UNIT-3(COMPONENTS)

COMPRESSORS

A compressor is the most important and often the costliest component (typically 30 to 40 percent of total cost) of any vapour compression refrigeration system (VCRS). The function of a compressor in a VCRS is to continuously draw the refrigerant vapour from the evaporator, so that a low pressure and low temperature can be maintained in the evaporator at which the refrigerant can boil extracting heat from the refrigerated space. The compressor then has to raise the pressure of the refrigerant to a level at which it can condense by rejecting heat to the cooling medium in the condenser.

CLASSIFICATION OF COMPRESSORS

Compressors used in refrigeration systems can be classified in several ways:

a) Based on the working principle:

i. Positive displacement type

ii. Roto-dynamic type

In positive displacement type compressors, compression is achieved by trapping a refrigerant vapour into an enclosed space and then reducing its volume. Since a fixed amount of refrigerant is trapped each time, its pressure rises as its volume is reduced. When the pressure rises to a level that is slightly higher than the condensing pressure, then it is expelled from the enclosed spaceand a fresh charge of low-pressure refrigerant is drawn in and the cycle continues. Since the flow of refrigerant to the compressor is not steady, the positive displacement type compressor is a pulsating flow device. However, since the operating speeds are normally very high the flow appears to be almost steady on macroscopic time scale. Since the flow is pulsating on a microscopic time scale, positive displacement type compressors are prone to high wear, vibration and noise level.

Depending upon the construction, positive displacement type compressors used in refrigeration and air conditioning can be classified into:

i. Reciprocating type

ii. Rotary type with sliding vanes (rolling piston type or multiple vane type)

iii. Rotary screw type (single screw or twin-screw type)

iv. Orbital compressors, and

v. Acoustic compressors.

In roto-dynamic compressors, the pressure rise of refrigerant is achieved by imparting kinetic energy to a steadily flowing stream of refrigerant by a rotating mechanical element and then converting into pressure as the refrigerant flows through a diverging passage. Unlike positive displacement type, the roto-dynamic type compressors are steady flow devices, hence are subjected to less wear and vibration.

Depending upon the construction, roto-dynamic type compressors can be classified into:

i. Radial flow type, or

ii. Axial flow type.

Centrifugal compressors (also known as turbo-compressors) are radial flow type, roto-dynamic compressors. These compressors are widely used in large capacity refrigeration and air conditioning systems. Axial flow compressors are normally used in gas liquefaction applications.

b) Based on arrangement of compressor motor or external drive:

i. Open type

ii. Hermetic (or sealed) type

iii. Semi-hermetic (or semi-sealed) type

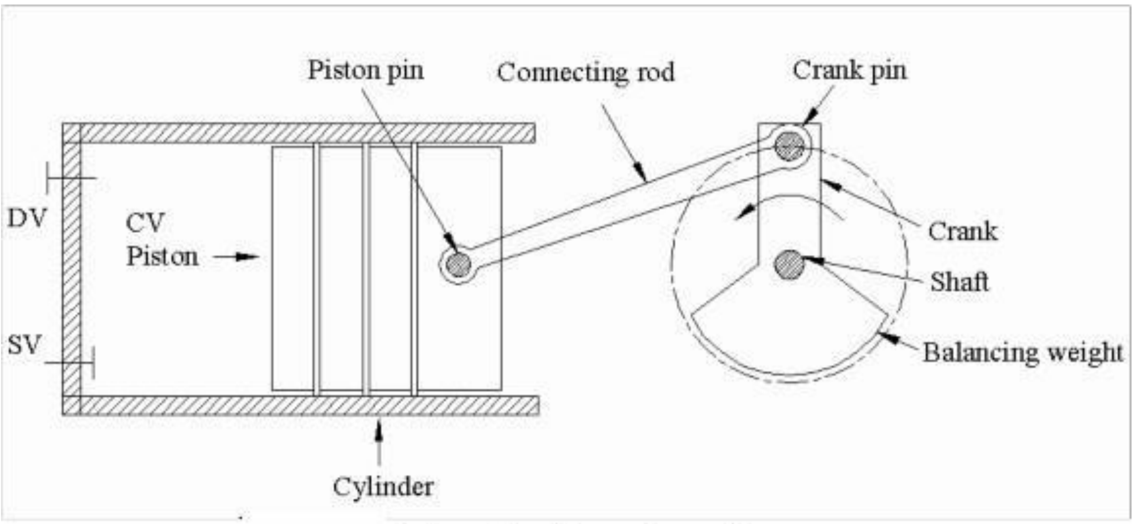
In open type compressors the rotating shaft of the compressor extends through a seal in the crankcase for an external drive. The external drive may be an electrical motor or an engine (e.g. diesel engine). The compressor may be belt driven or gear driven. Open type compressors are normally used in medium to large capacity refrigeration system for all refrigerants and for ammonia (due to its incompatibility with hermetic motor materials). Open type compressors are characterized by high efficiency, flexibility, better compressor cooling and service ability. However, since the shaft has to extend through the seal, refrigerant leakage from the system cannot be eliminated completely. Hence refrigeration systems using open type compressors require a refrigerant reservoir to take care of the refrigerant leakage for some time, and then regular maintenance for charging the system with refrigerant, changing of seals, gaskets etc.

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 leakagefrom 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 therefrigerant, 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.

Reciprocating compressors:

Reciprocating compressor is the workhorse of the refrigeration and air conditioning industry. It is the most widely used compressor with cooling capacities ranging from a few Watts to hundreds of kilowatts. Modern day reciprocating compressors are high speed (≈ 3000 to 3600 rpm), single acting, single or multi-cylinder (upto 16 cylinders) type. Reciprocating compressors consist of a piston moving back and forth in a cylinder, with suction and discharge valves to achieve suction and compression of the refrigerant vapor.



Schematic of a reciprocating compressor

Its construction and working are somewhat similar to a two-stroke engine, as suction and compression of the refrigerant vapor are completed in one revolution of the crank. The suction side of the compressor is connected to the exit of the evaporator, while the discharge side of the compressor is connected to the condenser inlet. The suction (inlet) and the discharge (outlet) valves open and close due to pressure differences between the cylinder and inlet or outlet manifolds respectively. The pressure in the inlet manifold is equal to or slightly less than the evaporator pressure. Similarly the pressure in the outlet manifold is equal to or slightly greater than the condenser pressure. The purpose of the manifolds is to provide stable inlet and outlet pressures for the smooth operation of the valves and also provide a space for mounting the valves.
The valves used are of reed or plate type, which are either floating or clamped. Usually, backstops are provided to limit the valve displacement and springs may be provided for smooth return after opening or closing. The piston speed is decided by valve type. Too high a speed will give excessive vapour velocities that will decrease the volumetric efficiency and the throttling loss will decrease the compression efficiency.

Rolling piston (fixed vane) type compressors:

Rolling piston or fixed vane type compressors are used in small refrigeration systems (upto 2kW capacity) such as domestic refrigerators or air conditioners. These compressors belong to the class of positive displacement type as compression is achieved by reducing the volume of the refrigerant. In this type of compressors, the rotating shaft of the roller has its axis of rotation that matches with the center line of the cylinder, however, it is eccentric with respect to the roller. This eccentricity of the shaft with respect to the roller creates suction and compression of the refrigerant as shown in Fig.20.1. A single vane or blade is positioned in the non-rotating cylindrical block. The rotating motion of the roller causes a reciprocating motion of the single vane.
This type of compressor does not require a suction valve but requires a dischargevalve. The sealing between the high and low pressure sides has to be provided:
-Along the line of contact between roller and cylinder block

This type of compressor does not require a suction valve but requires a discharge valve. The sealing between the high and low pressure sides has to be provided:
-Along the line of contact between roller and cylinder block

-Along the line of contact between vane and roller, and

-between the roller and end-pates

The leakage is controlled through hydrodynamic sealing and matching between the mating components. The effectiveness of the sealing depends on the clearance, compressor speed, surface finish and oil viscosity. Close tolerances and good surface finishing is required to minimize internal leakage. Unlike in reciprocating compressors, the small clearance volume filled with high-pressure refrigerant does not expand, but simply mixes with the suction refrigerant in the suction space. As a result, the volumetric efficiency does not reduce drastically with increasing pressure ratio, indicating small re-expansion losses. The compressor runs smoothly and is relatively quiet as the refrigerant flow is continuous.
The mass flow rate of refrigerant through the compressor is given by:

where A = Inner diameter of the cylinder B = Diameter of the roller
L = Length of the cylinder block N = Rotation speed, RPM
ηV = Volumetric efficiency
ve = specific volume of refrigerant at suction

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The mass flow rate of refrigerant through the compressor is given by:

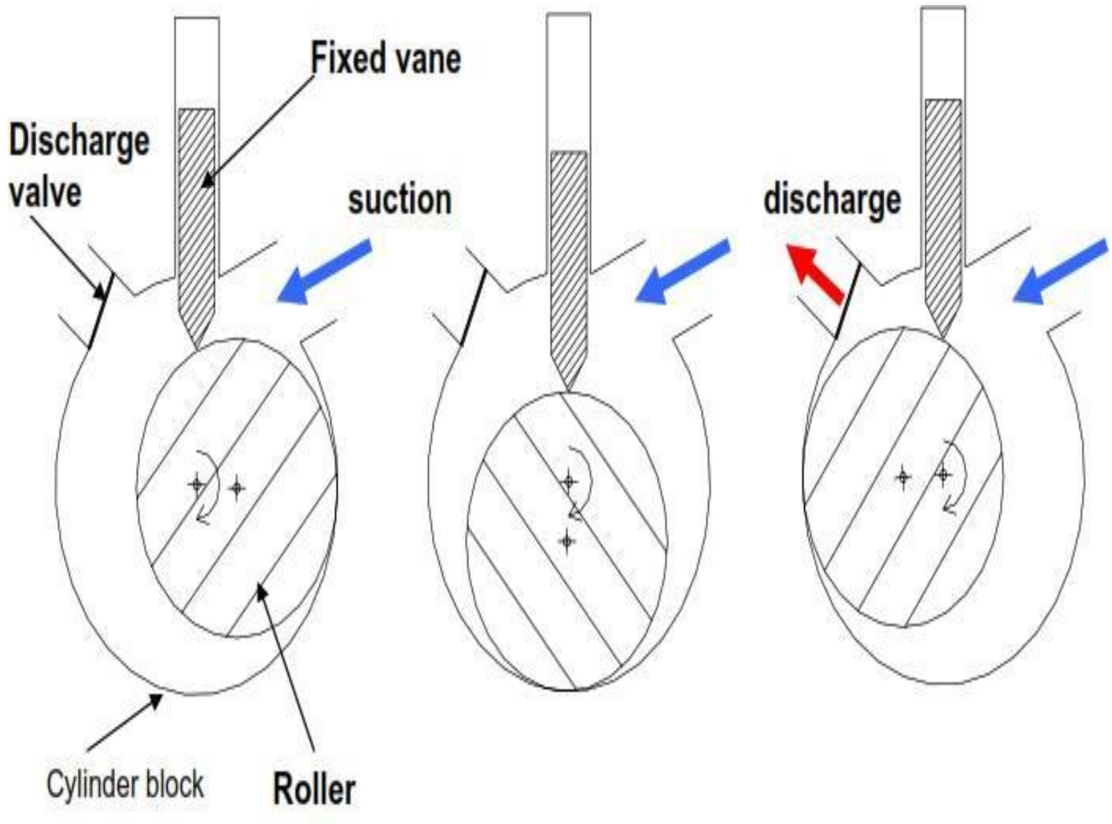
$$\dot{m}=\eta_V\left(\frac{\dot{V}_{SW}}{v_e}\right)=\left(\frac{\eta_V}{v_e}\right)\left(\frac{\pi}{4}\right)\left(\frac{N}{60}\right)(A^2-B^2)L$$

where A = Inner diameter of the cylinderB = Diameter of the roller
L = Length of the cylinder block

N = Rotation speed, RPM

η_V = Volumetric efficiency

v_e = specific volume of refrigerant at suction



Working principle of a rolling piston type compressor

Multiple vane type compressors:

In multiple vane type compressor, the axis of rotation coincides with the center of the roller (O), however, it is eccentric with respect to the center of the cylinder (O'). The rotor consists of a number of slots with sliding vanes. During the running of the compressor, the sliding vanes, which are normally made of non-metallic materials, are held against the cylinder due to centrifugal forces. The number of compression strokes produced in one revolution of the rotor is equal to the number of sliding vanes, thus a 4-vane compressor produces 4 compression strokes in one rotation.

In these compressors, sealing is required between the vanes and cylinder, between the vanes and the slots on the rotor and between the rotor and the end plate. However, since pressure difference across each slot is only a fraction of the total pressure difference, the sealing is not as critical as in fixed vane type compressor.

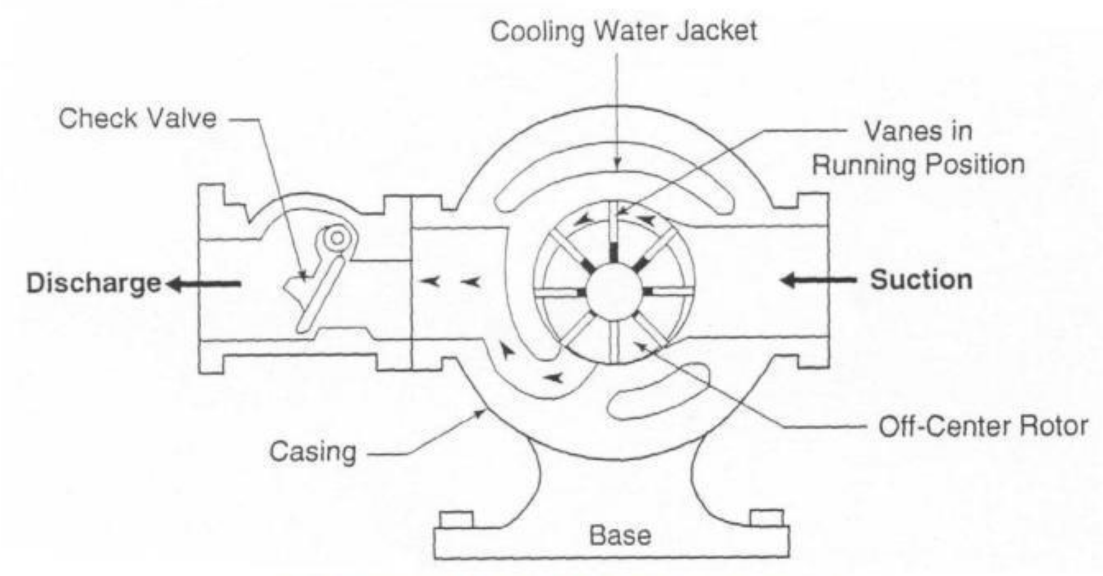
This type of compressor does not require suction or discharge valves, however, as shown in Fig., check valves are used on discharge side to prevent reverse rotation during off-time due to pressure difference. Since there are no discharge valves, the compressed refrigerant is opened to the discharge port when it has been compressed through a fixed volume ratio, depending upon the geometry. This implies that these compressors have a fixed built-in volume ratio. The built-in volume ratio is defined as "the ratio of a cell as it is closed off from the suction port to its volume before it opens to the discharge port". Since the volume ratio is fixed, the pressure ratio, rp is given by:

$$r_p = \left(\frac{P_d}{P_s}\right) = V_b^{\,k}$$

where Pd and Ps are the discharge and suction pressures, Vb is the built-in volume ratio and k is the index of compression. Since no centrifugal force is present when the compressor is off, the multiple vanes will not be pressed against the cylinder walls during the off-period.

