression

The Air drawn from refrigerator to air compressor cylinder where it compressed isentropically (constant entropy). No heat transfer by the air. During compression, the volume decreases while the pressure and temperature of air increases.

2-3: Constant pressure cooling process.

The warm compressed air is then passed through cooler, where it cooled down at constant pressure. The heat rejected per kg of air during this process is equal to $q_{2-3} = Cp(T_2-T_3)$

3-4: isentropic expansion

No heat transfer takesplcae. The air expands isentropically in expander cylinder. During expansion, the volume increases, Pressure P3 reduces to P_4. (P_4 = atmospheric pressure). Temperature also falls during expansion from T_3-T_4.

: Constant pressure expansion

Heat transfer from the refrigerator to air. The temperature increases from T_4 to T_1. Volume increases to V_4 due to heat transfer. Heat absorbed by air per kg during this process is equal to $q_{4-1} = Cp(T_1T_4)$

Equation of Coefficient of performance (COP) of Bell Coleman cycle

Heat absorbed during cycle per kg of air $q_{4-1} = Cp(T_1-T_4)$

Heat rejected during cycle per kg of air $q_{2-3} = Cp(T_2-T_3)$

Then the work done per kg of air during the cycle is = Heat rejected – Heat absorbed

$= Cp(T_2-T_3) - Cp(T_1-T_4)$

Coefficient of performance,

$$C.O.P. = \frac{Heat\ absorbed}{Work\ done} = \frac{C_p(T_1 - T_4)}{C_p(T_2 - T_3) - C_p(T_1 - T_4)}$$

$$= \frac{(T_1 - T_4)}{(T_2 - T_3) - (T_1 - T_4)}$$

$$C.O.P. = \frac{T_4(\frac{T_1}{T_4} - 1)}{T_3(\frac{T_2}{T_3} - 1) - T_4(\frac{T_1}{T_4} - 1)} \quad \text{(i)}$$

For isentropic compression process 1-2

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{(ii)}$$

For isentropic expansion process 3-4

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} \quad \text{(iii)}$$

Since, P2 = P3 and P1 = P4, therefore from equation (ii) and (iii)

Substitute equation (iv) in (i)

$$C.O.P. = \frac{T_4}{T_3 - T_4} = \frac{1}{\frac{T_3}{T_4} - 1}$$

$$= \frac{1}{\left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} - 1} = \frac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1}$$

$$C.O.P. = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}$$

$$r_p = Compression\ or Expansion\ ratio = \frac{P_2}{P_1} = \frac{P_3}{P_4}$$

Lecture note-2

Sub-Refrigeration and air conditioning

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Open and Closed Type of Refrigeration System – Advantages and Application

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Air cycle refrigeration is one of the earliest methods used for cooling. The key features of this method is that, the refrigerant air remain gaseous state throughout the refrigeration cycle. Based on the operation, the air refrigeration system can be classified into

1. Open air refrigeration cycle
2. Closed refrigeration cycle

Open air refrigeration cycle

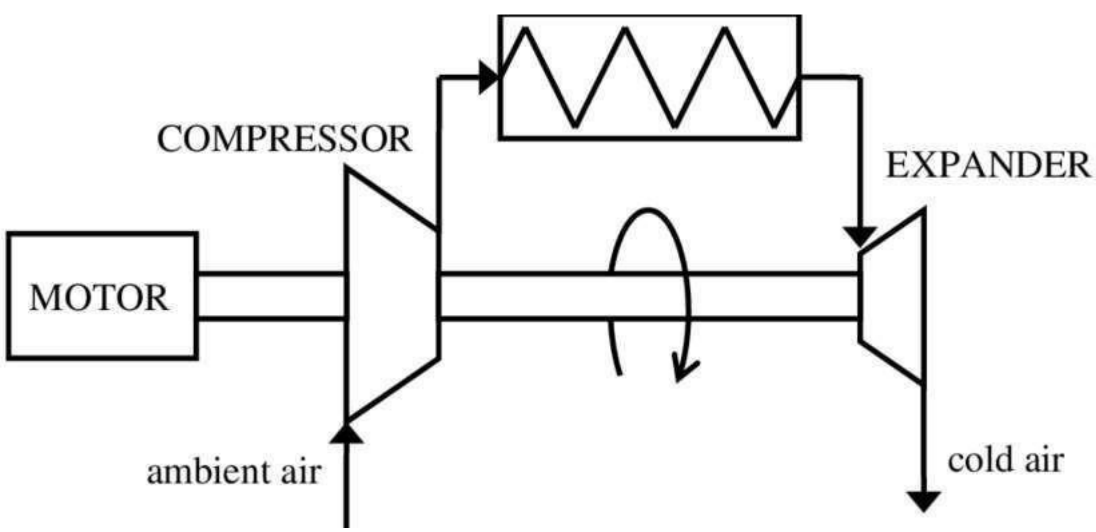
In an open refrigeration system, the air is directly passed over the space is to be cooled, and allowed to circulate through the cooler. The pressure of open refrigeration cycle is limited to the atmospheric pressure. A simple diagram of the open-air Refrigeration system is given below.

Advantages and application

- It eliminates the need of a heat exchanger.
- It is used in aircraft because it helps to achieve cabin pressurization and air conditioning at once

Disadvantages

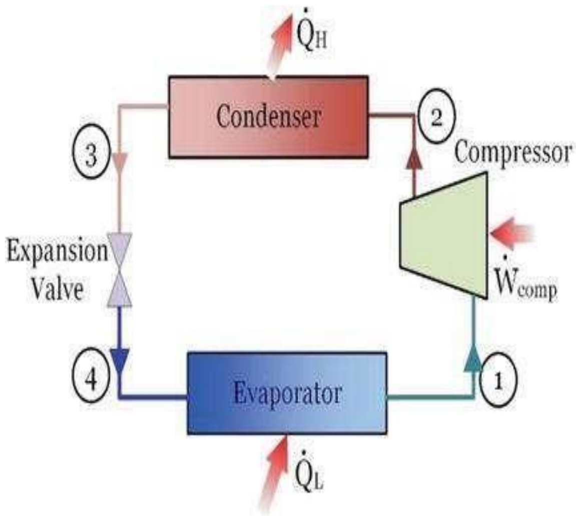
One of the disadvantages of this system is that its large size. The air supplied to the refrigeration system is at atmospheric pressure, so the volume of air handled by the system is large. Thus the size of compressor and expander also should be large. Another disadvantage of the open cycle system is that the moisture is regularly carried away by the circulating air, this leads to the formation of frost at the end of the expansion process and clogs the line, and hence a use of dryer is preferable to the open air refrigeration system.

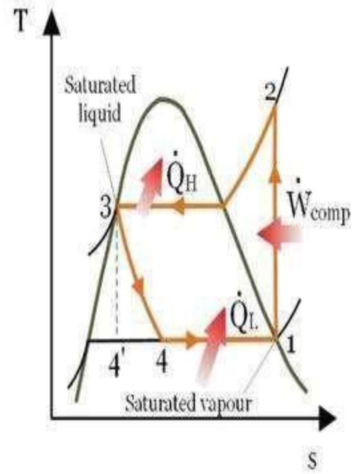


Open air refrigeration system

Closed refrigeration system / Dense air refrigeration cycle

In closed or dense air refrigeration cycle, air refrigerant is contained within pipes and component part of the system at all time. The circulated air does not have to direct contact with the space to be cooled. The air is used to cool another fluid (brine), and this fluid is circulated into the space to be cooled. So the disadvantages listed in open air refrigeration can be eliminated. The advantages of closed air refrigeration system are listed below.