As a result, high pressure refrigerant from the discharge side can flow back into the side and

pressure equalization between high and low pressure sides take place. This is beneficial from the compressor motor point-of-view as it reduces the required starting torque. However, this introduces cycling loss due to the entry of high pressure and hot refrigerant liquid into the evaporator. Hence, normally a non-return check valve is used on the discharge side which prevents the entry of refrigerant liquid from high pressure side into evaporator through the compressor during off-time, at the same time there will be pressure equalization across the vanes of the compressor. As a result,



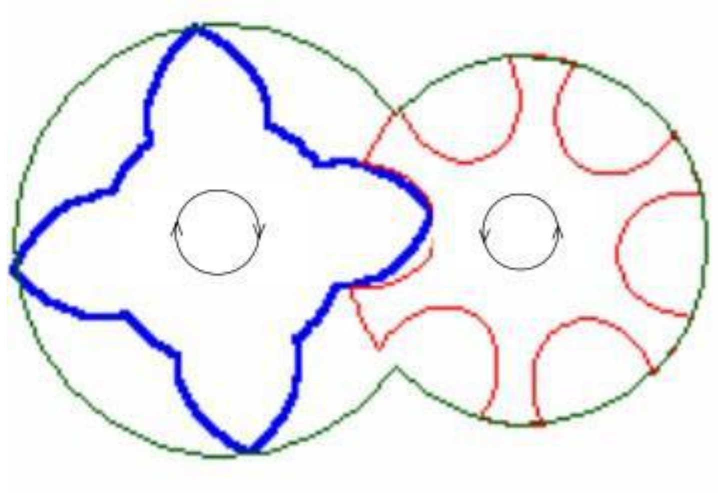
Sectional view of a multiple vane, rotary compressor

ROTARY, SCREW COMPRESSORS:

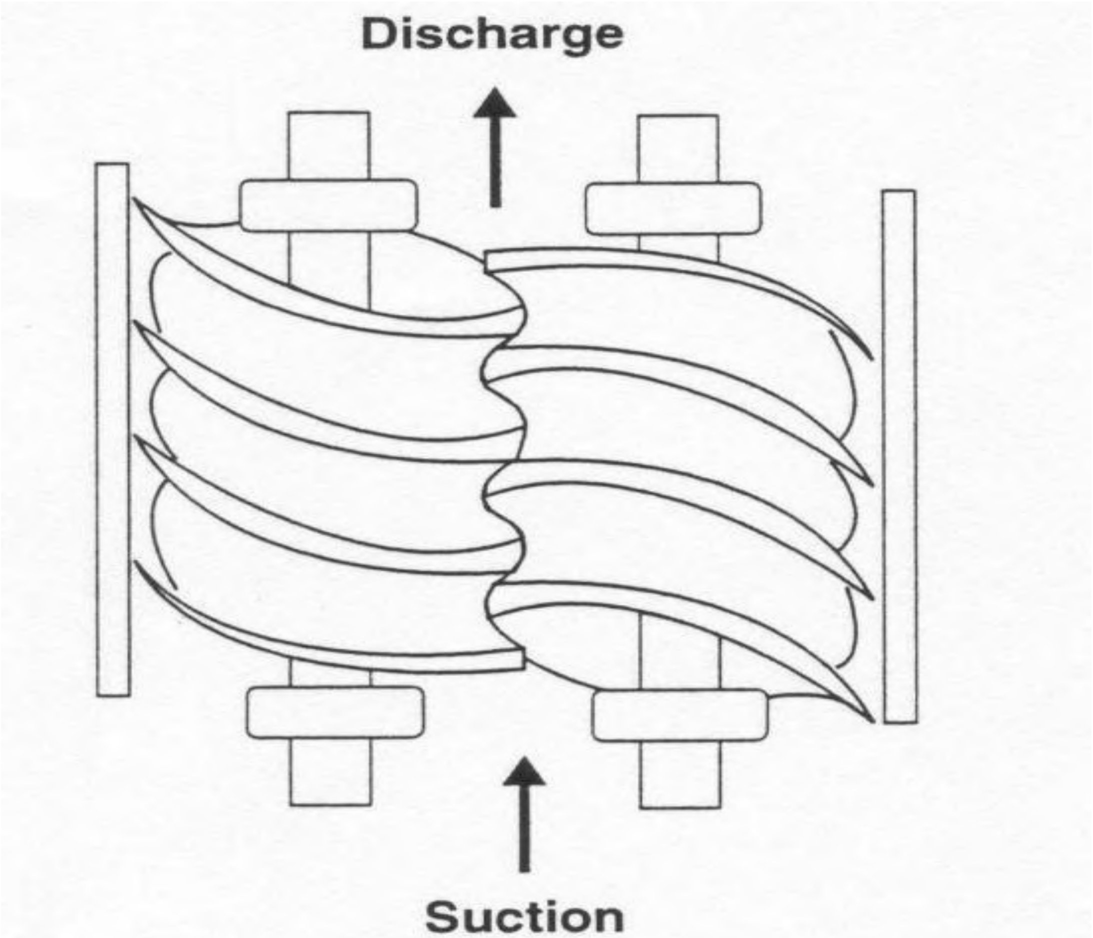
The rotary screw compressors can be either twin-screw type or single-screw

Twin-screw compressor:

The twin-screw type compressor consists of two mating helically grooved rotors, one male and the other female. Generally the male rotor drives the female rotor. The male rotor has lobes, while the female rotor has flutes or gullies. when the male rotor rotates at 3600RPM, the female rotor rotates at 2400 RPM. The flow is mainly in the axial direction. Suction an compression take place as the rotors unmesh and mesh. When one lobe-gully combination begins to unmesh the opposite lobe-gully combination begins to mesh.With 4 male lobes rotating at 3600 RPM, 4 interlobe volumes are per revolution, thus giving 4 X 3600 = 14400 discharges per minute.



Twin-screw compressor with 4 male lobes and 6 female gullies



Direction of refrigerant flow in a twin-screw compressor

Discharge takes place at a point decided by the designed built-in volume ratio, which depends entirely on the location of the delivery port and geometry of the compressor.

Since the built-in volume ratio is fixed by the geometry, a particular compressor is designed for a particular built-in pressure ratio. However, different built-in ratios can be obtained by changing the position of the discharge port. The built-in pressure ratio, rp given by:

$$r_p = \left(\frac{P_d}{P_s}\right) = V_b{}^k$$

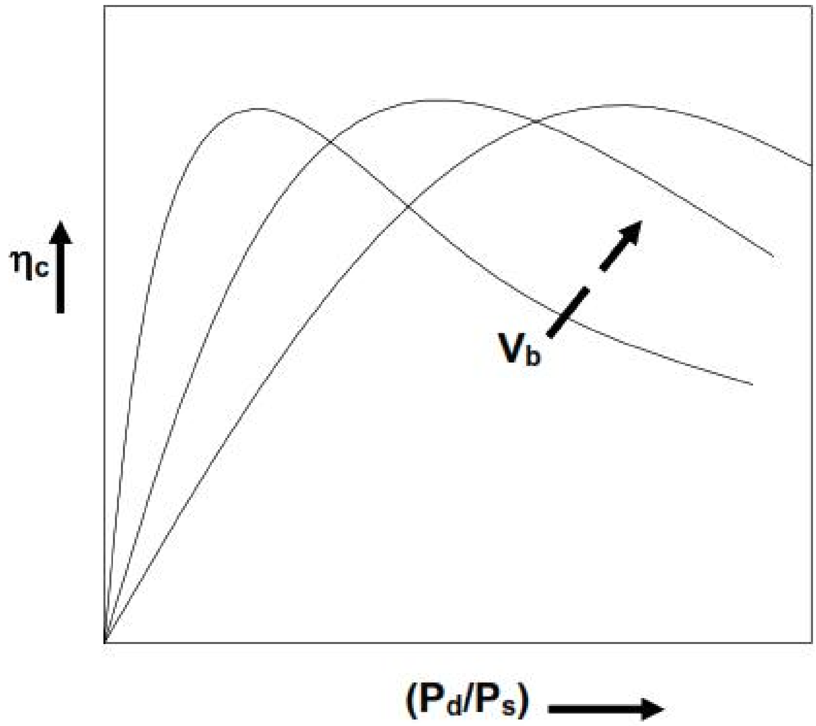
Where Pd and Ps are the discharge and suction pressures, Vb is the built-in volume ratio and k is the index of compression.

If the built-in pressure at the end of compression is less than the condensing pressure, high pressure refrigerant from discharge manifold flows back into the interlobe space when the discharge port is uncovered. This is called as under compression. On the other hand, if the built-in pressure at the end of compression is higher than the condensing pressure, then the compressed refrigerant rushes out in an unrestrained expansion as soon as the port is uncovered (over-compression).

Both under-compression and over-compression are undesirable as they lead to loss in efficiency. Lubrication and sealing between the rotors is obtained by injecting lubricating oil between the rotors. The oil also helps in cooling the compressor, as a result very high pressure ratios (upto 20:1) are possible without overheating the compressor.

The capacity of the screw compressor is normally controlled with the help of a slide valve. As the slide valve is opened, some amount of suction refrigerant escapes to the suction side without being compressed. This yields a smooth capacity control from 100 percent down to 10 percent of full load. It is observed that the power input is approximately proportional to refrigeration capacity upto about 30 percent, however, the efficiency decreases rapidly, there after. Figure shows the compression efficiency of a twin-screw compressor as a function of pressure ratio and built-in volume ratio. It can be seen that for a given built-in volume ratio, the efficiency reaches a peak at a particular optimum pressure ratio. The value of this optimum pressure ratio increases with built-in volume ratio as shown in the figure. If the design condition corresponds to the optimum pressure ratio, then the compression efficiency drops asthe system operates at off-design conditions. However, when operated at the optimum pressure ratio, the efficiency is much higher than other types of compressors.

As the rotor normally rotates at high speeds, screw compressors can handle fairly large amounts of refrigerant flow rates compared to other positive displacement type compressors. Screw compressors are available in the capacity range of 70 to 4600 kW. They generally compete with high capacity reciprocating compressors and low capacity centrifugal compressors. They are available for a wide variety of refrigerants and applications. Compared to reciprocating compressors, screw compressors are balanced and hence do not suffer from vibration problems.



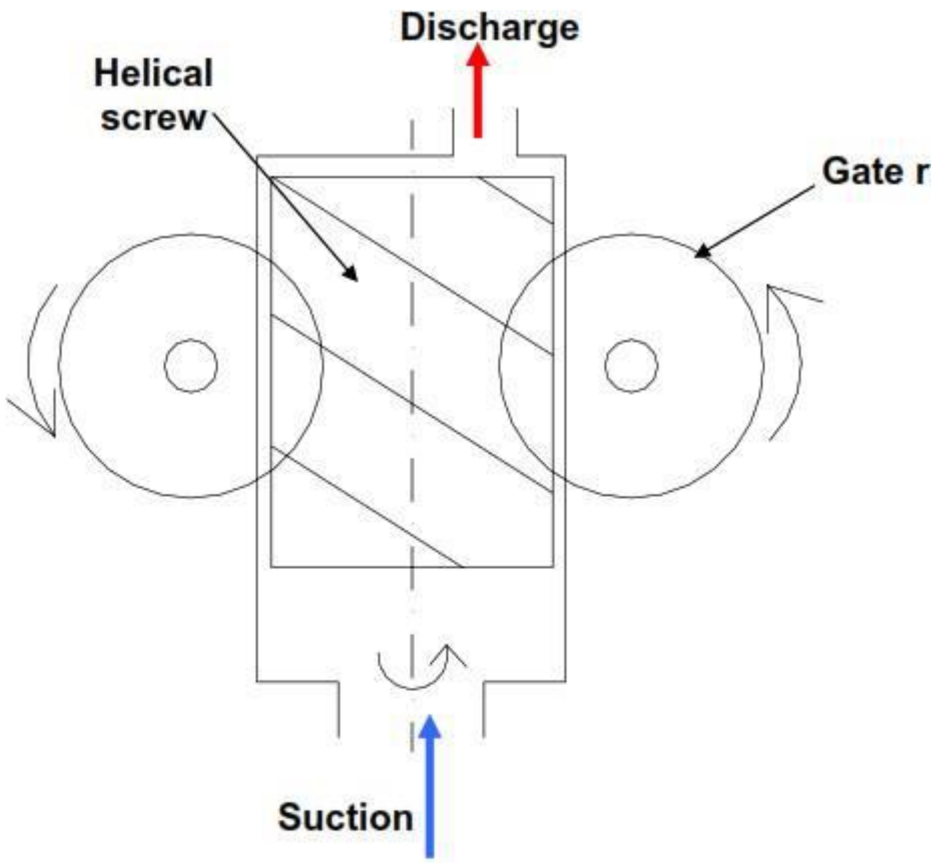
Variation of compression efficiency of a twin-screw compressor with pressure ratio and built-in volume ratio

Twin-screw compressors are rugged and are shown to be more reliable than reciprocating compressors; they are shown to run for 30000 – 40000 hours between major overhauls. They are compact compared to reciprocating compressors in the high capacity range.

Single-screw compressors:

As the name implies, single screw compressors consist of a single helical screw and two planet wheels or gate rotors. The helical screw is housed in a cylindrical casing with suction port at one end and discharge port at the other end as shown in Fig. Suction and compression are obtained as the screw and gate rotors unmesh and mesh. The high and low pressure regions in the cylinder casing are separated by the gate rotors.

The single screw is normally driven by an electric motor. The gate rotors are normally made of plastic materials. Very small power is required to rotate the gate rotors as the frictional losses between the metallic screw and the plastic gate rotors is very small. It is also possible to design the compressors with a single gate rotor. Similar to twin-screw, lubrication, sealing and compressor cooling is achieved by injecting lubricating oil into the compressor. An oil separator, oil cooler and pump are required to circulate the lubricating oil. It is also possible to achieve this by injecting liquid refrigerant, in which case there is no need for an oil separator. f plastic materials. Very small power is required to rotate the gate rotors as the frictional losses between the metallic screw and the plastic gate rotors is very small. It is also possible to design the compressors with a single gate rotor. Similar to twin-screw, lubrication, sealing and compressor cooling is achieved by injecting lubricating oil into the compressor. An oil separator, oil cooler and pump are required to circulate the lubricating oil. It is also possible to achieve this by injecting liquid refrigerant, in which case there is no need for an oil separator.

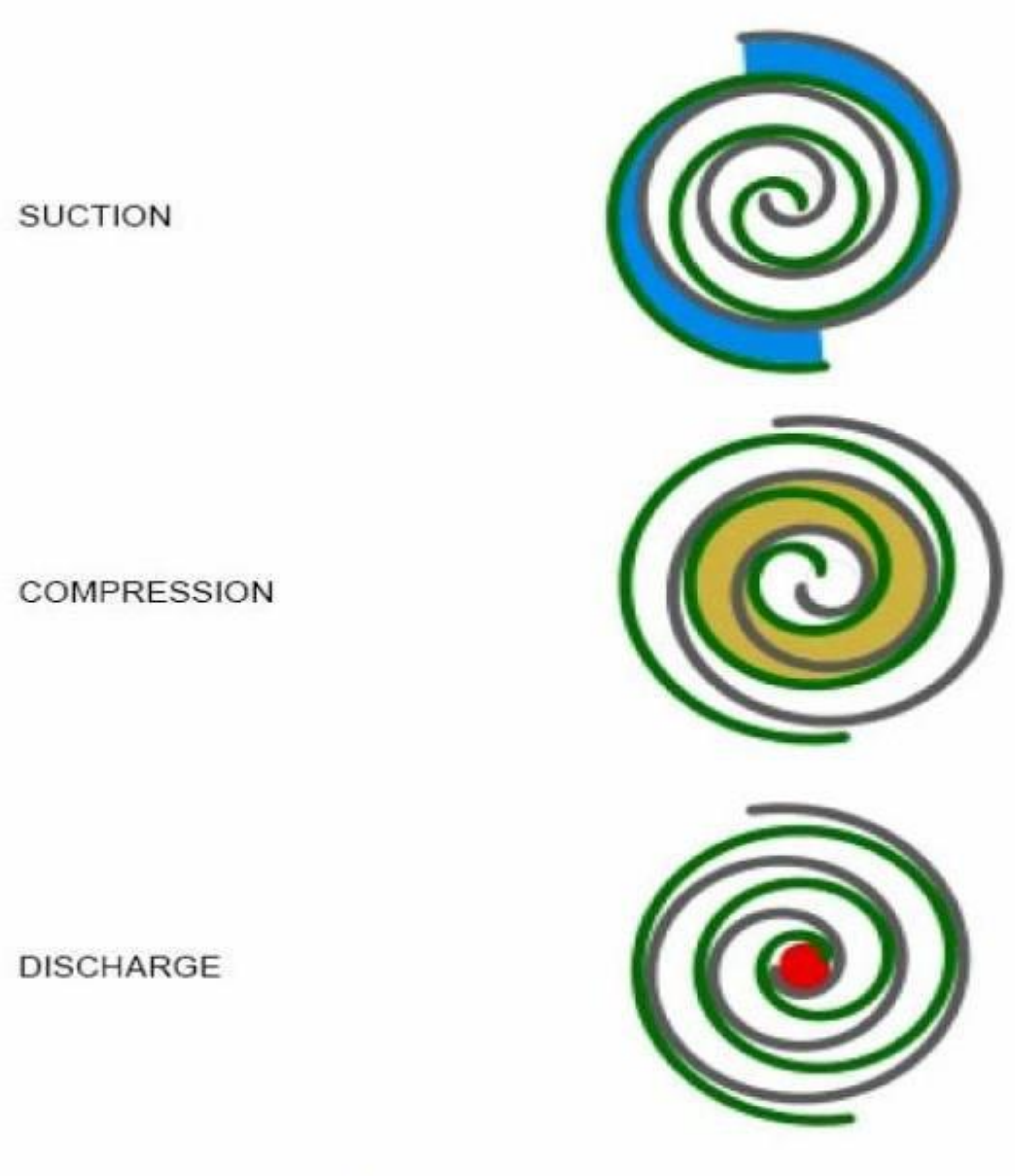


Working principle of a single-screw compressor

Scroll compressors:

Scroll compressors are orbital motion, positive displacement type compressors, in which suction and compression is obtained by using two mating, spiral shaped, scroll members, one fixed and the other orbiting. Figure shows the working principle of scroll compressors. Figures show the constructional details of scroll compressors. As shown in Fig, the compression processinvolves three orbits of the orbiting scroll. In the first orbit, the scrolls ingest and trap two pockets of suction gas. During the second orbit, the two pockets of gas are compressed to an intermediate pressure. In the final orbit, the two pockets reach discharge pressure and are simultaneously opened to the discharge port. This simultaneous process of suction, intermediate compression, and discharge leads to the smooth continuous compression process of the scroll compressor. One part that is not shown in this diagram but is essential to the operation of the scroll is the antirotation coupling. This device maintains a fixed angular relation of 180 degrees between the fixed and orbiting scrolls. This

fixed angular relation, coupled with the movement of the orbiting scroll, is the basis for the formation of gas compression pockets.



Working principle of a scroll compressor

Currently, the scroll compressors are used in small capacity (3 to 50 kW) refrigeration, air conditioning and heat pump applications. They are normally of hermetic type. Scroll compressors offer several advantages such as:

1. Large suction and discharge ports reduce pressure losses during suction and discharge

2. Physical separation of suction and compression reduce heat transfer to suction gas, leading to high volumetric efficiency

3. Volumetric efficiency is also high due to very low re-expansion losses and continuous flow over a wide range of operating conditions

4. Flatter capacity versus outdoor temperature curves

5. High compression efficiency, low noise and vibration compared to reciprocating compressors

6. Compact with minimum number of moving parts

As shown in, each scroll member is open at one end and bound by a base plate at the other end. They are fitted to form pockets of refrigerant between their respective base plates and various lines of contacts between the scroll walls. Compressor capacity is normally controlled by variable speed inverter drives.

Centrifugal compressors;

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. Unlike reciprocating compressors, centrifugal compressors are steady-flow devices hence they are subjected to less vibration and noise.

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 high speed impeller blades to the refrigerant confined between the blade passages. The increase in static pressureis 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:

$$h = \frac{V^2}{g}$$

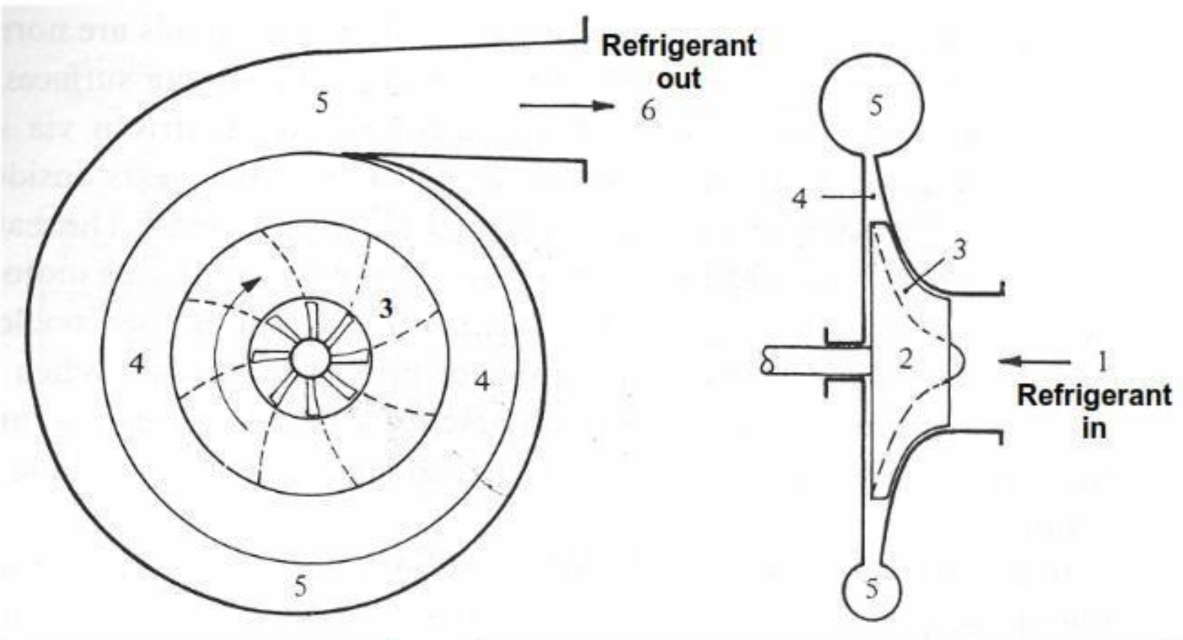
where h = static head developed, m

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:

$$\Delta P = \rho g h = \rho V^2$$



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

Thus it can be seen that for a given refrigerant with a fixed density, the pressure rise depends only on the peripheral velocity or tip speed of the blade. The tip speed of the blade is proportional to the rotational speed (RPM) of the impeller and the impeller diameter. The maximum permissible tip speed is limited by the strength of the structural materials of the blade (usually made of high speed chrome-nickel steel) and the sonic velocity of the refrigerant.Under these limitations, the maximum achievable pressure rise (hence maximum achievable temperature lift) of single stage centrifugal compressor is limited for a given refrigerant. Hence, multistage centrifugal compressors are used for large temperature lift applications. In multistage centrifugal compressors, the discharge of the lower stage compressor is fed to the inlet of the next stage compressor and so on. In multistage centrifugal compressors, the impeller diameter of all stages remains same, but the width of the impeller becomes progressively narrower in the direction of flow as refrigerant density increases progressively.

The blades of the compressor or either forward curved or backward curved or radial. Backward curved blades were used in the older compressors, whereas the modern centrifugal compressors use mostly radial blades.

The stationary diffuser can be vaned or vaneless. As the name implies, in vaned diffuser vanes are used in the diffuser to form flow passages. The vanes can be fixed or adjustable. Vaned diffusers are compact compared to the vaneless diffusers and are commonly used for high discharge pressure applications. However, the presence of vanes in the diffusers can give rise to shocks, as the refrigerant velocities at the tip of the impeller blade could reach sonic velocities in large, high-speed centrifugal compressors. In vaneless diffusers the velocity of refrigerant in the diffuser decreases and static pressure increases as the radius increases. As a result, for a required pressure rise, the required size of the vaneless diffuser could be large compared to vaned diffuser. However, the problem of shock due to supersonic velocities at the tip does not arise with vaneless diffusers as the velocity can be diffused smoothly.

Generally adjustable guide vanes or pre-rotation vanes are added at the inlet (eye) of the impeller for capacity control.

Commercially centrifugal compressors are available for a wide variety of refrigeration and air conditioning applications with a wide variety of refrigerants.

These machines are available for the following ranges:

Evaporator temperatures	:	-100°C to +10°C
Evaporator pressures	:	14 kPa to 700 kPa
Discharge pressure	:	upto 2000 kPa
Rotational speeds	:	1800 to 90,000 RPM
Refrigeration capacity	:	300 kW to 30000 kW

As mentioned before, on the lower side the capacity is limited by the impeller width and tipspeeds and on the higher side the capacity is limited by the physical size (currently the maximum impeller diameter is around 2 m).

Since the performance of centrifugal compressor is more sensitive to evaporator and condensing temperatures compared to a reciprocating compressor, it is essential to reduce the pressure drops when a centrifugal compressor is used in commercial systems. Commercial refrigeration systems using centrifugal compressors normally incorporate flash intercoolers to improve the system performance. Since the compressor is normally multi-staged, use of flash intercooler is relatively easy in case of centrifugal compressors.

Centrifugal compressors are normally lubricated using an oil pump (force feed) which can be driven either directly by the compressor rotor or by an external motor. The lubrication system consists of the oil pump, oil reservoir and an oil cooler. The components requiring lubrication are the main bearings, a thrust bearing (for the balancing disc) and the shaft seals. Comparedto reciprocating compressors, the lubrication for centrifugal compressors is simplified as very little lubricating oil comes in direct contact with the refrigerant. Normally labyrinth type oil seals are used on the rotor shaft to minimize the leakage of lubricating oil to the refrigerant side. Sometimes oil heaters may be required to avoid excessive dilution of lubricating oil during the plant shutdown.

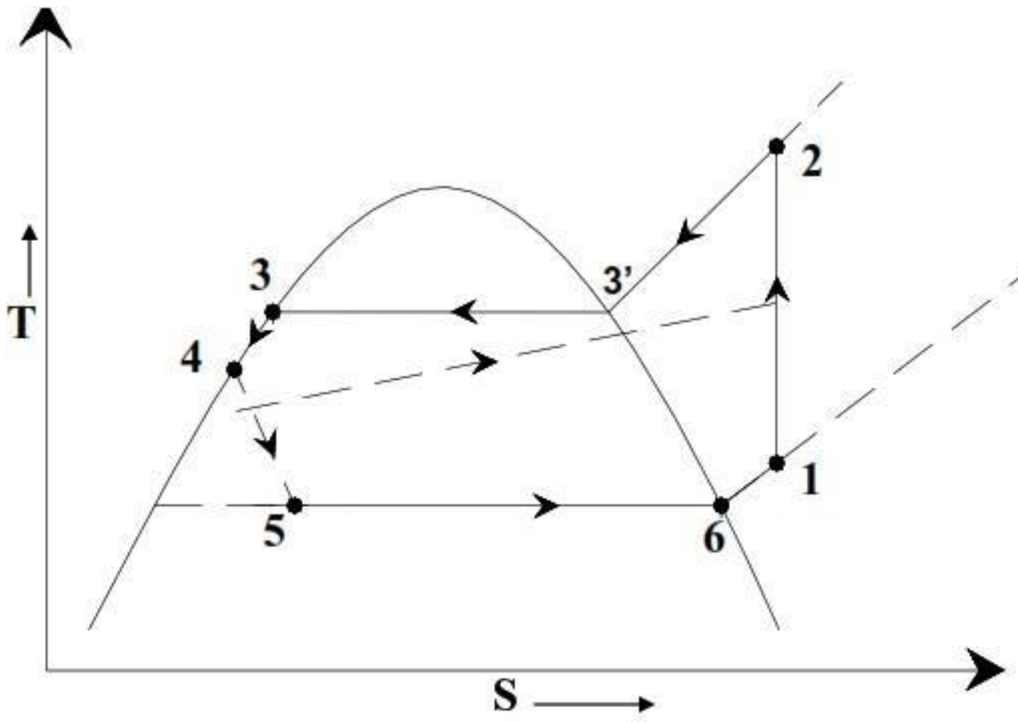
Commercially both hermetic as well as open type centrifugal compressors are available. Open type compressors are driven by electric motors, internal combustion engines (using a wide variety of fuels) or even steam turbines.

CONDENSORS:

Introduction to condensers

Condensers and evaporators are basically heat exchangers in which the refrigerant undergoes a phase change. Next to compressors, proper design and selection of condensers and evaporators is very important for satisfactory performance of any refrigeration system. Since both condensers and evaporators are essentially heat exchangers, they have many things in common as far as the design of these components is concerned. However, differences exist as far as the heat transfer phenomena is concerned. In condensers the refrigerant vapour condenses by rejecting heat to an external fluid, which acts as a heat sink. Normally, the external fluid does not undergo any phase change, except in some special cases such as in cascade condensers, where the external fluid (another refrigerant) evaporates. In evaporators, the liquid refrigerant evaporates by extracting heat from an external fluid (low temperature heat source). The external fluid may not undergo phase change, for example if the system is used for sensibly cooling water, air or some other fluid. There are many refrigeration and air conditioning applications, where the external fluid also undergoes phase change. For example, in a typical summer air conditioning system, the moist air is dehumidified by condensing water vapour and then, removing the condensed liquid water. In many low temperature refrigeration applications freezing or frosting of evaporators takes place. These aspects have to be considered while designing condensers and evaporators.

Condenser is an important component of any refrigeration system. In a typical refrigerant condenser, the refrigerant enters the condenser in a superheated state. It is first de- superheated and then condensed by rejecting heat to an external medium. The refrigerant may leave the condenser as a saturated or a sub-cooled liquid, depending upon the temperature of the external medium and design of the condenser. Figure shows the variation of refrigeration cycle on T-s diagram. In the figure, the heat rejection process is represented by 2-3'-3-4. The temperature profile of the external fluid, which is assumed to undergo only sensible heat transfer, is shown by dashed line. It can be seen that process 2-3' is a de-superheating process, during which the refrigerant is cooled sensibly from a temperature T2 to the saturation temperature corresponding condensing pressure, T3'. Process 3'-3 is the condensation process,during which the temperature of the refrigerant remains constant as it undergoes a phase change process. In actual refrigeration systems with a finite pressure drop in the condenser or in a system using a zeotropic refrigerant mixture, the temperature of the refrigerant changes during the condensation process also. However, at present for simplicity, it is assumed that the refrigerant used is a pure refrigerant (or an azeotropic mixture) and the condenser pressure remains constant during the condensation process. Process 3-4 is a sensible, sub cooling process, during which the refrigerant temperature drops from T3 to T4 .



Refrigeration cycle on T-s diagram

Classification of condensers:

Based on the external fluid, condensers can be classified as:

a) Air cooled condensers

b) Water cooled condensers, and

c) Evaporative condensers

Air-cooled condensers:

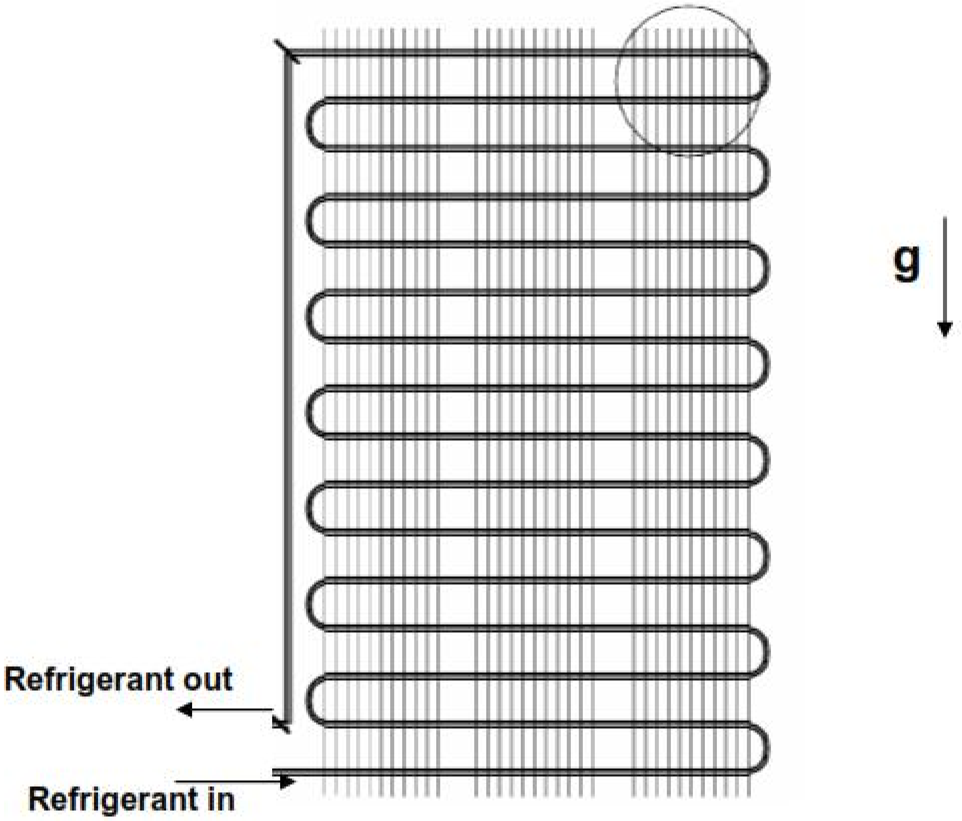
As the name implies, in air-cooled condensers air is the external fluid, i.e., the refrigerant rejects heat to air flowing over the condenser. Air-cooled condensers can be further classified into natural convection type or forced convection type.