Advantages

- The suction to the compressor may be at high pressure, therefore the volume of air handled by the compressor and expander is low when compared to an open system. Hence the size of compressor and expander is small compared to the open air system.
- The chance of freezing of moister and choke the valve is eliminated.
- In this system, higher coefficient of performance can be achieved by reducing operating pressure ratio.

Lecture note

Sub-Refrigeration and air conditioning

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Problem 1 A cold storage is to be maintained at -5°C (268k) while the surroundings are at 35°C. the heat leakage from the surroundings into the cold storage is estimated to be 29kW. The actual C.O.P of the refrigeration plant is one third of an ideal plant working between the same temperatures. Find the power required to drive the plant.

Solution : -

$T_1 = 35°C = 308k \qquad T_2 = 5°C = 268k$

C.O.P of the ideal plant is nothing but

C.O.P based on carnot cycle.

$$\therefore \text{C.O.P ideal} = \frac{T_2}{T_1 - T_2}$$

$$= \frac{268}{308 - 268} = 6.7$$

Actual C.O.P =1/3 of theoretical C.O.P = 6.7/3 = 2.23

Q2 = The heat removed from low temperature reservoir (cold storage) must be equal to heat leakage from surroundings to the cold storage(which is 29kw)

Q2 = 29KW

ACTUAL COP = Q2/W=2.23

W = 29/2.23 = 12.98 KW

Sub-refrigeration and air coinditioning

Sem-5th sem Mechanical diploma

Refrigerating Compressor-

A refrigerating Compressor is amachine that compresses vapour refrigerant from the evaporator and to raise its pressure so that the corresponding saturation temperature is higher than that of the cooling medium.

Classification

1. ***According to the method of compression***

(*a*) Reciprocating compressors,

(*b*) Rotary compressors, and

(*c*) Centrifugal compressors.

2. ***According to the number of working strokes***

(*a*) Single acting compressors, and

(*b*) Double acting compressors.

3. ***According to the number of stages***

(*a*) Single-stage (or single-cylinder) compressors, and

(*b*) Multi-stage (or multi-cylinder) compressors.

4. ***According to the method of drive employed***

(*a*) Direct drive compressors, and

(*b*) Belt drive compressors.

5. ***According to the location of the prime mover***

(*a*) Semi-hermetic compressors (direct drive, motor and compressor in separate housings), and

(*b*) Hermetic compressors (direct drive, motor and compressor in same housings).

Important terms-

1. ***Suction pressure.*** It is the absolute pressure of refrigerant at the inlet of a compressor.

2. ***Discharge pressure.*** It is the absolute pressure of refrigerant at the outlet of a compressor.

3. ***Compression ratio (or pressure ratio).*** It is the ratio of absolute discharge pressure to the absolute suction pressure. Since the absolute discharge pressure is always more than the absolute suction pressure, therefore, the value of compression ratio is more than unity.

Note : The compression ratio may also be defined as the ratio of total cylinder volume to the clearance volume.

4. ***Suction volume.*** It is the volume of refrigerant sucked by the compressor during its suction stroke. It is usually denoted by v_s.

5. ***Piston displacement volume or stroke volume or swept volume.*** It is the volume swept by the piston when it moves from its top or inner dead position to bottom or outer dead centre position. Mathematically, piston displacement volume or stroke volume or swept volume,

$$v_p = \frac{\pi}{4} \times D^2 \times L$$

where D = Diameter of cylinder, and

L = Length of piston stroke.

6. ***Clearance factor.*** It is the ratio of clearance volume (v_c) to the piston displacement volume (v_p). Mathematically, clearance factor,

$$C = \frac{v_c}{v_p}$$

7. ***Compressor capacity.*** It is the volume of the actual amount of refrigerant passing through the compressor in a unit time. It is equal to the suction volume (v_s). It is expressed in m^3/s.

8. ***Volumetric efficiency.*** It is the ratio of the compressor capacity or the suction volume (v_s) to the piston displacement volume (v_p). Mathematically, volumetric efficiency,

$$\eta_v = \frac{v_s}{v_p}$$

Reciprocating Compressor-

The compressors in which the vapour refrigerant is compressed by the reciprocating (*i.e.* back and forth) motion of the piston are called *reciprocating compressors*. These compressors are used for refrigerants which have comparatively low volume per kg and a large differential pressure, such as ammonia (R-717), R-12, R-22, and methyl chloride (R-40). The reciprocating compressors are available in sizes as small as 1/12 kW which are used in small domestic refrigerators and up to about 150 kW for large capacity installations.

The two types of reciprocating compressors in general use are single acting vertical compressors and double acting horizontal compressors. The single acting compressors usually have their cylinders arranged vertically, radially or in a *V* or *W* form. The double acting compressors usually have their cylinders arranged horizontally.

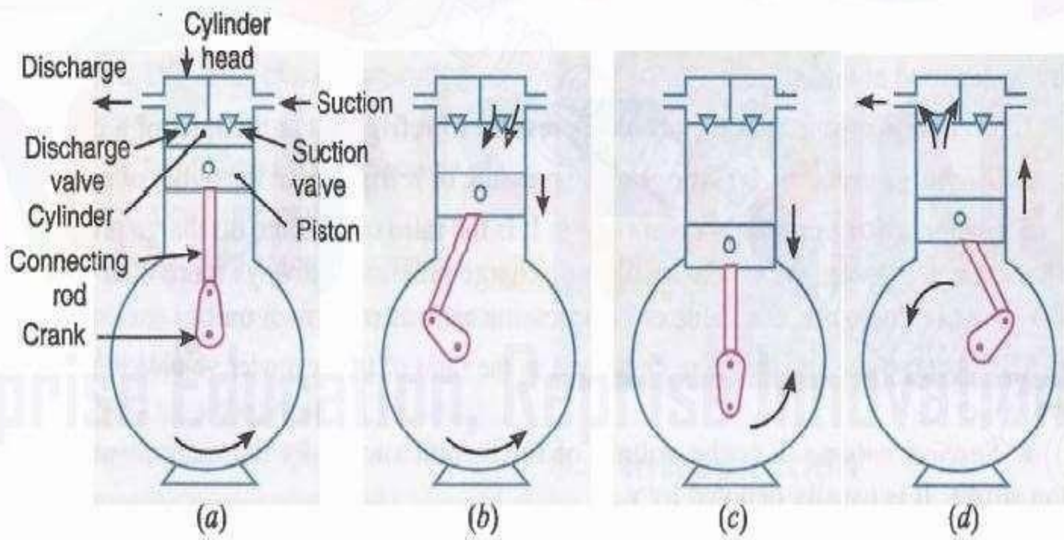


Fig. 9.1. Principle of operation of a single stage, single acting reciprocating compressor.

Working-

Let us Consider that the piston is at the top of its strokea shown in (a).

It is called top dead dead centre od thepiston.

In this position ,the suction valve is held closed because of the pressure in the clearance space between the top pf the piston and the cylinder head.the discharge valve is also closed because of the cylinder pressure acting on its top.

When the piston moves down,in suction stroke as in (b).The refrigerant left in the clearance space expands.Thus the volume of the cylinder increases and the pressure inside the cylinder decreases.When the pesssure becomes slightly less than te suction pressure ,the suction valve opens and the vapour refrigerant flows inside the cylinder.The flow continues until the piston reaches the bottom of the stroke.At the bottom of stroke as in (c),the suction stroke closed because of the spring action.When the piston moves upward during compression stroke as in (d),the pressure inside the cylinder becomes greater than that on the top of the discharge valve,hence the discharge valve opens and the vapour refrigerant is discharged to condenser and the cycle is repeated.