Natural convection type:

In natural convection type, heat transfer from the condenser is by buoyancy induced natural convection and radiation. Since the flow rate of air is small and the radiation heat transfer is also not very high, the combined heat transfer coefficient in these condensers is small. As a result a relatively large condensing surface is required to reject a given amount of heat. Hence these condensers are used for small capacity refrigeration systems like household refrigerators and freezers. The natural convection type condensers are either plate surface type or finned tube type. In plate surface type condensers used in small refrigerators and freezers, the refrigerant carrying tubes are attached to the outer walls of the refrigerator. The whole body of the refrigerator (except the door) acts like a fin. Insulation is provided between the outer cover that acts like fin and the inner plastic cover of the refrigerator. It is for this reason that outer body of the refrigerator is always warm. Since the surface is warm, the problem of moisture condensation on the walls of the refrigerator does not arise in these systems. These condensers are sometimes called as flat back condensers.

The finned type condensers are mounted either below the refrigerator at an angle or on the backside of the refrigerator. In case, it is mounted below, then the warm air rises up and to assist it an air envelope is formed by providing a jacket on backside of the refrigerator. The fin spacing is kept large to minimize the effect of fouling by dust and to allow air to flow freelywith little resistance.

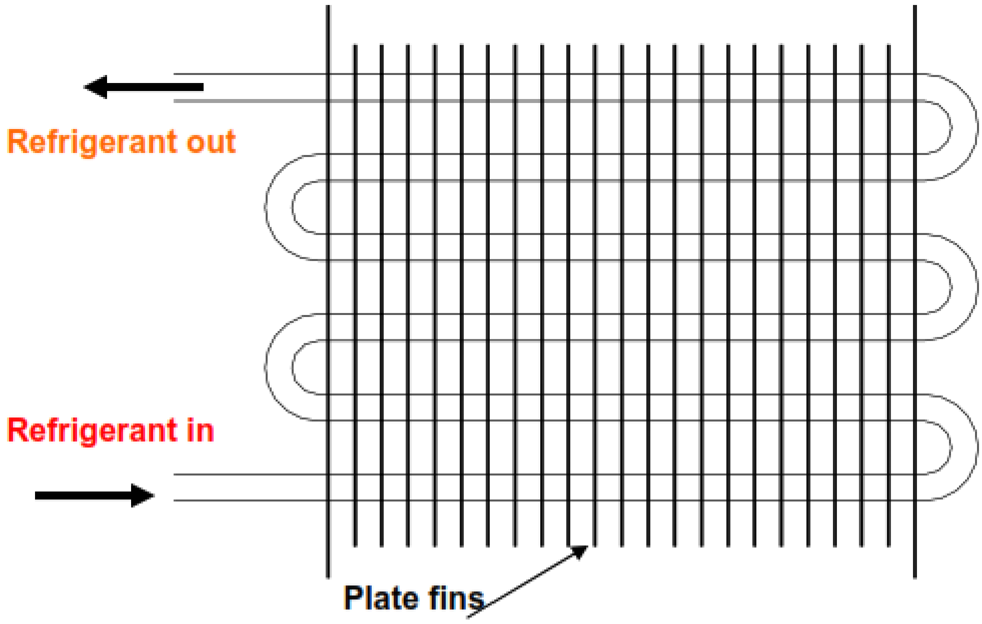
In the older designs, the condenser tube (in serpentine form) was attached to a plate and the plate was mounted on the backside of the refrigerator. The plate acted like a fin and warm air rose up along it. In another common design, thin wires are welded to the serpentine tube coil. The wires act like fins for increased heat transfer area. Figure shows the schematic of a wire- and-tube type condenser commonly used in domestic refrigerators. Regardless of the type, refrigerators employing natural convection condenser should be located in such a way that air can flow freely over the condenser surface.



Schematic of a wire-and-tube type condenser used in small refrigeration systems

Forced convection type:

In forced convection type condensers, the circulation of air over the condenser surface is maintained by using a fan or a blower. These condensers normally use fins on air-side for good heat transfer. The fins can be either plate type or annular type. Figure 22.3 shows the schematic of a plate-fin type condenser. Forced convection type condensers are commonly used in window air conditioners, water coolers and packaged air conditioning plants. These areeither chassis mounted or remote mounted. In chassis mounted type, the compressor, induction motor, condenser with condenser fan, accumulator, HP/LP cut- out switch and pressure gauges are mounted on a single chassis. It is called condensing unit of rated capacity. The components are matched to condense the required mass flow rate of refrigerant to meet the rated cooling capacity. The remote mounted type, is either vertical or roof mounted horizontal type. Typically the air velocity varies between 2 m/s to 3.5 m/s for economic design with airflow rates of 12 to 20 cmm per ton of refrigeration (TR). The air specific heat is 1.005 kJ/kg-K and density is 1.2 kg/m3.. Therefore for 1 TR the temperature rise $\Delta ta = 3.5167/(1.2x1.005 \times 16/60) = 10.9oC$ for average air flow rate of 16 cm. Hence, the air temperature rises by 10 to 15oC as compared to 3 to 6oC for water in water cooled condensers.



Forced convection, plate fin-and-tube type condenser

The area of the condenser seen from outside in the airflow direction is called face area. The velocity at the face is called face velocity. This is given by the volume flow rate divided by the face area. The face velocity is usually around 2m/s to 3.5 m/s to limit the pressure drop due to frictional resistance. The coils ofthe tube in the flow direction are called rows. A condenser may have two to eight rows of the tubes carrying the refrigerant. The moist air flows over the fins while the refrigerant flows inside the tubes. The fins are usually of aluminum and tubes are made of copper. Holes of diameter slightly less than the tube diameter are punched in the plates and plates are slid over the tube bank. Then the copper tubes are pressurized which expands the tubes and makes a good thermal contact between the tube and fins. This processis also known as bulleting. For ammonia condensers mild steel tubes with mild steel fins are used. In this case the fins are either welded or galvanizing is done to make a good thermal contact between fin and tube. In case of ammonia, annular crimpled spiral fins are also used over individual tubes instead of flat-plate fins. In finned tube heat exchangers the fin spacing may vary from 3 to 7 fins per cm. The secondary surface area is 10 to 30 times the bare pipe area hence; the finned coils are very compact and have smaller weight.

Water Cooled Condensers:

In water cooled condensers water is the external fluid. Depending upon the construction, water cooled condensers can be further classified into:

1. Double pipe or tube-in-tube type

2. Shell-and-coil type

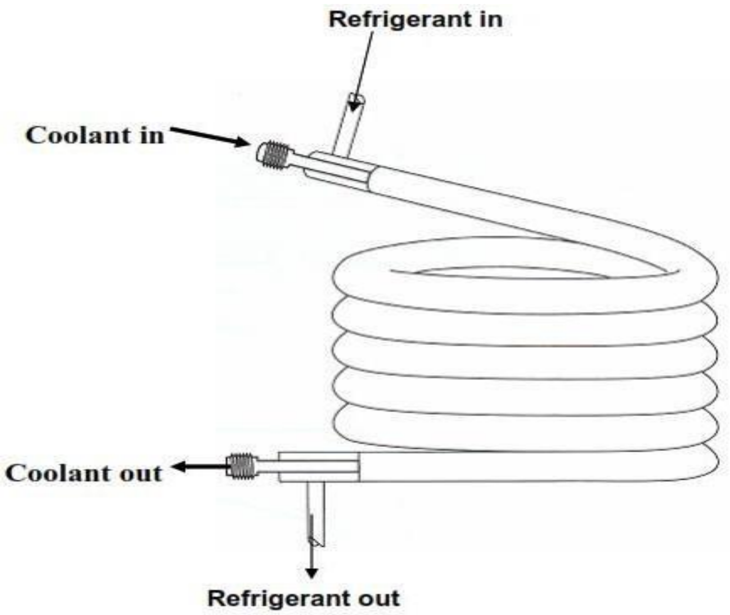
3. Shell-and-tube type

Double Pipe or tube-in-tube type:

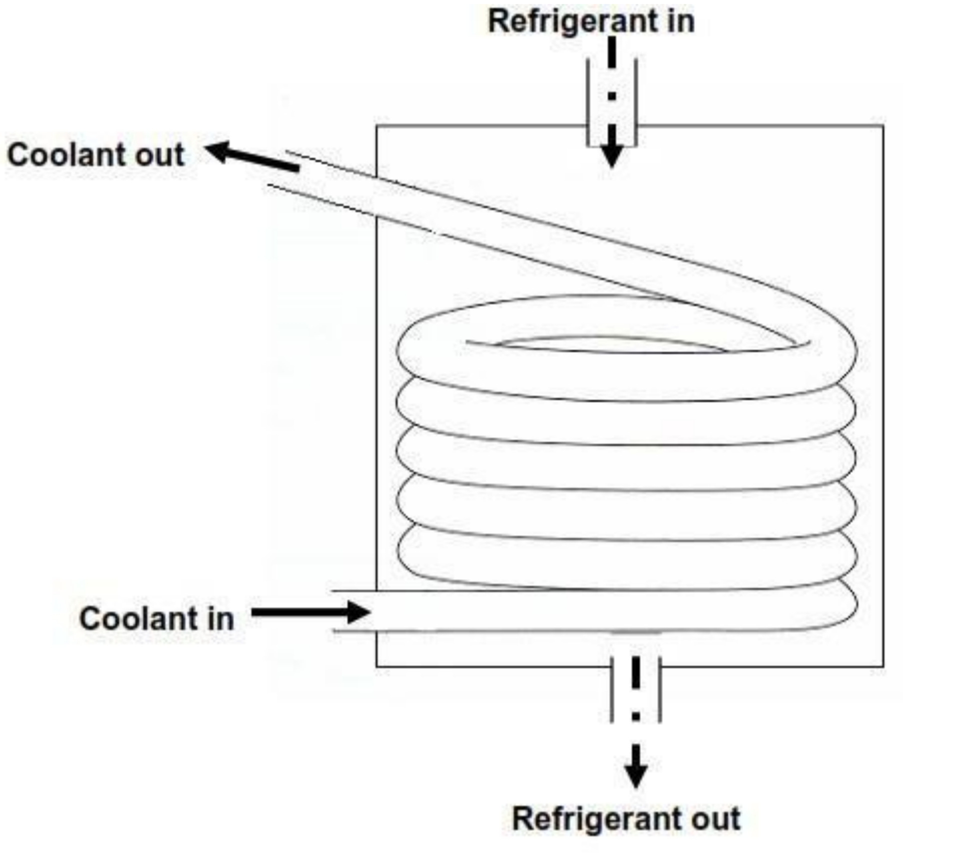
Double pipe condensers are normally used up to 10 TR capacity. Figure shows the schematic of a double pipe type condenser. As shown in the figure, in these condensers the cold water flows through the inner tube, while the refrigerant flows through the annulus in counter flow. Headers are used at both the ends to make the length of the condenser small and reduce pressure drop. The refrigerant in the annulus rejects a part of its heat to the surroundings by free convection and radiation. The heat transfer coefficient is usually low because of poor liquid refrigerant drainage if the tubes are long.

Shell-and-coil type:

These condensers are used in systems up to 50 TR capacity. The water flows through multiple coils, which may have fins to increase the heat transfer coefficient. The refrigerant flowsthrough the shell. In smaller capacity condensers, refrigerant flows through coils while water flows through the shell. Figure shows a shell-and-coil type condenser. When water flows through the coils, cleaning is done by circulating suitable chemicals through the coils.



Double pipe (tube-in-tube) type condenser

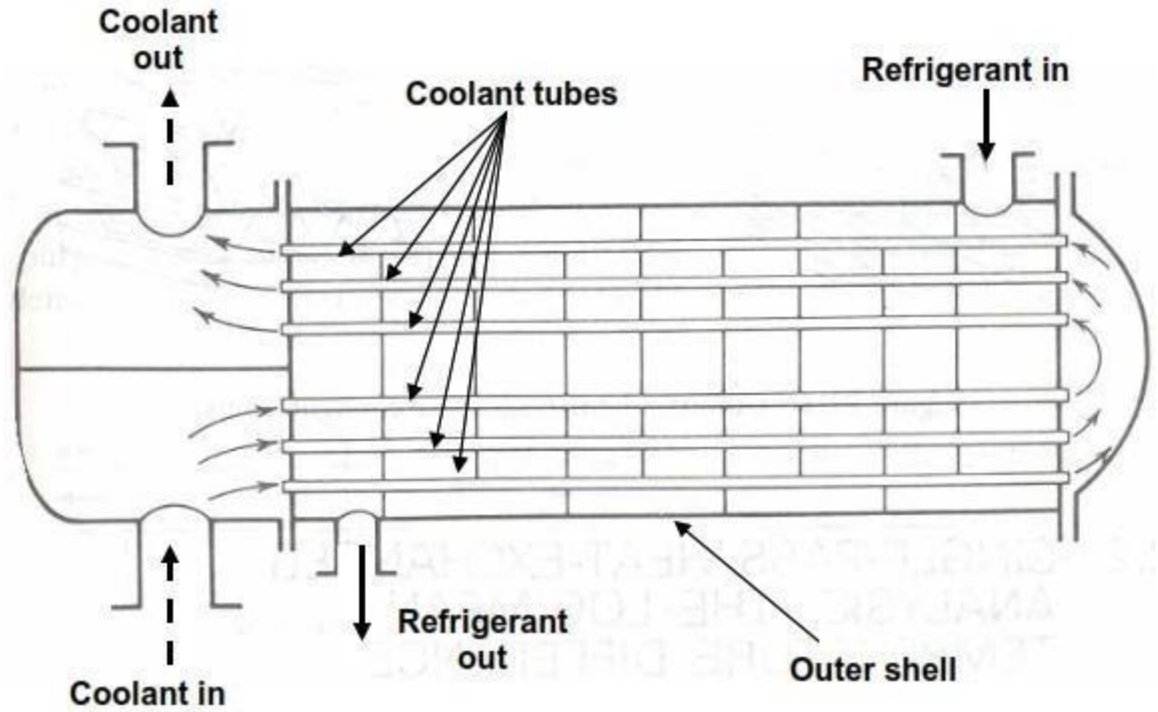


Shell-and-coil type condenser

Shell-and-tube type:

This is the most common type of condenser used in systems from 2 TR upto thousands of TR capacity. In these condensers the refrigerant flows through the shell while water flows through the tubes in single to four passes. The condensed refrigerant collects at the bottom of the shell. The coldest water contacts the liquid refrigerant so that some subcooling can also be obtained. The liquid refrigerant is drained from the bottom to the receiver. There might be a vent connecting the receiver to the condenser for smooth drainage of liquid refrigerant. The shell also acts as a receiver. Further the refrigerant also rejects heat to the surroundings from the shell. The most common type is horizontal shell type. A schematic diagram of horizontal shell-and-tube type condenser is shown in Fig.

Vertical shell-and-tube type condensers are usually used with ammonia in large capacity systems so that cleaning of the tubes is possible from top while the plant is running.