Lecture note

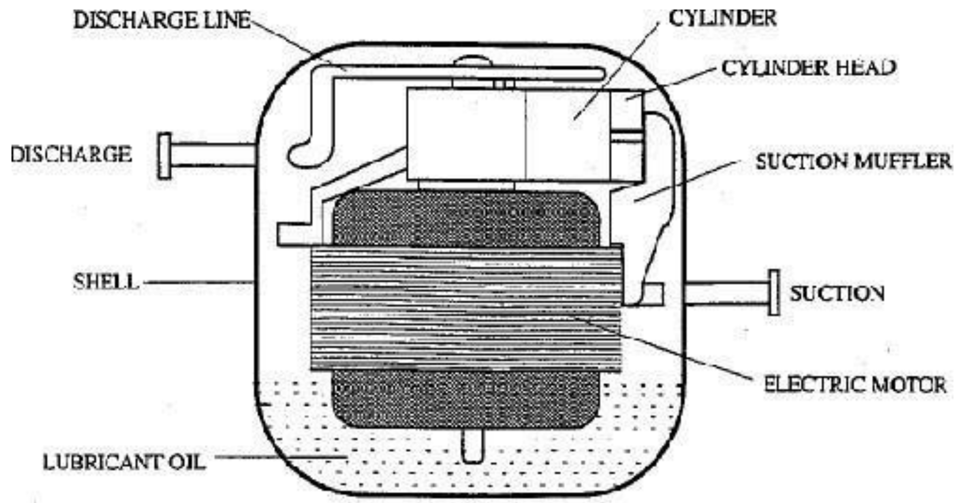
Sub-Refrigeration and air conditioning

Sem-5th sem Mechanical

Hermetically and Semi-hermetically sealed compressor

In hermetic compressors, the motor and the compressor are enclosed in the same housing to prevent refrigerant leakage. The housing has welded connections for refrigerant inlet and outlet and for power input socket. As a result of this, there is virtually no possibility of refrigerant leakage from the compressor. All motors reject a part of the power supplied to it due to eddy currents and friction, that is, inefficiencies. Similarly the compressor also gets heated-up due to friction and also due to temperature rise of the vapor during compression. In Open type, both the compressor and the motor normally reject heat to the surrounding air for efficient operation. In hermetic compressors heat cannot be rejected to the surrounding air since both are enclosed in a shell. Hence, the cold suction gas is made to flow over the motor and the compressor before entering the compressor. This keeps the motor cool. The motor winding is in direct contact with the refrigerant hence only those refrigerants, which have high dielectric strength, can be used in hermetic compressors. The cooling rate depends upon the flow rate of the refrigerant, its temperature and the thermal properties of the refrigerant. If flow rate is not sufficient and/or if the temperature is not low enough the insulation on the winding of the motor can burn out and short-circuiting may occur. Hence, hermetically sealed compressors give satisfactory and safe performance over a very narrow range of design temperature and should not be used for off-design conditions.

In some (usually larger) hermetic units, the cylinder head is removable so that the valves and the piston can be serviced. This type of unit is called a semi-hermetic (or semi-sealed) compressor.



Hermetically sealed compressor

Semi-hermetically sealed compressor

Advantages and disadvantages of hermetic seal compressor

Advantages

- Leak proof / completely sealed housing - There is no route for gas to leak out this system. There are no shaft sales since both compressor and motor sealed in the same casing.
- Portable compressor and motor act as a single unit.
- No belt pulley coupling arrangement - No need disassembles the compressor from the motor to move the system from one place to another.
- Since there is no belt coupling or crankshaft, cost involved with the maintenance is
- less.
- It is compact; they require small space.
- Lubrication is simple; there is no external lubrication is required.
- It is less noisy

Installation of hermetic sealed compressor is very easy.

Disadvantages

- They are not intended to repairing since the moving parts are inaccessible if there is any problem you need to do you replace the whole unit.
- Burnout winding can contaminate entire system. –

Only electric power sources can run this unit.

Lecture note

Sub-Refrigeration and air conditioning

Sem-5th sem Mechanical

Centrifugal Compressor

Centrifugal compressors; also known as turbo-compressors belong to the roto-dynamic type of compressors. In these compressors the required pressure rise takes place due to the continuous conversion of angular momentum imparted to the refrigerant vapour by a high-speed impeller into static pressure.

Working of Centrigugal Compressor

The Figure shows the working principle of a centrifugal compressor. As shown in the figure, low-pressure refrigerant enters the compressor through the eye of the impeller (1). The impeller (2) consists of a number of blades, which form flow passages (3) for refrigerant. From the eye, the refrigerant enters the flow passages formed by the impeller blades, which rotate at very high speed. As the refrigerant flows through the blade passages towards the tip of the impeller, it gains momentum and its static pressure also increases. From the tip of the impeller, the refrigerant flows into a stationary diffuser (4). In the diffuser, the refrigerant is decelerated and as a result the dynamic pressure drop is converted into static pressure rise, thus increasing the static pressure further. The vapour from the diffuser enters the volute casing (5) where further conversion of velocity into static pressure takes place due to the divergent shape of the volute. Finally, the pressurized refrigerant leaves the compressor from the volute casing (6). The gain in momentum is due to the transfer of momentum from the highspeed impeller blades to the refrigerant confined between the blade passages. The increase in static pressure is due to the self-compression caused by the centrifugal action. This is analogous to the gravitational effect, which causes the fluid at a higher level to press the fluid below it due to gravity (or its weight). The static pressure produced in the impeller is equal to the static head, which would be produced by an equivalent gravitational column. If we assume the impeller blades to be radial and the inlet diameter of the impeller to be small, then the static head, h developed in the impeller passage for a single stage is given by:

$H= v^2/g$ where h = static head

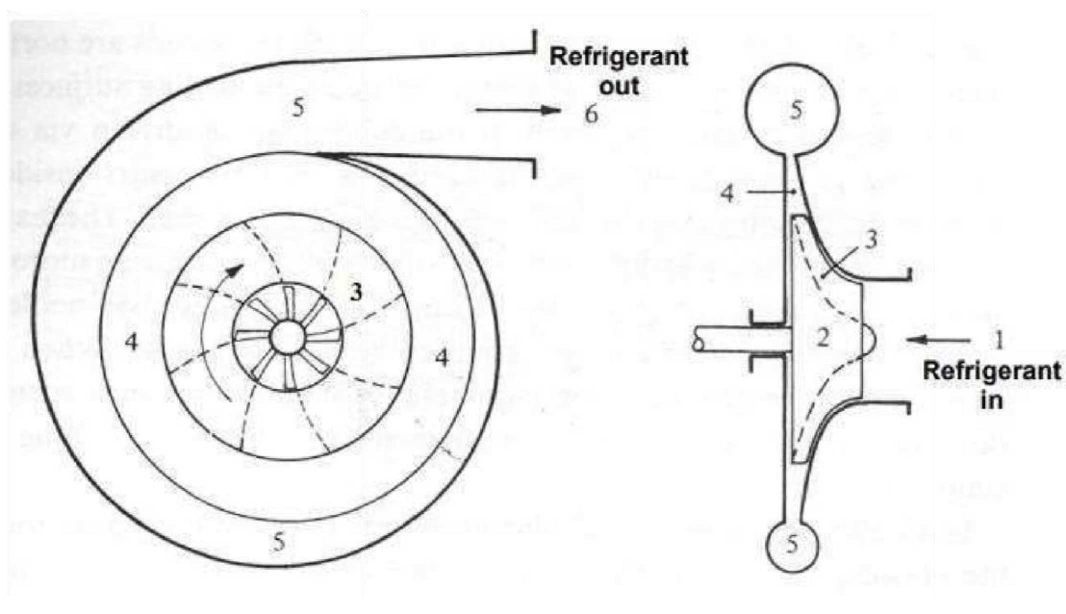
developed, m

V = peripheral velocity of the impeller wheel or tip speed, m/s

g = acceleration due to gravity, m/s^2

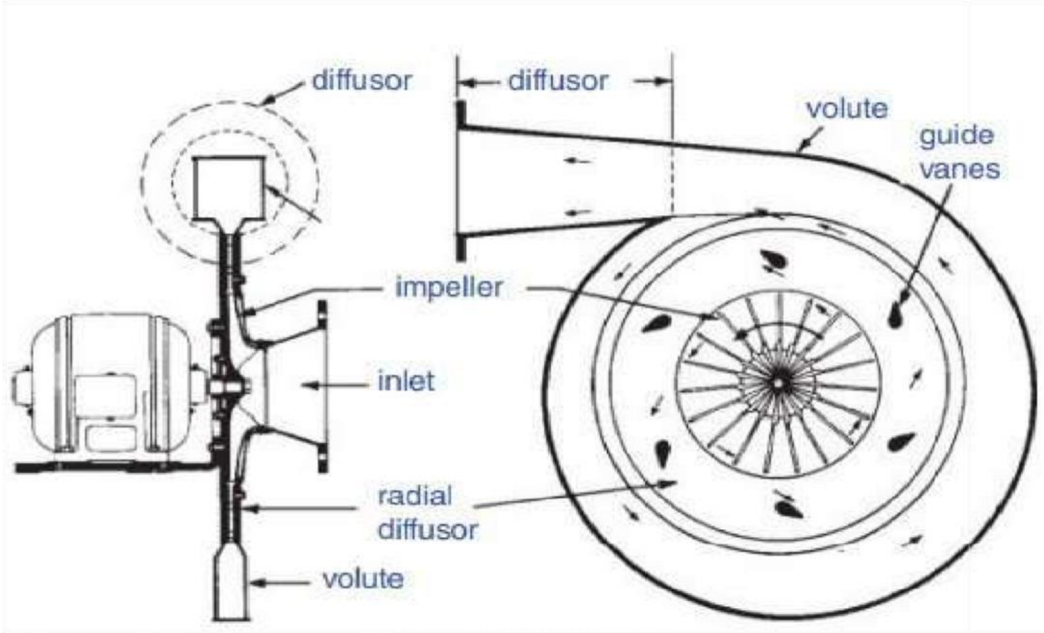
Hence increase in total pressure, ΔP as the refrigerant flows through the passage is given by:

$$\Delta P=\rho gh=\rho V^2$$



Centifugal Compressor

1: Refrigerant inlet (eye); 2: Impeller; 3: Refrigerant passages
4: Vaneless diffuser; 5: Volute casing; 6: Refrigerant discharge



Lecture note

Sub-refrigeration and air conditioning

Sem-5th mechanical

Condensers

The condenser is the 'hot' end of a refrigeration plant and can serve as a useful heat source where heat is needed at relatively low temperatures, e.g. for washing water. The implications of raising the condenser temperature to increase the usefulness of the available heat should only be considered with care.

A condenser's function is to allow high pressure and temperature refrigerant vapor to condense and eject heat. There are three main types: air-cooled, evaporative, and water-cooled condensers.

Air-Cooled

Air-cooled condensers usually consist of pipes with fins attached, but can occasionally have wires, or even a plate, affixed to the refrigerant's piping.

These give the condenser a greater surface area and allow for more efficient cooling. Air circulation is achieved either by static means, where air in contact with the pipes becomes hot and rises to be displaced by cooler air. Or, more typically, there is forced convection, where fans pass air over the condenser

The condenser fins need be kept clean to maximize heat transfer and cooling effect on the refrigerant.

Water-Cooled

Water-cooled condensers normally consist of an outer tube carrying hot vaporized refrigerant which flows over an inner tube containing a counterflow of cool water. These shell-within-tube condensers are very efficient. Water-cooled condensers are more complex than air- cooled condensers as there are design considerations in water flow regulation and corrosion prevention. However, the advantages of water-cooled systems are that water has a higher exchange coefficient than air so heat transfer will be more efficient.

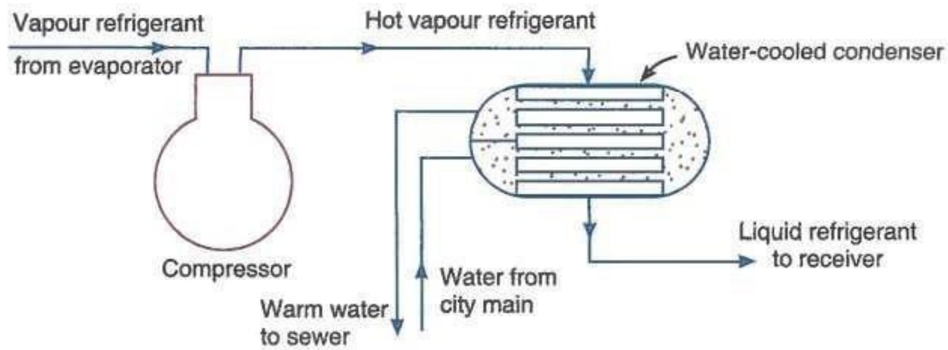
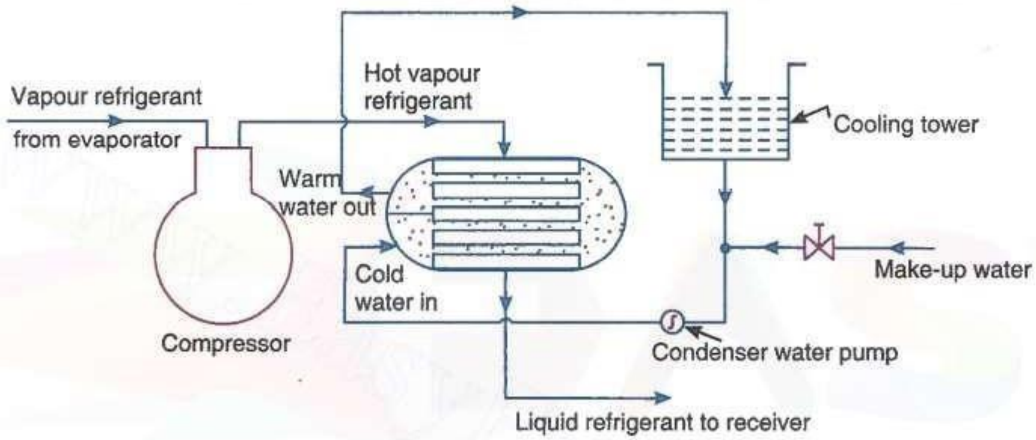
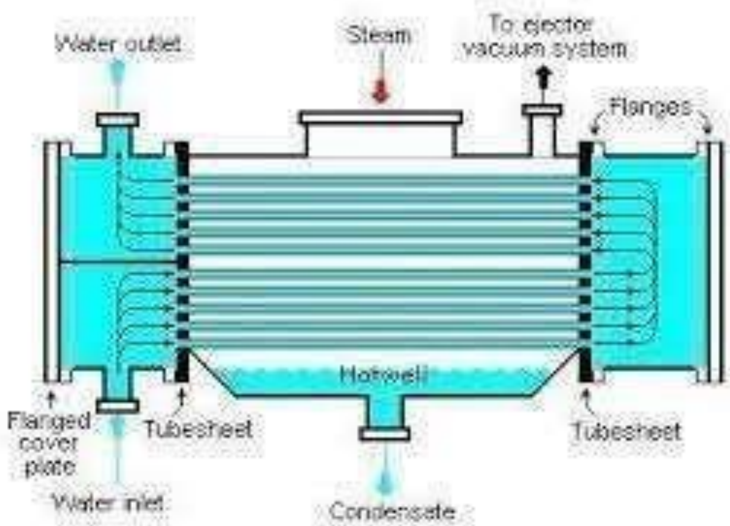


Fig. 10.3. Water-cooled condenser using waste water system.