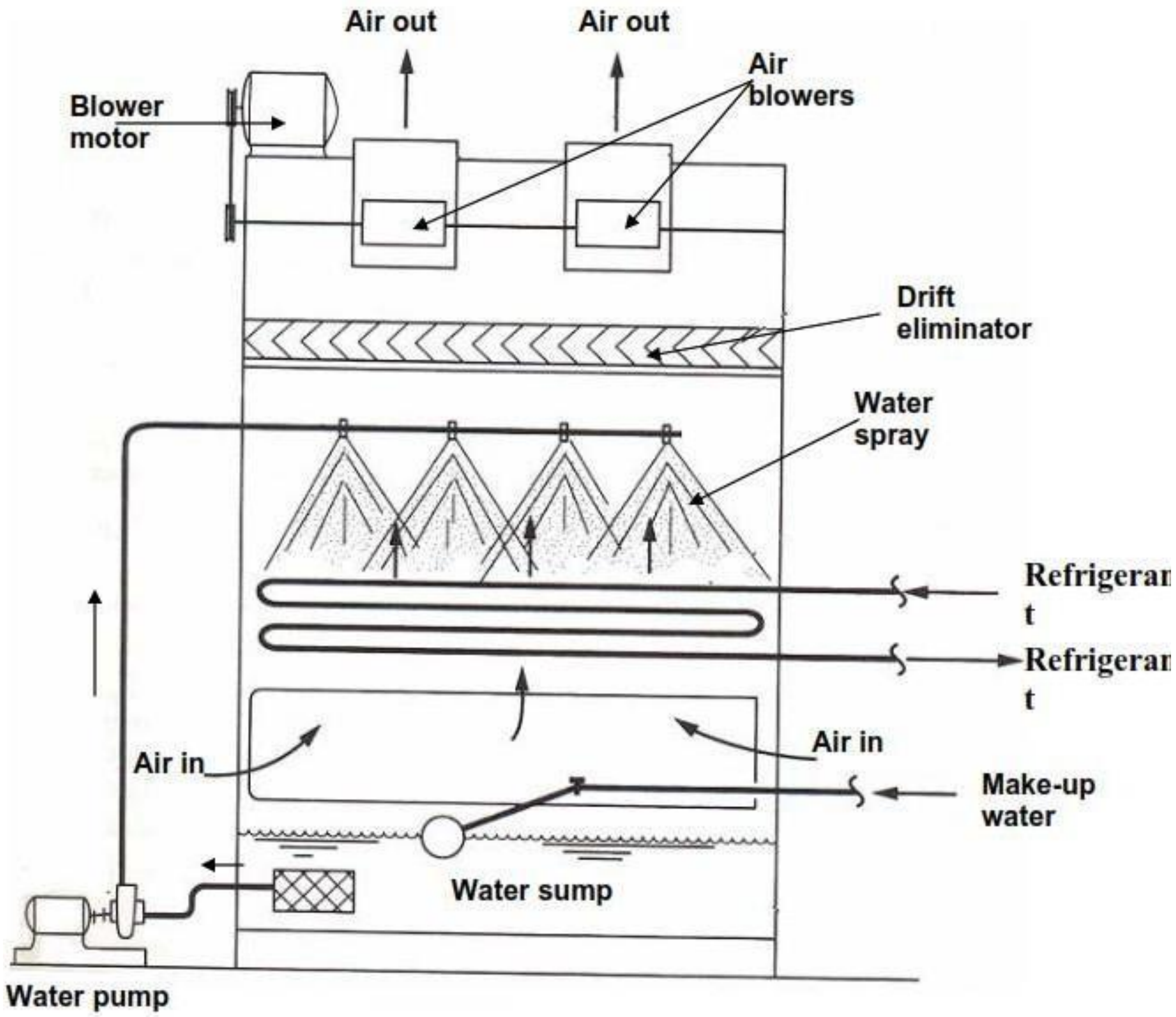


A two-pass, shell-and-tube type condenser

Evaporative condensers:

In evaporative condensers, both air and water are used to extract heat from the condensing refrigerant. Figure shows the schematic of an evaporative condenser. Evaporative condensers combine the features of a cooling tower and water-cooled condenser in a single unit. In these condensers, the water is sprayed from top part on a bank of tubes carrying the refrigerant and air is induced upwards. There is a thin water film around the condenser tubes from which evaporative cooling takes place. The heat transfer coefficient for evaporative cooling is very large. Hence, the refrigeration system can be operated at low condensingtemperatures (about 11 to 13 K above the wet bulb temperature of air). The water spray counter current to the airflow acts as cooling tower. The role of air is primarily to increase the rate of evaporation of water.

The required air flow rates are in the range of 350 to 500 m3/h per TR of refrigeration capacity.



Schematic of an evaporative condenser

Evaporative condensers are used in medium to large capacity systems. These are normally cheaper compared to water cooled condensers, which require a separate cooling tower. Evaporative condensers are used in places where water is scarce. Since water is used in a closed loop, only a small part of the water evaporates. Make-up water is supplied to take care of the evaporative loss. The water consumption is typically very low, about 5 percent of an equivalent water cooled condenser with a cooling tower. However, since condenser has to be kept outside, this type of condenser requires a longer length of refrigerant tubing, which calls for larger refrigerant inventory and higher pressure drops. Since the condenser is kept outside, to prevent the water from freezing, when outside temperatures are very low, a heater is placed in the water tank. When outside temperatures are very low it is possible to switch-off thewater pump and run only the blowers, so that the condenser acts as an air cooled condenser.

Another simple form of condenser used normally in older type cold storages is called as atmospheric condenser. The principle of the atmospheric condenser is similar to evaporative condenser, with a difference that the air flow over the condenser takes place by natural means as no fans or blowers are used. A spray system sprays water over condenser tubes. Heat transfer outside the tubes takes by both sensible cooling and evaporation, as a result the external heat transfer coefficient is relatively large. The condenser pipes are normally large, and they can be either horizontal or vertical. Though these condensers are effective and economical they are being replaced with other types of condensers due to the problems such as algae formation on condenser tubes, uncertainity due to external air circulation etc.

Evaporators

An evaporator, like condenser is also a heat exchanger. In an evaporator, the refrigerant boils or evaporates and in doing so absorbs heat from the substance being refrigerated. The name evaporator refers to the evaporation process occurring in the heat exchanger.

Classification

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

Natural and Forced Convection Type

The evaporator may be classified as natural convection type or forced convection type. In forced convection type, a fan or a pump is used to circulate the fluid being refrigerated and make it flow over the heat transfer surface, which is cooled by evaporation of refrigerant. In natural convection type, the fluid being cooled flows due to natural convection currents arising out of density difference caused by temperature difference. The refrigerant boils inside tubes and evaporator is located at the top. The temperature of fluid, which is cooled by it,decreases and its density increases. It moves downwards due to its higher density and the warm fluid rises up to replace it.

Refrigerant Flow Inside or Outside Tubes

The heat transfer phenomenon during boiling inside and outside tubes is very different; hence, evaporators are classified as those with flow inside and outside tubes.

In natural convection type evaporators and some other evaporators, the refrigerant is confined and boils inside the tubes while the fluid being refrigerated flows over the tubes. The direct expansion coil where the air is directly cooled in contact with the tubes cooled by refrigerant boiling inside is an example of forced convection type of evaporator where refrigerant isconfined inside the tubes.

In many forced convection type evaporators, the refrigerant is kept in a shell and the fluid being chilled is carried in tubes, which are immersed in refrigerant. Shell and tube type brine and water chillers are mainly of this kind.

Flooded and Dry Type

The third classification is flooded type and dry type. Evaporator is said to be flooded type if liquid refrigerant covers the entire heat transfer surface. This type of evaporator uses a float type of expansion valve. An evaporator is called dry type when a portion of the evaporator is used for superheating the refrigerant vapour after its evaporation.

Natural Convection type evaporator coils

These are mainly used in domestic refrigerators and cold storages. When used in cold storages, long lengths of bare or finned pipes are mounted near the ceiling or along the high sidewalls of the cold storages. The refrigerant from expansion valve is fed to these tubes. The liquid refrigerant evaporates inside the tubes and cools the air whose density increases. The high-density air flows downwards through the product in the cold storage. The air becomes warm by the time it reaches the floor as heat is transferred from the product to air. Some free area like a passage is provided for warm air to rise up. The same passage is used for loading and unloading the product into the cold storage.

The advantages of such natural convection coils are that the coil takes no floor space and it also requires low maintenance cost. It can operate for long periods without defrosting the ice formed on it and it does not require special skill to fabricate it. Defrosting can be done easily (e.g. by scraping) even when the plant is running. These are usually welded at site. However, the disadvantage is that natural convection heat transfer coefficient is very small hence very long lengths are required which may cause excessive refrigerant side pressure drops unless parallel paths are used. The large length requires a larger quantity of refrigerant than the forced convection coils. The large quantity of refrigerant increases the time required for defrosting, since before the defrosting can start all the liquid refrigerant has to be pumped out of the evaporator tubes. The pressure balancing also takes long time if the system trips or is to be restarted after load shedding. Natural convection coils are very useful when low air velocities and minimum dehumidification of the product is required. Household refrigerators, display cases, walk-in-coolers, reach-in refrigerators and obviously large cold storages are few of its applications. Sufficient space should be provided between the evaporator and ceiling to permit the air circulation over the top of the coil.

Baffles are provided to separate the warm air and cold air plumes. Single ceiling mounted is used for rooms of width less than 2.5 m. For rooms with larger widths more evaporator coils are used. The refrigerant tubes are made of steel or copper. Steel tubes are used for ammonia and in large capacity systems.

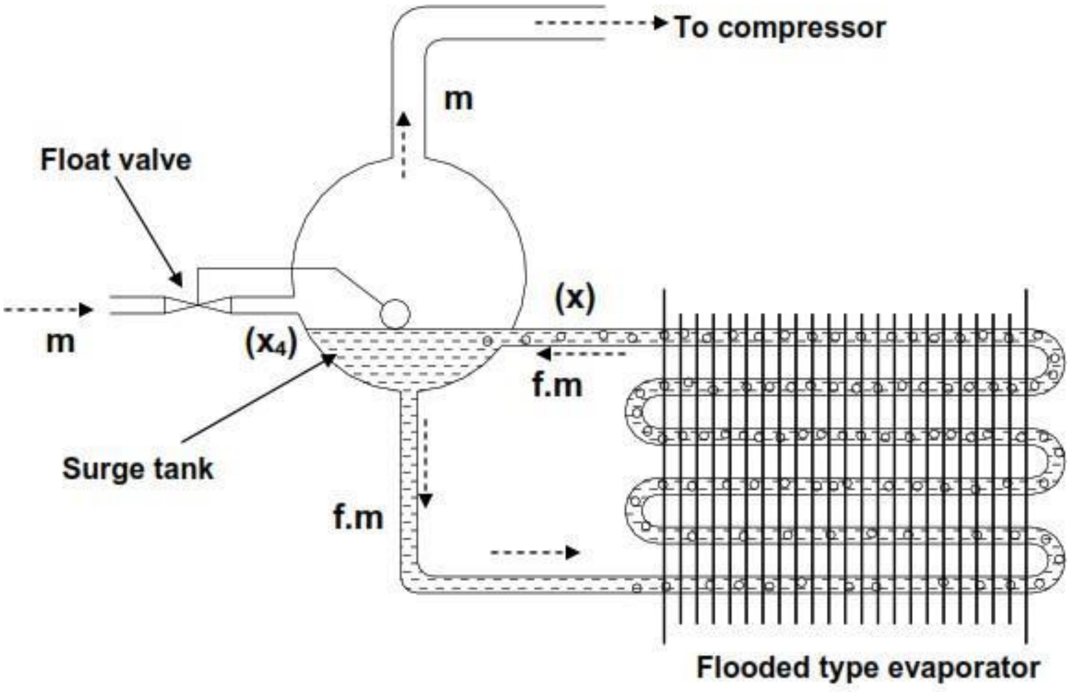
Flooded Evaporator

This is typically used in large ammonia systems. The refrigerant enters a surge drum through a float type expansion valve. The compressor directly draws the flash vapour formed during expansion. This vapour does not take part in refrigeration hence its removal makes the evaporator more compact and pressured drop due to this is also avoided. The liquid refrigerant enters the evaporator from the bottom of the surge drum. This boils inside the tubes as heat is absorbed. The mixture of liquid and vapour bubbles rises up along the evaporator tubes. The vapour is separated as it enters the surge drum. The remaining unevaporated liquid circulates again in the tubes along with the constant supply of liquid refrigerant from the expansion valve. The mass flow rate in the evaporator tubes is m.f where m is the mass flow rate through the expansion valve and to the compressor. The term f is called recirculation factor. Let x4 be the quality of mixture after the expansion valve and x be the quality of mixture after boiling in the tubes as shown in Figure. In steady state mass flow rate from expansion valve is same as the mass flow rate to the compressor hence mass conservation gives

$$x_4.\dot{m} + x.f.\dot{m} = \dot{m}$$

$$\therefore f = \frac{(1 - x_4)}{x}$$

For x4 = x = 0.25, for example, the circulation factor is 3, that is mass flow rate through the evaporator is three times that through the compressor. Since, liquid refrigerant is in contact with whole of evaporator surface, the refrigerant side heat transfer coefficient will be very high. Sometimes a liquid refrigerant pump may also be used to further increase the heat transfer coefficient. The lubricating oil tends to accumulate in the flooded evaporator hence an effective oil separator must be used immediately after the compressor.



Schematic of a flooded evaporator

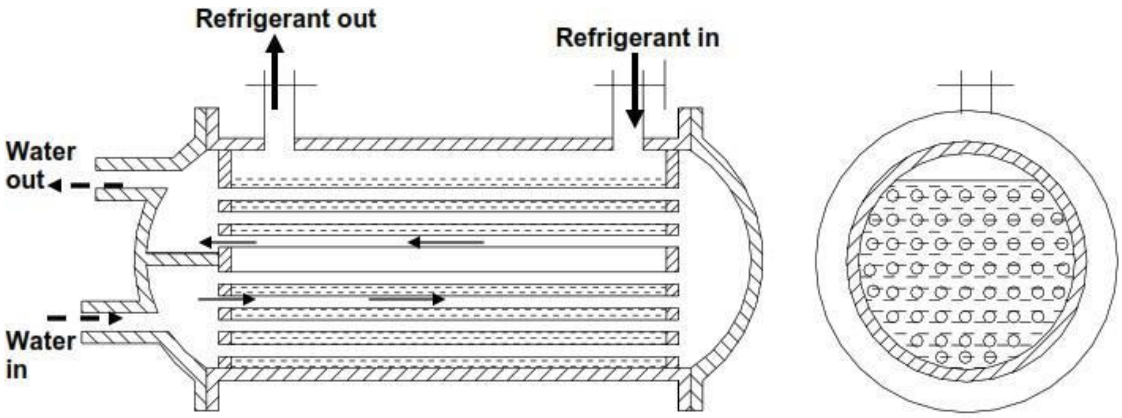
Shell-and-Tube Liquid Chillers

The shell-and-tube type evaporators are very efficient and require minimum floor space and headspace. These are easy to maintain, hence they are very widely used in medium to large capacity refrigeration systems. The shell-and-tube evaporators can be either dry type or flooded type. As the name implies, a shell-and-tube evaporator consists of a shell and a large number of straight tubes arranged parallel to each other. In dry expansion type, the refrigerant flows through the tubes while in flooded type the refrigerant is in the shell. A pump circulates the chilled water or brine. The shell diameters range from 150 mm to 1.5 m. The number of tubes may be less than 50 to several thousands and length may be between 1.5 m to 6 m. Steel tubes are used with ammonia while copper tubes are used with freons. Ammonia has a very high heat transfer coefficient while freons have rather poor heat transfer coefficient hence fins are used on the refrigerant side. Dry expansion type uses fins inside the tubes while flooded type uses fins outside the tube. Dry-expansion type requires less charge of refrigerant and have positive lubricating oil return. These are used for small and medium capacity refrigeration plants with capacity ranging from 2 TR to 350 TR. The flooded type evaporators are available in larger capacities ranging from 10 TR to thousands of TR.