Water cooled condenser can be of shell and coil type or tube in tube type

In tube and tube type both water and refrigerant are in tubes while in case of shell and coil type,only one of them is in tube and the other one is in shell.

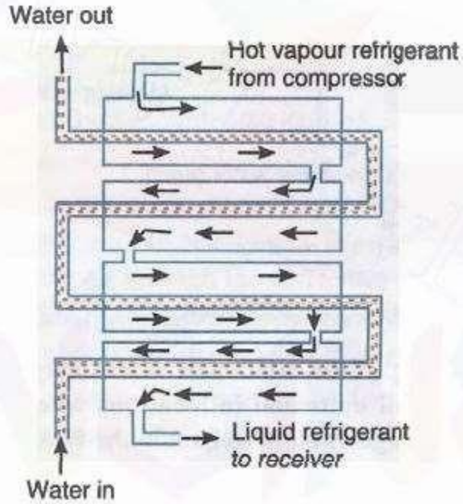


Fig. 10.5. Tube-in-tube condenser.

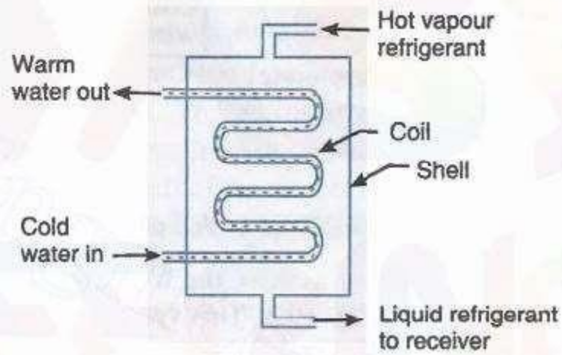
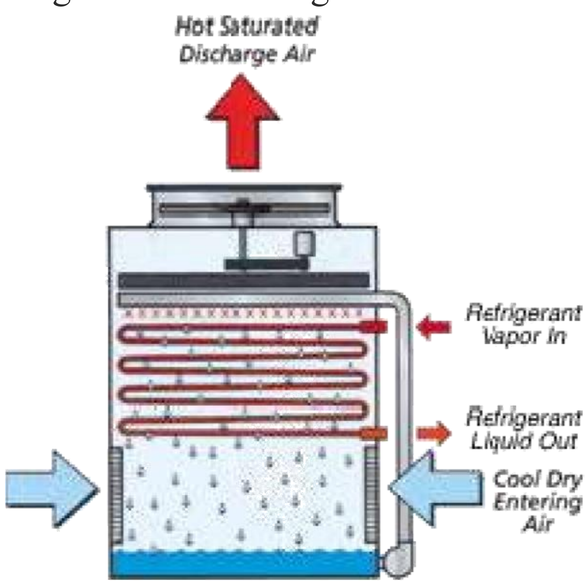


Fig. 10.6. Shell and coil condenser.

Evaporative Condensers

In large systems, evaporative condensers are utilized combining airflow with water. The refrigerant is condensed by using a combination of airflow and water sprayed onto a coil, usually in a tower. The water is then collected in a sump and pumped back to the sprayer. Air is forced up through the tower using forced ventilation.



Principle of Operation

Comparison of Air cooled and water cooled condenser

S.No.	Air-cooled condenser	Water-cooled condenser
1.	Since the construction of air-cooled condenser is very simple, therefore the initial cost is less. The maintenance cost is also low.	Since the construction of water-cooled condenser is complicated, therefore the initial cost is high. The maintenance cost is also high.
2.	There is no handling problem with air-cooled condensers.	The water-cooled condensers are difficult to handle.
3.	The air-cooled condensers do not require piping arrangement for carrying the air.	The pipes are required to take water to and from the condenser.
4.	There is no problem in disposing of used air.	There is a problem of disposing the used water unless a recirculation system is provided.
5.	Since there is no corrosion, therefore fouling effect is low.	Since corrosion occurs inside the tubes carrying the water, therefore fouling effects are high.
6.	The air-cooled condensers have low heat transfer capacity due to low thermal conductivity of air.	The water-cooled condensers have high heat transfer capacity due to high thermal conductivity of water.
7.	These condensers are used for low capacity plants (less than 5 TR).	These condensers are used for large capacity plants.
8.	Since the power required to drive the fan is excessive, therefore, the fan noise becomes objectionable.	There is no fan noise.
9.	The distribution of air on condenser surface is not uniform.	There is even distribution of water on the condensing surface.
10.	The air-cooled condensers have high flexibility.	The water-cooled condensers have low flexibility.

HEAT rejection factor

It is the load on condenser per kg of refrigeration capacity.

$$Q_C = \text{Refrigeration capacity} + \text{Work done by the compressor}$$
$$= R_E + W$$

$\therefore$ Heat rejection factor,

$$\text{HRF} = \frac{Q_C}{R_E} = \frac{R_E + W}{R_E} = 1 + \frac{W}{R_E} = 1 + \frac{1}{\text{COP}} \quad \ldots \left(\because \text{COP} = \frac{R_E}{W} \right)$$

<u>Cooling tower and spray ponds</u>

A *cooling tower* is an enclosed tower-like structure through which atmospheric air circulates to cool large quantities of warm water by direct contact. A *spray pond* consists of a piping and spray nozzle arrangement suspended over an outdoor open reservoir or pond. It can also cool large quantities of warm water. The cooling towers and spray ponds, used for refrigeration and air conditioning systems, cool the warm water pumped from the water-cooled condensers. Then the same water can be used again and again to cool the condenser.

The principle of cooling the water in cooling towers and spray ponds is similar to that of evaporative condensers, *i.e.* the warm water is cooled by means of evaporation. The air surrounding the falling water droplets from the spray nozzles causes some of the water droplets to evaporate. The evaporating water absorbs latent heat of evaporation from the remaining water and thus cools it. The air also absorbs a small amount of sensible heat from the the remaining water. The cooled water collects in the pond or in a sump at the cooling tower which is recirculated through the condenser.

Lecture note

Sub-refrigeration and air conditioning

Sem-5^{th} mechanical

Evapourator

The evaporator is an important device used in the low pressure side of a refrigeration system. The liquid refrigerant from the expansion valve enters into the evaporator where it boils and changes into vapour. The function of an evaporator is to absorb heat from the surrounding location or medium which is to be cooled, by means of a

Refrigerant.

the function of the evaporator is to absorb the heat from the space or surrounding medium which is to be cooled by means of refrigeration. The process of heat removal from the substance to be cooled or refrigerated is done in the evaporator. The liquid refrigerant is vaporized inside the evaporator (coil or shell) in order to remove heat from a fluid such as air, water etc.

Construction of Evaporator :

The evaporator as shown in the figure is the part of the refrigeration system where the refrigerant vaporizes as it picks up heat. Heated air is forced through and past the fins and tubes of the evaporator. The heat from the air is picked up by the boiling refrigerant and is carried in the system to the condenser. The evaporator is usually installed in housing under the dash panel.

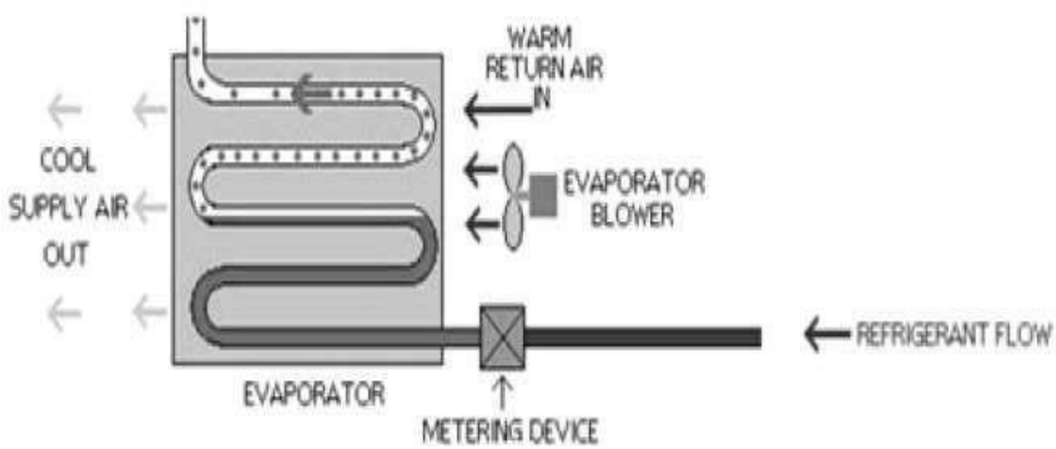


Figure: Evaporator

Working of Evaporator:

When the air conditioning system is turned on, warm air from the passenger compartment is blown through the coils and fins of the evaporator. The evaporator receives refrigerant from the thermostatic expansion valve or orifice tube as low pressure, cold atomized liquid. As the cold refrigerant passes through the evaporator coil, heat moves from the warm air into

the cooler refrigerant. When the liquid refrigerant receives enough heat, a change of state – from a low-pressure liquid into a low-Pressure vapor – takes place.
The thermostatic expansion valve or orifice tube continually meters the precise amount of refrigerant necessary to maintain optimum heat transfer, which ensures that all of the liquid refrigerants will have changed to a vapor by the time it reaches the evaporator outlet. The vaporized refrigerant then continues on to the inlet (suction) side of the compressor.

Finned evaporator

The finned evaporators are the bare tube type of evaporators covered with the fins. When the fluid (air or water) to be chilled flows over the bare tube evaporator lots of cooling effect from the refrigerant goes wasted since there is less surface for the transfer of heat from the fluid to the refrigerant. The fluid tends to move between the open spaces of the tubing and does not come in contact with the surface of the coil, thus the bare tube evaporators are less effective. The fins on the external surface of the bare tube evaporators increase the contact surface of the of the metallic tubing with the fluid and increase the heat transfer rate, thus the finned evaporators are more effective than the bare tube evaporators.

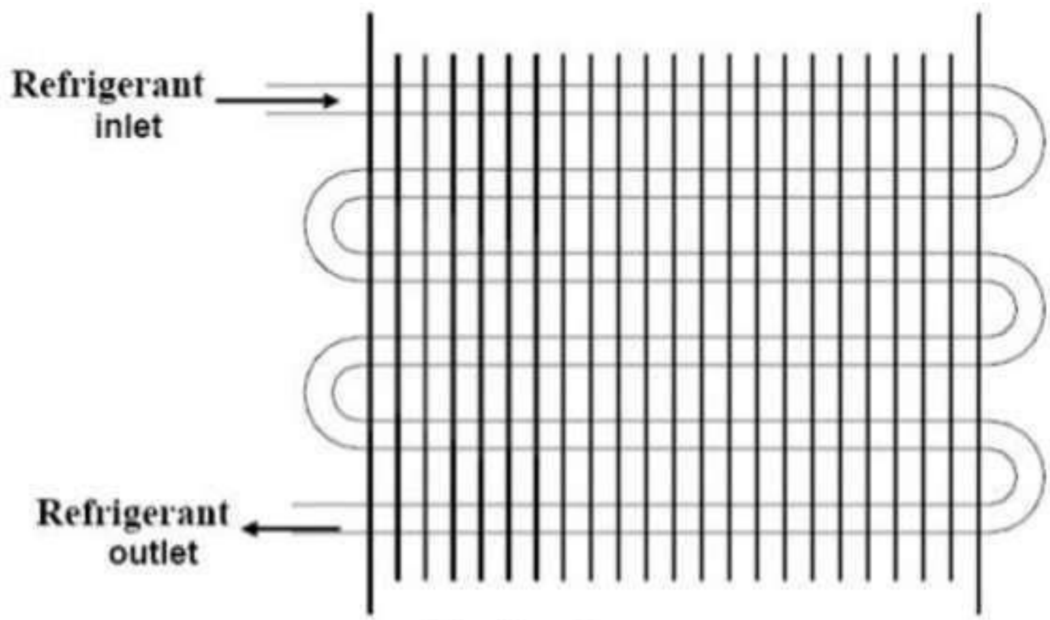


Fig. finned evaporators

The fins are the external protrusions from the surface of the coil and they extend into the open space. For the fins to be effective it is very important that there is very good contact between the coil and the fins. In some cases, the fins are soldered directly to the surface of the coil and in other cases, the fins are just slipped over the surface of the fins, and then they are expanded thus ensuring close thermal contact between the two. Tough the fins help increase the heat transfer, rate, adding them beyond certain numbers won't produce any additional benefits, hence the only a certain number of fins should be applied on the external surface of the tube.
The finned evaporators are most commonly used in the air conditioners of almost all types like a window, split, packaged, and the central air conditioning systems.

Bare Tube Evaporators

The bare tube evaporators are made up of copper tubing or steel pipes. The copper tubing is used for small evaporators where the refrigerant other than ammonia is used, while the steel pipes are used with the large evaporators where ammonia is used as the refrigerant. The bare tube evaporator comprises of several turns of the tubing, though most commonly flat zigzag and oval trombone are the most common shapes. The bare tube evaporators are usually used for liquid chilling. In the blast cooling and the freezing operations the atmospheric air flows over the bare tube evaporator and the chilled air leaving it used for the cooling purposes. The bare tube evaporators are used in very few applications, however the bare tube evaporators fitted with the fins, called as finned evaporators are used very commonly.

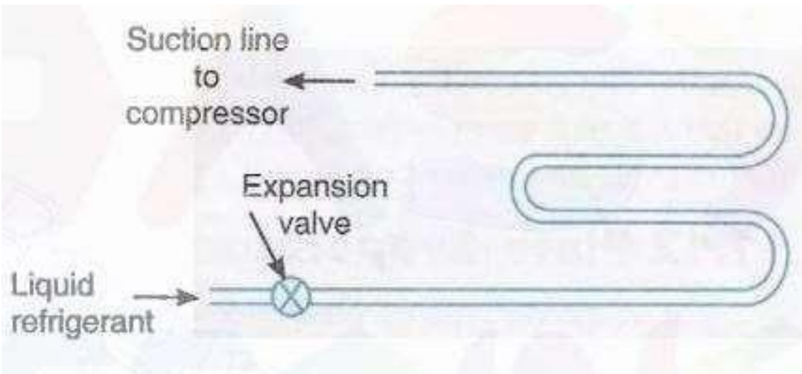


Fig. 11.4. Bare tube coil evaporator.

Shell and Tube types of Evaporators

The shell and tube types of evaporators are used in the large refrigeration and central air conditioning systems. The evaporators in these systems are commonly known as the chillers. The chillers comprise of large number of the tubes that are inserted inside the drum or the shell. Depending on the direction of the flow of the refrigerant in the shell and tube type of chillers, they are classified into two types: dry expansion type and flooded type of chillers. In dry expansion chillers the refrigerant flows along the tube side and the fluid to be chilled flows along the shell side. The flow of the refrigerant to these chillers is controlled by the expansion valve. In case of the flooded type of evaporators the refrigerant flows along the shell side and fluid to be chilled flows along the tube. In these chillers the level of the refrigerant is kept constant by the float valve that acts as the expansion valve also.