Flooded Type Shell-and-Tube Evaporator

Figure shows a flooded type of shell and tube type liquid chiller where the liquid (usually brine or water) to be chilled flows through the tubes in double pass just like that in shell and tube condenser. The refrigerant is fed through a float valve, which maintains a constant level of liquid refrigerant in the shell. The shell is not filled entirely with tubes as shown in the end view of Fig. This is done to maintain liquid refrigerant level below the top of the shell so that liquid droplets settle down due to gravity and are not carried by the vapour leaving the shell. If the shell is completely filled with tubes, then a surge drum is provided after the evaporator to collect the liquid refrigerant.

Shell-and-tube evaporators can be either single pass type or multipass type. In multipass type, the chilled liquid changes direction in the heads. Shell and-tube evaporators are available in vertical design also. Compared to horizontal type, vertical shell-and-tube type evaporators require less floor area. The chilled water enters from the top and flows downwards due to gravity and is then taken to a pump, which circulates it to the refrigeration load. At the inlet to tubes at the top a special arrangement introduces swirling action to increase the heat transfer coefficient.



Schematic of a flooded type shell-and-tube evaporator

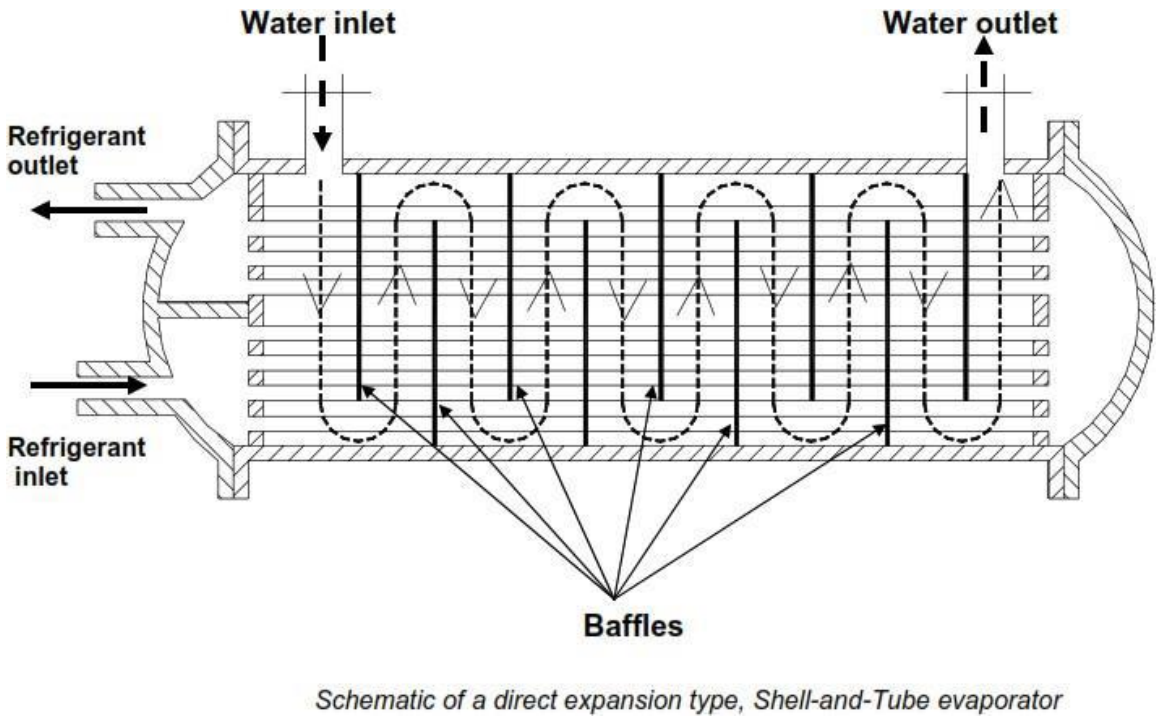
Direct expansion type, Shell-and-Tube Evaporator

Figure 23.3 shows a liquid chiller with refrigerant flowing through the tubes and water flowing through the shell. A thermostatic expansion valve feeds the refrigerant into the tubes through the cover on the left. It may flow in several passes through the dividers in the covers of the shell on either side. The liquid to be chilled flows through the shell around the baffles. The presence of baffles turns the flow around creating some turbulence thereby increasing the heat transfer coefficient. Baffles also prevent the short-circuiting of the fluid flowing in the shell. This evaporator is of dry type since some of the tubes superheat the vapour. To maintain the chilled liquid velocity so as to obtain good heat transfer coefficient, the length and the spacing of segmental baffles is varied. Widely spaced baffles are used when the flow rate is high or the liquid viscosity is high. The number of passes on the refrigerant side are decided by the partitions on the heads on the two sides of the heat exchanger. Some times more than one circuit is also provided. Changing the heads can change the number of passes. It depends upon the chiller load and the refrigerant velocity to be maintained in the heat exchanger.

Shell-and-Coil type evaporator

These are of smaller capacity than the shell and tube chillers. These are made of one or more spiral shaped bare tube coils enclosed in a welded steel shell. It is usually dry-expansion type with the refrigerant flowing in the tube and chilled liquid in the shell. In some cases the chiller operates in flooded mode also with refrigerant in the shell and chilled water flowing thorough the spiral tube. The water in the shell gives a large amount of thermal storage capacity called hold-up capacity. This type is good for small but highly infrequent peak loads. It is used for cooling drinking water in stainless steel tanks to maintain sanitary conditions. It is also used in bakeries and photographic laboratories.

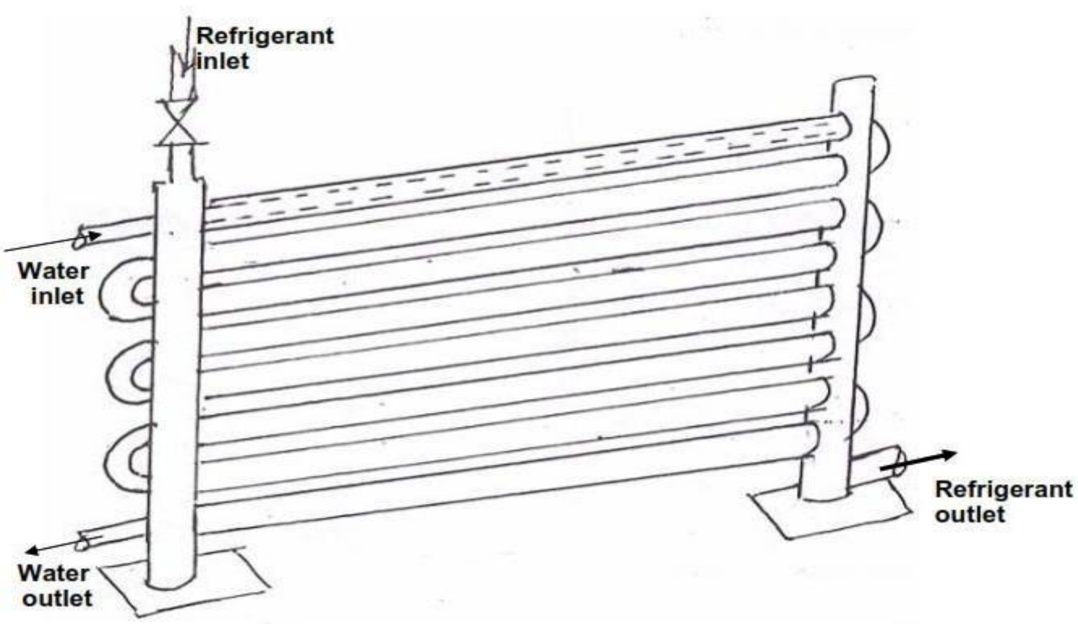
When the refrigerant is in the shell that is in flooded mode it is called instantaneous liquid chiller. This type does not have thermal storage capacity, the liquid must be instantaneously chilled whenever required. In the event of freeze up the water freezes in the tube, whichcauses bursting of the tubes since water expands upon freezing. When water is in the shell there is enough space for expansion of water if the freezing occurs. The flooded types are not recommended for any application where the temperature of chilled liquid may be below 3^oC.



Schematic of a direct expansion type, Shell-and-Tube evaporator

Double pipe type evaporator

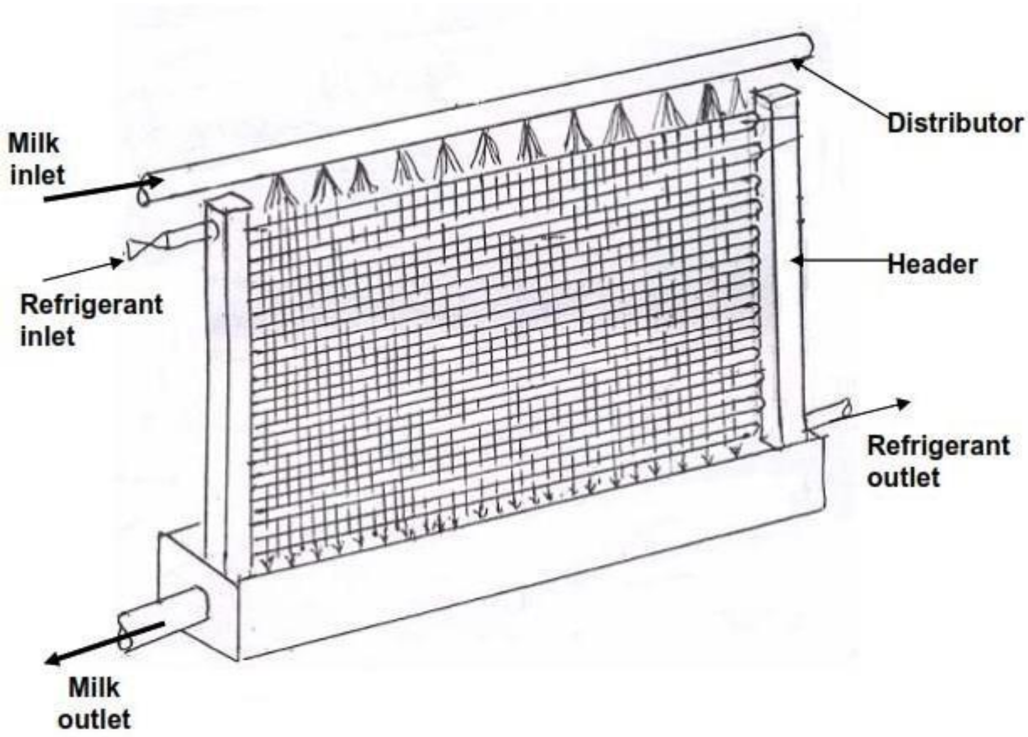
This consists of two concentric tubes, the refrigerant flows through the annular passage while the liquid being chilled flows through the inner tube in counter flow. One design is shown in Fig. 23.4 in which the outer horizontal tubes are welded to vertical header tubes on either side. The inner tubes pass through the headers and are connected together by 180o bends. The refrigerant side is welded hence there is minimum possibility of leakage of refrigerant. These may be used in flooded as well as dry mode. This requires more space than other designs. Shorter tubes and counter flow gives good heat transfer coefficient. It has to be insulated from outside since the refrigerant flows in the outer annulus which may be exposed to surroundings if insulation is not provided.



Schematic of a double pipe type evaporator

Baudelot type evaporators

This type of evaporator consists of a large number of horizontal pipes stacked one on top of other and connected together to by headers to make single or multiple circuits. The refrigerant is circulated inside the tubes either in flooded or dry mode. The liquid to be chilled flows in a thin layer over the outer surface of the tubes. The liquid flows down by gravity from distributor pipe located on top of the horizontal tubes as shown in Figure The liquid to be chilled is open to atmosphere, that is, it is at atmospheric pressure and its aeration may take place during cooling. This is widely used for cooling milk, wine and for chilling water for carbonation in bottling plants. The liquid can be chilled very close to its freezing temperature since freezing outside the tubes will not damage the tubes. Another advantage is that the refrigerant circuit can be split into several parts, which permit a part of the cooling done by cold water and then chilling by the refrigerant.

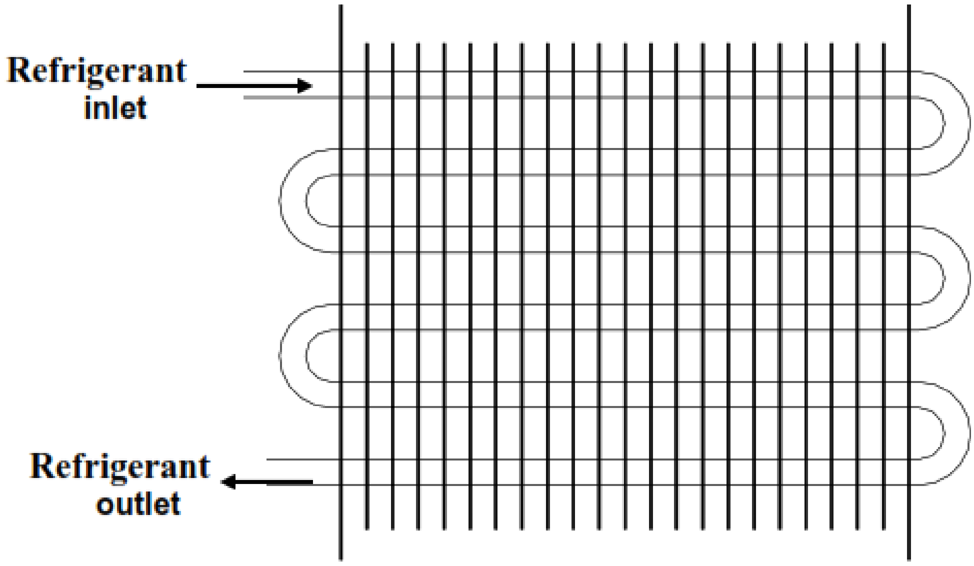


Schematic of a Baudelot type evaporator for chilling of milk

Direct expansion fin-and-tube type

These evaporators are used for cooling and dehumidifying the air directly by the refrigerant flowing in the tubes. Similar to fin-and-tube type condensers, these evaporator consists of coils placed in a number of rows with fins mounted on it to increase the heat transfer area. Various fin arrangements are used. Tubes with individual spiral straight fins or crimpled fins welded to it are used in some applications like ammonia. Plate fins accommodating a number of rows are used in air conditioning applications with ammonia as well as synthetic refrigerants such as fluorocarbon based refrigerants.

The liquid refrigerant enters from top through a thermostatic expansion valve as shown in Fig.. This arrangement makes the oil return to compressor better rather than feeding refrigerant from the bottom of the coil. When evaporator is close to the compressor, a direct expansioncoil is used since the refrigerant lines are short, refrigerant leakage will be less and pressure drop is small. If the air-cooling is required away from the compressor, it is preferable to chill water and pump it to air-cooling coil to reduce the possibility of refrigerant leakage and excessive refrigerant pressure drop, which reduces the COP.