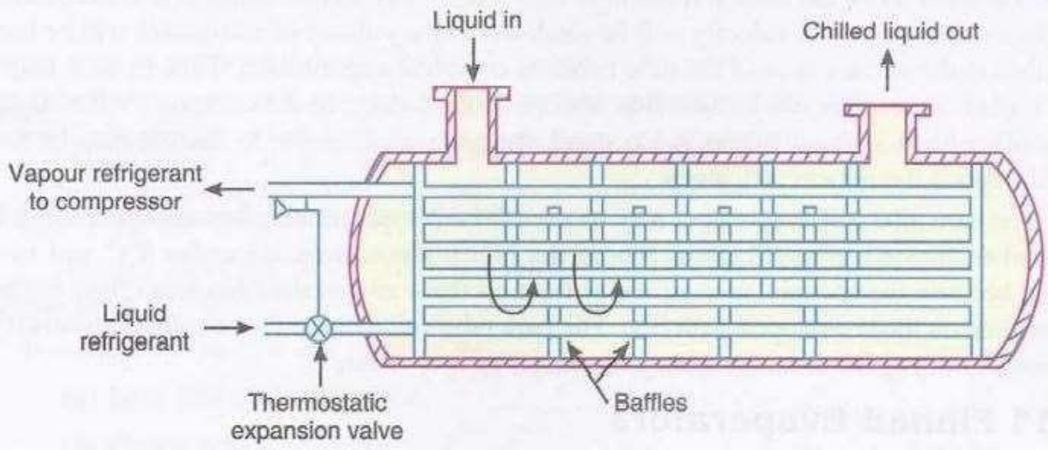


Fig. 11.7. Shell and tube evaporator.

Lecture note

Sub-refrigeration and air conditioning

Sem-5th mechanical

Expansion valve

Automatic expansion valve

Automatic expansion valve works in response to the pressure changes in the evaporator due to increase in refrigeration load (pressure increases) or due to decrease in refrigeration load (pressure decreases). This valve maintains constant pressure throughout the range of varying load conditions on the evaporator by controlling the quantity of refrigerant flowing into the evaporator. Therefore, this valve is also known as constant pressure expansion valve. It is used with dry expansion evaporators, where the load is relatively constant.

Construction of Automatic Expansion Valve

The automatic expansion valve consists of a needle valve and a seat (which forms an orifice), a metallic diaphragm or bellows, spring and an adjusting screw. Refer Fig. 1. The opening and closing of the valve with respect to the seat depends upon the following two opposing forces acting on the diaphragm:

- A force exerted by the spring pressure (P_S), Which acts on the top of diaphragm in vertically downward direction causing the valve to open.
- A force exerted by the evaporator pressure (P_E), which acts beneath (under) the diaphragm in vertically upward direction causing the valve to get closed.

When the compressor is running, the valve maintains an evaporator pressure in equilibrium with the spring pressure and the atmospheric pressure. The spring pressure can be varied by adjusting the tension of the spring with the help of adjusting screw. Once the spring is adjusted for a desired evaporator pressure, then the valve operates automatically to maintain constant evaporator pressure by control ing the flow of re-frigerant to the evaporator.

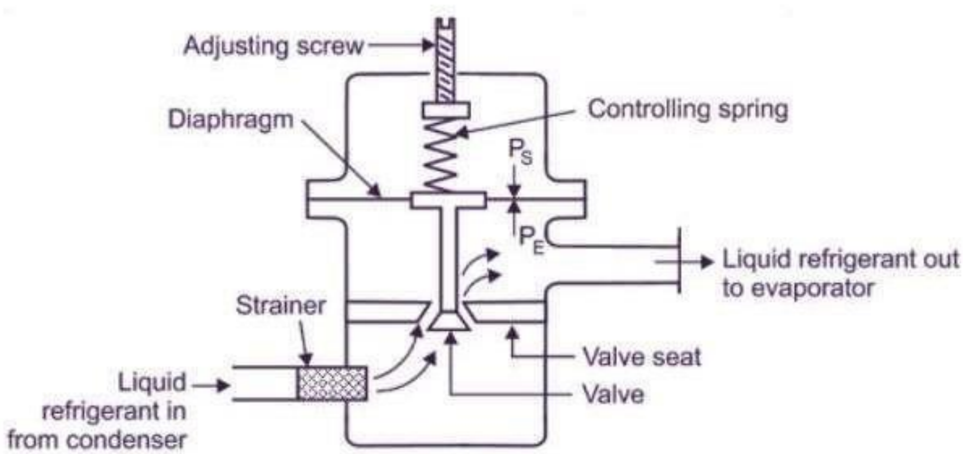


Fig. 1: Automatic expansion valve

Working of Automatic Expansion Valve

When refrigeration load decreases, thereby reducing the evaporator pressure

Due to decrease in evaporator pæssure, P_E will be less than P_S. Therefore, diaphragm will move downwards, causing the valve to open. This allows more liquid refrigerant to enter into the evaporator and thus increasing the evaporator pressure, till the desired evaporator pressure is reached.

When refrigeration load increases, thereby increasing the evaporator pressure

Due to increase in evaporator pressure, P_E will be more than P_S. Therefore, diaphragm will move upwards, causing the opening of the valve to reduce. Since, opening of is less, the flow of liquid refrigerant to the evaporator Will reduce, which in turn, lowers the evaporator pressure, till the desired evaporator pressure is reached. When the compressor stops, the liquid refrigerant continues to flow into the evaporator and increases the pressure in the evaporator. This increase in evaporator pressure causes the diaphragm to move upwards and the valve is closed. It remains closed until the compressor starts again and reduces the pressure in the evaporator.

Advantages of Automatic Expansion Valve

1. AEV is inexpensive.
2. It does not require maintenance, due to absence of moving parts.

Limitations of Automatic Expansion Valve

Automatic expansion valve is not used in actual practice or engineering applications due to following two major limitations.

1. When the refrigeration load decreases, the evaporator pressure will decrease. This makes the valve to open fully, attempting to bring the evaporator pressure up to the pressure setting of the valve. This results in the liquid refrigerant flooding back to the compressor and causing serious damage to the compressor.
2. When refrigeration load increases, the evaporator pressure will increase above the pressure setting of the valve. This makes the valve to close, until the evaporator pressure is reduced up to the pressure setting of the valve 'starving' the evaporator.

Thermostatic Expansion device

Thermostatic expansion valve (TEV) is the most commonly used expansion device in commercial and industrial refrigeration systems.

Working Principle of Thermostatic Expansion Valve

Thermostatic expansion valve maintains a constant superheat of the vapour refrigerant at the end of the evaporator coil, by controlling the flow of liquid refrigerant through the evaporator. Thus, its operation is based on the principle of constant degree of superheat at the evaporator outlet by controlling the flow of liquid refrigerant through the evaporator. Therefore, it is called as Constant superheat valve.

Construction of Thermostatic Expansion Valve

Thermostatic expansion valve consists of a needle valve and a seat, a metallic diaphragm, a spring and an adjusting screw. Refer Fig. 1. In addition to this, it has a feeler or thermal bulb, which is mounted on the suction line near the outlet of the evaporator coil. The feeler bulb is partly filled with the same liquid refrigerant as used in the refrigeration system. The opening and closing of the valve depends upon the following forces acting on the diaphragm.

1. The spring pressure (P_S) acting vertically upwards on the bottom side of daphragm,
2. The evaporator pressure (P_E) acting vertically upwards on the bottom side of diaphragm, and
3. The feeler bu b pressure (P_B) acting vertically downwards on the top side of diaphragm.