Schematic of a direct expansion fin-and-tube type

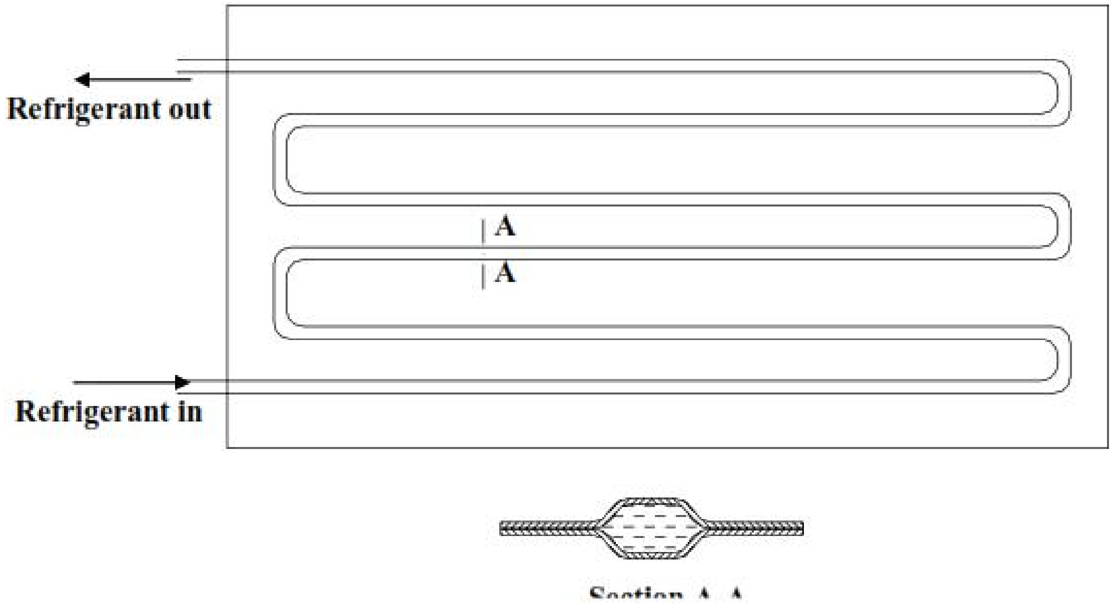
The fin spacing is kept large for larger tubes and small for smaller tubes. 50 to 500 fins per meter length of the tube are used in heat exchangers. In evaporators, the atmospheric water vapour condenses on the fins and tubes when the metal temperature is lower than dew point temperature. On the other hand frost may form on the tubes if the surface temperature is less than 0 C.Hence for low temperature coils a wide spacing with about 80 to 200 fins per m is used to avoid restriction of flow passage due to frost formation. In air-conditioning o applications a typical fin spacing of 1.8 mm is used. Addition of fins beyond a

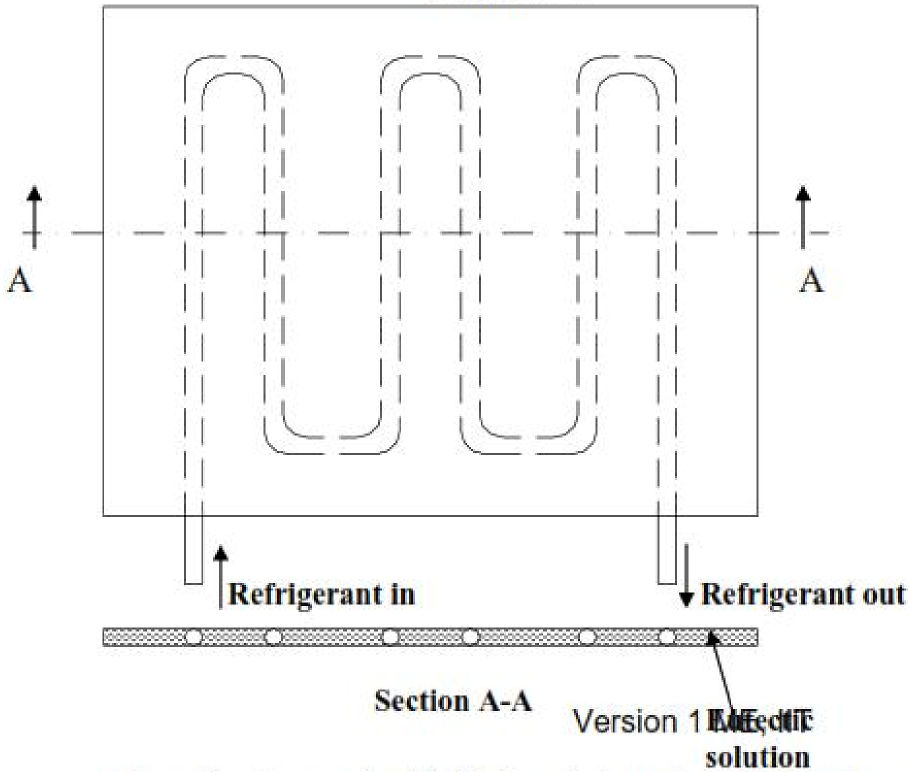
certain value will not increase the capacity of evaporator by restricting the airflow. The frost layer has a poor thermal conductivity hence it decreases the overall heat transfer coefficient apart from restricting the flow. Therefore, for applications in freezers below 0oC, frequent defrosting of the evaporator is required.

Plate Surface Evaporators

These are also called bonded plate or roll-bond type evaporators. Two flat sheets of metal (usually aluminum) are embossed in such a manner that when these are welded together, the embossed portion of the two plates makes a passage for refrigerant to flow. This type is used in household refrigerators.

In another type of plate surface evaporator, a serpentine tube is placed between two metal plates such that plates press on to the tube. The edges of the plates are welded together. The space between the plates is either filled with a eutectic solution or evacuated. The vacuum between the plates and atmospheric pressure outside, presses the plates on to the refrigerant carrying tubes making a very good contact between them. If eutectic solution is filled into the void space, this also makes a good thermal contact between refrigerant carrying tubes and the plates. Further, it provides an additional thermal storage capacity during offcycle and load shedding to maintain a uniform temperature. These evaporators are commonly used in refrigerated trucks. Figure shows an embedded tube, plate surface evaporator.

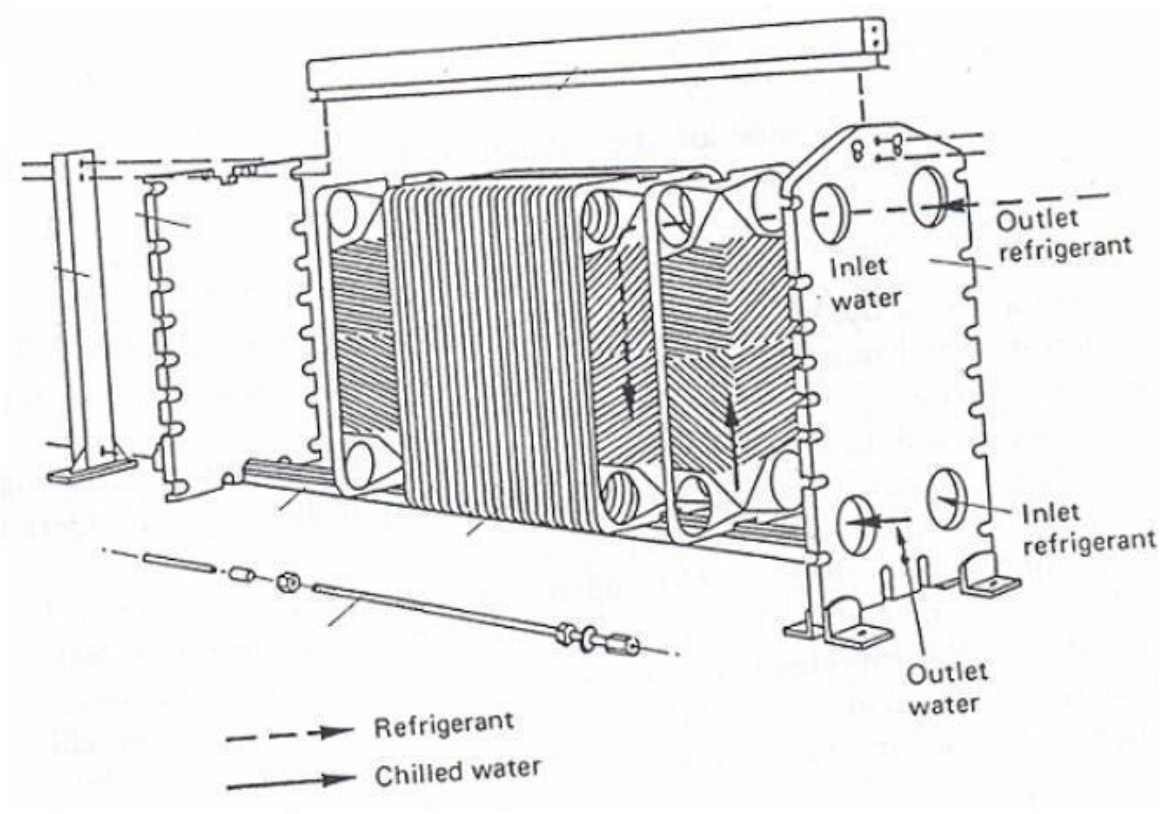




chematic of an embedded tube, plate surface evaporator

Plate type evaporators:

Plate type evaporators are used when a close temperature approach (0.5 K or less) between the boiling refrigerant and the fluid being chilled is required. These evaporators are widely used in dairy plants for chilling milk, in breweries for chilling beer. These evaporators consist of a series of plates (normally made of stainless steel) between which alternately the milk or beer tobe cooled and refrigerant flow in counterflow direction. The overall heat transfer coefficient of these plate type evaporators is very high (as high as 4500 W/m K in case of ammonia/water and 3000 W/m2 K in case of R 22/water). In addition they also require very less refrigerant inventory for the same capacity (about 10 percent or even less than that of shell-and-tube type evaporators). Another important advantage when used in dairy plants and breweries is that, it is very easy to clean the evaporator and assemble it back as and when required. The capacity can be increased or decreased very easily by adding or removing plates. Hence these evaporators are finding widespread use in a variety of applications. Figure shows the schematic of a plate type evaporator.



Schematic of a plate type evaporator

Expansion Devices:

An expansion device is another basic component of a refrigeration system. The basic functions of an expansion device used in refrigeration systems are to:

1. Reduce pressure from condenser pressure to evaporator pressure, and

2. Regulate the refrigerant flow from the high-pressure liquid line into the evaporator at a rate equal to the evaporation rate in the evaporator.

Under ideal conditions, the mass flow rate of refrigerant in the system should be proportional to the cooling load. Sometimes, the product to be cooled is such that a constant evaporator temperature has to be maintained. In other cases, it is desirable that liquid refrigerant should not enter the compressor. In such a case, the mass flow rate has to be controlled in such a manner that only superheated vapour leaves the evaporator. Again, an ideal refrigeration system should have the facility to control it in such a way that the energy requirement is minimum and the required criterion of temperature and cooling load are satisfied. Some additional controls to control the capacity of compressor and the space temperature may be required in addition, so as to minimize the energy consumption.

The expansion devices used in refrigeration systems can be divided into fixed opening type or variable opening type. As the name implies, in fixed opening type the flow area remains fixed, while in variable opening type the flow area changes with changing mass flow rates. There are basically seven types of refrigerant expansion devices. These are:

1. Hand (manual) expansion valves

2. Capillary Tubes

3. Orifice

4. Constant pressure or Automatic Expansion Valve (AEV)

5. Thermostatic Expansion Valve (TEV)

6. Float type Expansion Valve

   a) High Side Float Valve
   b) Low Side Float Valve

7. Electronic Expansion Valve

Of the above seven types, Capillary tube and orifice belong to the fixed opening type, while the rest belong to the variable opening type. Of the above seven types, the hand operated expansion valve is not used when an automatic control is required. The orifice type expansionis used only in some special applications. Hence these two are not discussed here.

Capillary Tube

A capillary tube is a long, narrow tube of constant diameter. The word "capillary" is a misnomer since surface tension is not important in refrigeration application of capillary tubes. Typical tube diameters of refrigerant capillary tubes range from 0.5 mm to 3 mm and the length rangesfrom 1.0 m to 6 m. The pressure reduction in a capillary tube occurs due to the following two factors:

1. The refrigerant has to overcome the frictional resistance offered by tube walls. This leads to some pressure drop, and
2. The liquid refrigerant flashes (evaporates) into mixture of liquid and vapour as its pressure reduces. The density of vapour is less than that of the liquid. Hence, the average density of refrigerant decreases as it flows in the tube. The mass flow rate and tube diameter (hence area) being constant, the velocity of refrigerant increases since $m = \rho VA$. The increase in velocity or acceleration of the refrigerant also requires pressure drop.

Several combinations of length and bore are available for the same mass flow rate and pressure drop. However, once a capillary tube of some diameter and length has been installed in a refrigeration system, the mass flow rate through it will vary in such a manner that the total pressure drop through it matches with the pressure difference between condenser and the evaporator. Its mass flow rate is totally dependent upon the pressure difference across it; it cannot adjust itself to variation of load effectively.

Advantages and disadvantages of capillary tubes

Some of the advantages of a capillary tube are:

1. It is inexpensive.

2. It does not have any moving parts hence it does not require maintenance

3. Capillary tube provides an open connection between condenser and the evaporator hence during off-cycle, pressure equalization occurs between condenser and evaporator. This reduces the starting torque requirement of the motor since the motor starts with same pressure on the two sides of the compressor. Hence, a motor with low starting torque (squirrel cage Induction motor) can be used.

4. Ideal for hermetic compressor based systems, which are critically charged and factory assembled.

Some of the disadvantages of the capillary tube are:

1. It cannot adjust itself to changing flow conditions in response to daily and seasonal variation in ambient temperature and load. Hence, COP is usually low under off design conditions.

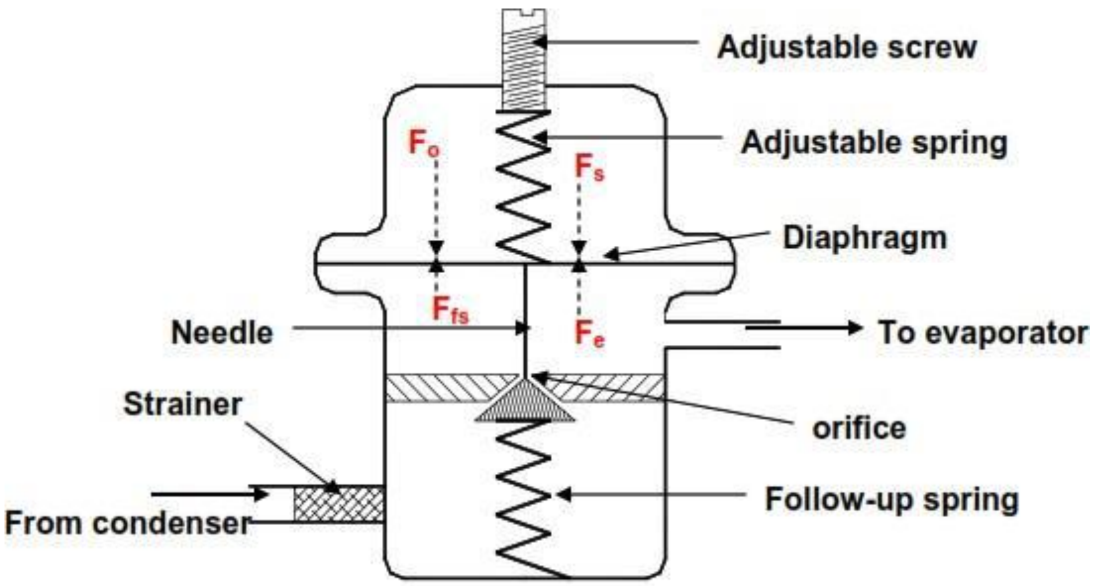
2. It is susceptible to clogging because of narrow bore of the tube, hence, utmost care is required at the time of assembly. A filter-drier should be used ahead of the capillary to prevent entry of moisture or any solid particles

3. During off-cycle liquid refrigerant flows to evaporator because of pressure difference between condenser and evaporator. The evaporator may get flooded and the liquid refrigerant may flow to compressor and damage it when it starts. Therefore critical charge is used in capillary tube based systems. Further, it is used only with hermetically sealed compressors where refrigerant does not leak so that critical charge can be used .Normally an accumulator is provided after the evaporator to prevent slugging of compressor.

Automatic Expansion Valve (AEV)

An Automatic Expansion Valve (AEV) also known as a constant pressure expansion valve acts in such a manner so as to maintain a constant pressure and thereby a constant temperature in the evaporator. The schematic diagram of the valve is shown in Fig. As shown in the figure, the valve consists of an adjustment spring that can be adjusted to maintain the required temperature in the evaporator. This exerts force Fs on the top of the diaphragm. The atmospheric pressure, Po also acts on top of the diaphragm and exerts a force of

F = Po .Ad , Ad being the area of the diaphragm. The evaporator pressure Pe acts below the diaphragm. The force due to evaporator pressure is F e = Pe. Ad. The net downward force Fs + Fo - Fe is fed to the needle by the diaphragm. This net force along with the force due to follow-up spring F_{fs} controls the location of the needle with respect to the orifice and thereby controls the orifice opening.