Since the feeler bulb is installed on the suction line, therefore it will be at the same temperature as the refrigerant at the point of surface contact. Any changes in the temperature of the refrigerant will cause a change in pressure in the feeler bulb, which will be transmitted to the top of the diaphragm. Under normal operating conditions, the feeler bulb pressure acting on the top side of diaphragm is balanced by spring pressure and evaporator pressure acting on the bottom side of the diaphragm. i.e.

$$P_B = P_S + P_E$$

The force tending to close the valve is dependent upon, (i) Spring pressure (P_S) and (ii) Evaporator pressure (P_E), which depends upon the saturation temperature of refrigerant in the evaporator coil. The force tending to open the valve depends upon the feeler bulb pressure (P_B), which depends upon the temperature of refrigerant in the feeler bulb. Thus, the operation of valve is control ed by the difference between the two temperatures (i.e. saturation temperature and feeler bulb temperature). This temperature difference is called as degree of superheat. The degree of superheat of the vapour refrigerant leaving the evaporator depends upon the initial setting of spring tension, which can be changed with the help of spring adjusting screw. When the valve is set for certain superheat, then it maintains those settings under all load conditions on the evaporator.

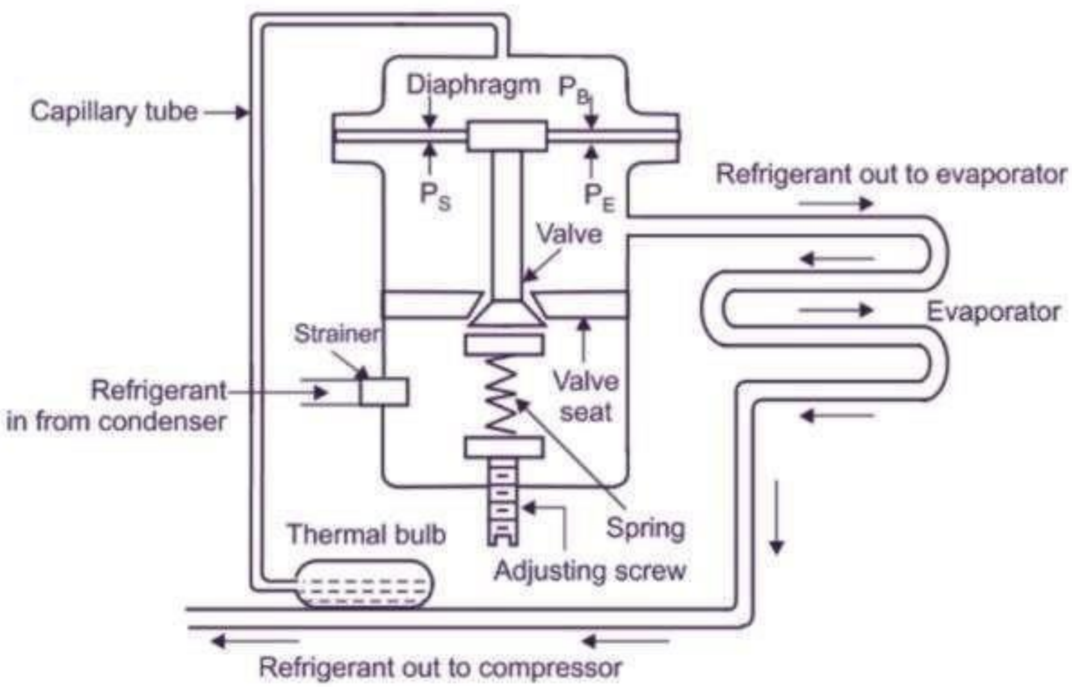


Fig. 1: Thermostatic expansion valve

Working of Thermostatic Expansion Valve

When refrigeration load on the evaporator increases

If refrigeration load on the evaporator increases, it causes the liquid refrigerant to boil faster in the evaporator coil. The temperature of feeler bulb increases due to early vapourization of liquid refrigerant. Thus, the feeler bulb pressure increases and this pressure is transmitted through a small diameter tube (also known as capillary tube) to the diaphragm. The diaphragm moves downwards and opens the valve to admit more quantity of liquid refrigerant to the evaporator. This continues till the pressure equilibrium on the diaphragm is reached.

When refrigeration load on the evaporator decreases

On the other hand, when refrigeration load on the evaporator decreases, less amount of liquid refrigerant evaporates in the evaporator coil. The excess liquid refrigerant flows towards the evaporator outlet, which cools the feeler bulb. Due to this, the feeler bulb pressure decreases due to decrease in its temperature. The low feeler bulb pressure is transmitted through the capillary tube to the diaphragm and moves the diaphragm in upward direction. This reduces the opening of valve and thus, reduces the flow of liquid refrigerant to the evaporator. The evaporator pressure decreases due to reduced quantity of liquid refrigerant flowing to the evaporator. This continues till the evaporator pressure and the spring pressure maintains equilibrium with the feeler bulb pressure.

Functions performed by thermostatic expansion valve in a refrigerating system

Throttling action: The thermostatic valve, like any other valve, has a pressure drop across it. It separates the high pressure side from the low pressure side of the system.

Modulating action: It feeds the proper amount of liquid refrigerant in to evaporator. Neither, it dries the evaporator nor it floods evaporator with refrigerant.

Controlling action: It meets the need of changing loads. As the load on refrigeration system increases, the expansion valve modulates towards the wider opening position. When refrigeration load decreases, it acts in opposite manner.

Applications of Thermostatic Expansion Valve

Besides the capillary tube, the thermostatic expansion valve is used Widely in the refrigeration and air conditioning systems. Capillary tube is used in the small capacity systems like domestic appliances, whereas, the thermostatic expansion valve is used in commercial and industrial refrigeration systems of higher capacity. Thermostatic expansion valve is commonly used in,

1. Industrial refrigeration plants.
2. Commercial units such as supermarkets, freezers, ice maker machines.
3. High capacity split air conditioners.
4. Packaged air conditioners.
5. Refrigerated containers.

Advantages of Thermostatic Expansion Valve

1. TEV maintains the flow of the refrigerant to the evaporator as per the cool ng load (i.e. refrigeration load) inside. Thus, the refrigeration or the air conditioning plant can be run to the optimum capacity as per the changing load requirements.
2. TEV keeps the evaporator fully active and helps to obtain the optimum cooling effect.
3. If the refrigerant entering the compressor contain liquid droplets, then It leads to breakdown of the compressor due to compression of liquid refrigerant. Since the entire refrigerant in the evaporator gets vapourized, therefore the chances of the liquid refrigerant particles going to the compressor are reduced. Thus, TEV increases life of compressor.
4. The compressor can also work at the optimum capacity as per the refrigeration load on the system. If the load is lesser, it has to compress less amount of refrigerant and work on lesser capacity, thus consuming less electric power. If load is higher, it can also work at higher capacities.

Disadvantages of Thermostatic Expansion Valve

1. Thermostatic expansion valve does not work well, if its feeler bulb is not in a good thermal contact with the refrigerant tube.
2. If there is very small extent of superheating, thermostatic expansion valve cannot be used.

Lecture note

Sub-Refrigeration and air conditioning

Sem-5th sem Mechanical

Refrigerants

The refrigerant is a heat carrying medium which during their cycle (*i.e.* compression, condensation, expansion and evaporation) in the refrigeration system absorbs heat from a low temperature system and discards the heat so absorbed to a higher temperature system.

Desirable properties of refrigerants

1. Low boiling and freezing point,
2. High critical pressure and temperature,
3. High latent heat of vaporisation,
4. Low specific heat of liquid, and high specific heat of vapour,
5. Low specific volume of vapour,
6. High thermal conductivity,
7. Non-corrosive to metal,
8. Non-flammable and non-explosive,
9. Non-toxic,
10. Low cost,
11. Easily and regularly available,
12. Easy to liquify at moderate pressure and temperature,
13. Easy of locating leaks by odour or suitable indicator,
14. Mixes well with oil,
15. High coefficient of performance, and
16. Ozone friendly.

Classification of refrigerants

There are two types of refrigerants.

1)Primary refrigerants

2)secondary refrigerants