Schematic of an Automatic Expansion Valve

If $F_e + F_{fs} > F_s + F_o$ the needle will be pushed against the orifice and the valve will be fully closed.

On the other hand if $F_e + F_{fs} < F_s + F_o$, the needle will be away from the orifice and the valve will be open. Hence the relative magnitude of these forces controls the mass flow rate through the expansion valve.

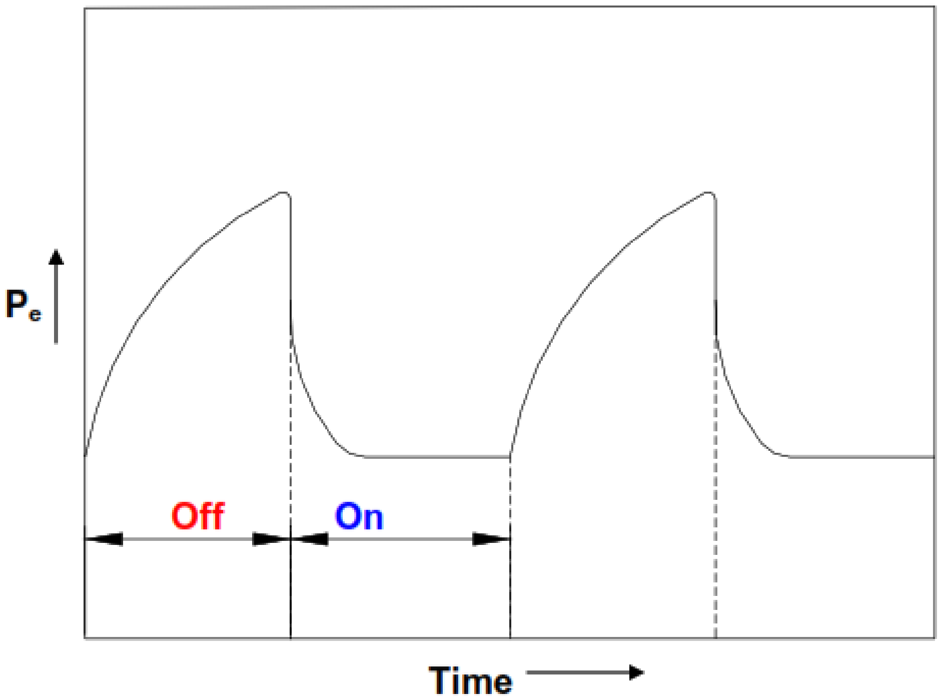
The adjustment spring is usually set such that during off-cycle the valve is closed, that is, the needle is pushed against the orifice. Hence,

$$\boldsymbol{F_{eo} + F_{fso} > F_{so} + F_o}$$

Where, subscript $_o$ refers to forces during off cycle. During the off-cycle, the refrigerant remaining in the evaporator will vaporize but will not be taken out by the compressor, as a result the evaporator pressure rises during the off-cycle as shown in Fig.24.10.

When the compressor is started after the off-cycle period, the evaporator pressure P_e starts decreasing at a very fast rate since valve is closed; refrigerant is not fed to evaporator while the compressor removes the refrigerant from the evaporator. This is shown in Fig.24.10. As P_e decreases the force F_e decreases from F_{eo} to ($F_{eo} - \Delta F_e$). At one stage, the sum $F_e + F_{fs}$ becomes less than $F_s + F_o$, as a result the needle stand moves downwards (away from the needle stand) and the valve opens. Under this condition,

$$(F_{eo} - \Delta F_e) + F_{fso} < F_{so} + F_o$$



Variation of evaporator pressure during on- and off-cycles of an AEV based refrigeration system

When the refrigerant starts to enter the evaporator, the evaporator pressure does not decrease at the same fast rate as at starting time. Thus, the movement of the needle stand will slow down as the refrigerant starts entering. As the needle moves downwards, the adjustment spring elongates, therefore the force F_s decreases from its off-cycle value of F_{s0}, the decrease being proportional to the movement of the needle.

As the needle moves downwards, the follow-up spring is compressed; as a result, F_{fs} increases from its off-cycle value. Hence, the final equation may be written as,

$$(F_{eo} - \Delta F_e) + (F_{fso} + \Delta F_{fs}) = (F_{so} - \Delta F_s) + F_o \quad \text{or}$$

$$F_e + F_{fs} = F_s + F_o \quad = \text{constant}$$

The constant is sum of force due to spring force and the atmospheric pressure, hence it depends upon position of adjustment spring. This will be the equilibrium position. Then onwards, the valve acts in such a manner that the evaporator pressure remains constant as long as the refrigeration load is constant. At this point, the mass flow rate through the valve is the same as that through the compressor.

Applications of automatic expansion valve

The automatic expansion valves are used wherever constant temperature is required, for example, milk chilling units and water coolers where freezing is disastrous. In air-conditioning systems it is used when humidity control is by DX coil temperature. Automatic expansion valves are simple in design and are economical. These are also used in home freezers and small commercial refrigeration systems where hermetic compressors are used. Normally the usage is limited to systems of less than 10 TR capacities with critical charge. Critical charge has to be used since the system using AEV is prone to flooding. Hence, no receivers are used in these systems. In some valves a diaphragm is used in place of bellows.

Thermostatic Expansion Valve (TEV)

Thermostatic expansion valve is the most versatile expansion valve and is most commonly used in refrigeration systems. A thermostatic expansion valve maintains a constant degree of superheat at the exit of evaporator; hence it is most effective for dry evaporators in preventing the slugging of the compressors since it does not allow the liquid refrigerant to enter the compressor. The schematic diagram of the valve is given in Figure. This consists of a feeler bulb that is attached to the evaporator exit tube so that it senses the temperature at the exit of evaporator. The feeler bulb is connected to the top of the bellows by a capillary tube. The feeler bulb and the narrow tube contain some fluid that is called power fluid. The power fluid may be the same as the refrigerant in the refrigeration system, or it may be different. In case it is different from the refrigerant, then the TEV is called TEV with cross charge. The pressure of the power fluid Pp is the saturation pressure corresponding to the temperature at the evaporator exit. If the evaporator temperature is Te and the corresponding saturation evaporator pressure is Pe, then the purpose of TEV is to maintain a temperature Te +ΔTs at the evaporator exit, where ΔTs is the degree of superheat required from the TEV. The power fluid senses this temperature Te +ΔTs by the feeler bulb and its pressure Pp is the saturationpressure at this temperature. The force Fp exerted on top of bellows of area A due to this pressure is given by:

$$F_p = A_b P_p$$

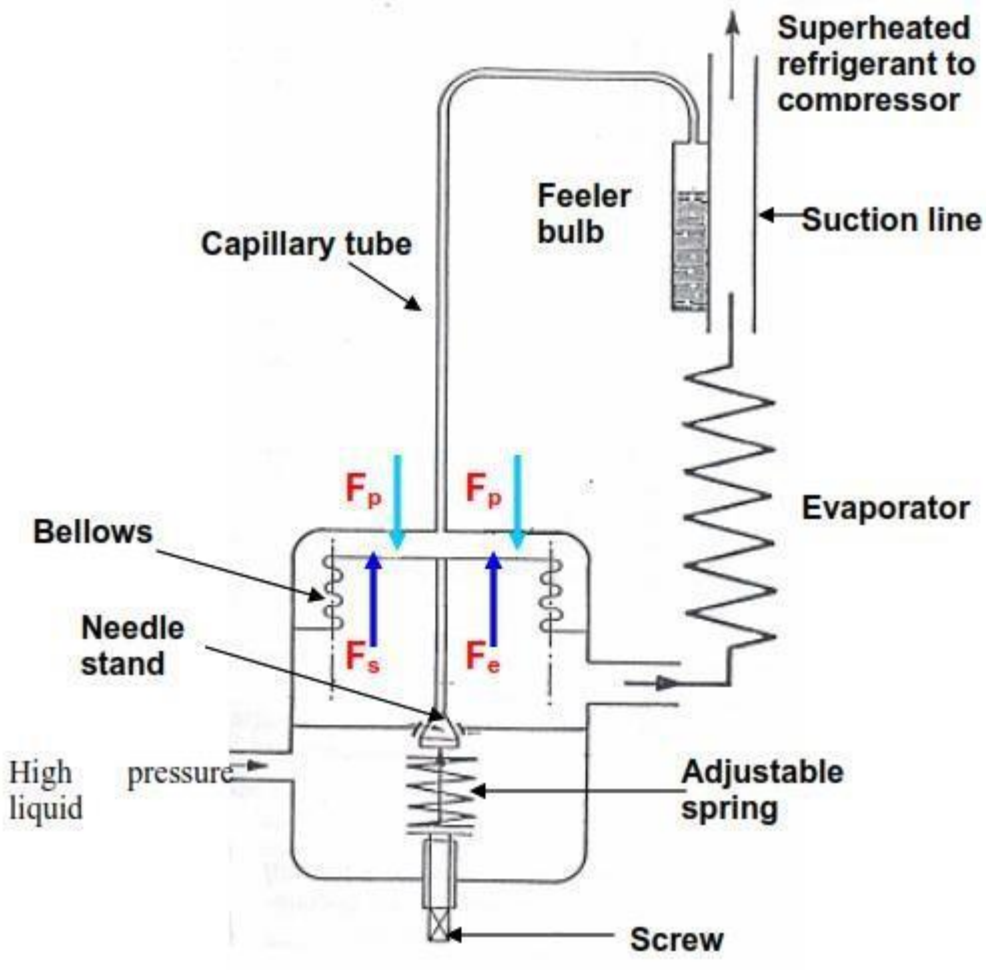
The evaporator pressure is exerted below the bellows. In case the evaporator is large and has a significant pressure drop, the pressure from evaporator exit is fed directly to the bottom of the bellows by a narrow tube. This is called pressure equalizing connection. Such a TEV is called TEV with external equalizer, otherwise it is known as TEV with internal equalizer. The force Fe exerted due to this pressure Pe on the bottom of the bellows is given by

$$F_e = A_b P_e$$

The difference of the two forces Fp and Fe is exerted on top of the needle stand. There is an adjustment spring below the needle stand that exerts an upward spring force Fs on the needle stand. In steady state there will be a force balance on the needle stand, that is,

$$F_s = F_p - F_e$$

During off-cycle, the evaporator temperature is same as room temperature throughout, that is, degree of superheat ΔT_s is zero. If the power fluid is the same as the refrigerant, then $P_p = P_e$ and $F_p = F_e$. Therefore any arbitrarily small spring force F_s acting upwards will push the needle stand against the orifice and keep the TEV closed. If it is *TEV with cross charge* or if there is a little degree of superheat during off-cycle then for TEV to remain closed during off-cycle, F_s should be slightly greater than $(F_p - F_e)$.



Schematic of a Thermostatic Expansion Valve (TEV)

As the compressor is started, the evaporator pressure decreases at a very fast rate hence the force Fe decreases at a very fast rate. This happens since TEV is closed and no refrigerant is fed to evaporator while compressors draws out refrigerant at a very fast rate and tries to evacuate the evaporator. The force Fp does not change during this period since the evaporator temperature does not change. Hence, the difference Fp -Fe, increases as the compressor runs for some time after starting. At one point this difference becomes greater than the spring force Fs and pushes the needle stand downwards opening the orifice. The valve is said to open up. Since a finite downward force is required to open the valve, a minimum degree of superheat is required for a finite mass flow rate. As the refrigerant enters the evaporator it arrests the fast rate of decrease of evaporator pressure. The movement of needle stand also slows down. The spring, however gets compressed as the needle stand moves downward to open

the orifice. If F_{s0} is the spring force in the rest position, that is, off-cycle, then during open valve position

$$\mathbf{F_s = F_{s0} + \Delta F_s}$$

Eventually, the needle stand reaches a position such that,

$$F_s = F_p - F_e = A_b\,(P_p - P_e)$$

That is, F_p is greater than F_e or P_p is greater than P_e. The pressure P_p and P_e are saturation pressures at temperature ($T_e + \Delta T_s$) and T_e respectively. Hence, for a given setting force F_s of the spring, TEV maintains the difference between F_p and F_e or the degree of superheat ΔT_s constant.

$$\Delta T_s \propto (F_p - F_e)$$
$$\propto F_s$$

This is irrespective of the level of P_e, that is, evaporator pressure or temperature, although degree of superheat may be slightly different at different evaporator temperatures for same spring force, F_s. It will be an ideal case if the degree of superheat is same at all evaporator temperatures for a given spring force.

Advantages, disadvantages and applications of TEV

The advantages of TEV compared to other types of expansion devices are:

1. It provides excellent control of refrigeration capacity as the supply of refrigerant to the evaporator matches the demand

2. It ensures that the evaporator operates efficiently by preventing starving under high load conditions

3. It protects the compressor from slugging by ensuring a minimum degree of superheat under all conditions of load, if properly selected.

However, compared to capillary tubes and AEVs, a TEV is more expensive and proper precautions should be taken at the installation. For example, the feeler bulb must always be in good thermal contact with the refrigerant tube. The feeler bulb should preferably be insulated to reduce the influence of the ambient air. The bulb should be mounted such that the liquid is always in contact with the refrigerant tubing for proper control.

The use of TEV depends upon degree of superheat. Hence, in applications where a closeapproach between the fluid to be cooled and evaporator temperature is desired, TEV cannot beused since very small extent of superheating is available for operation. A counter flow arrangement can be used to achieve the desired superheat in such a case. Alternately, a subcooling HEX may be used and the feeler bulb mounted on the vapour exit line of the HEX. The valves with bellows have longer stroke of the needle, which gives extra sensitivity compared to diaphragm type of valve. But valves with bellows are more expensive.

Thermostatic Expansion Valves are normally selected from manufacturers' catalogs. The selection is based on the refrigeration capacity, type of the working fluid, operating temperature range etc. In practice, the design is different to suit different requirements such as single evaporators, multi-evaporators etc.

Float type expansion valves:

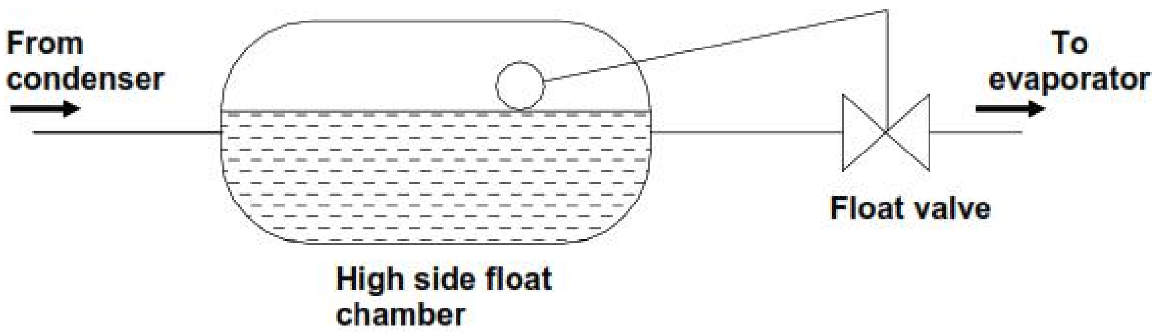
Float type expansion valves are normally used with flooded evaporators in large capacity refrigeration systems. A float type valve opens or closes depending upon the liquid level as sensed by a buoyant member, called as float. The float could take the form of a hollow metal or plastic ball, a hollow cylinder or a pan. Thus the float valve always maintains a constant liquid level in a chamber called as float chamber. Depending upon the location of the float chamber, a float type expansion valve can be either a low-side float valve or a high-side float valve.

Low-side float valves:

A low-side float valve maintains a constant liquid level in a flooded evaporator or a float chamber attached to the evaporator. When the load on the system increases, more amount of refrigerant evaporates from the evaporator. As a result, the refrigerant liquid level in the evaporator or the low-side float chamber drops momentarily. The float then moves in such a way that the valve opening is increased and more amount of refrigerant flows into the evaporator to take care of the increased load and the liquid level is restored. The reverse process occurs when the load falls, i.e., the float reduces the opening of the valve and less amount of refrigerant flows into the evaporator to match the reduced load. As mentioned, these valves are normally used in large capacity systems and normally a by-pass line with a hand-operated expansion is installed to ensure system operation in the event of float failure.

High-side float valves:

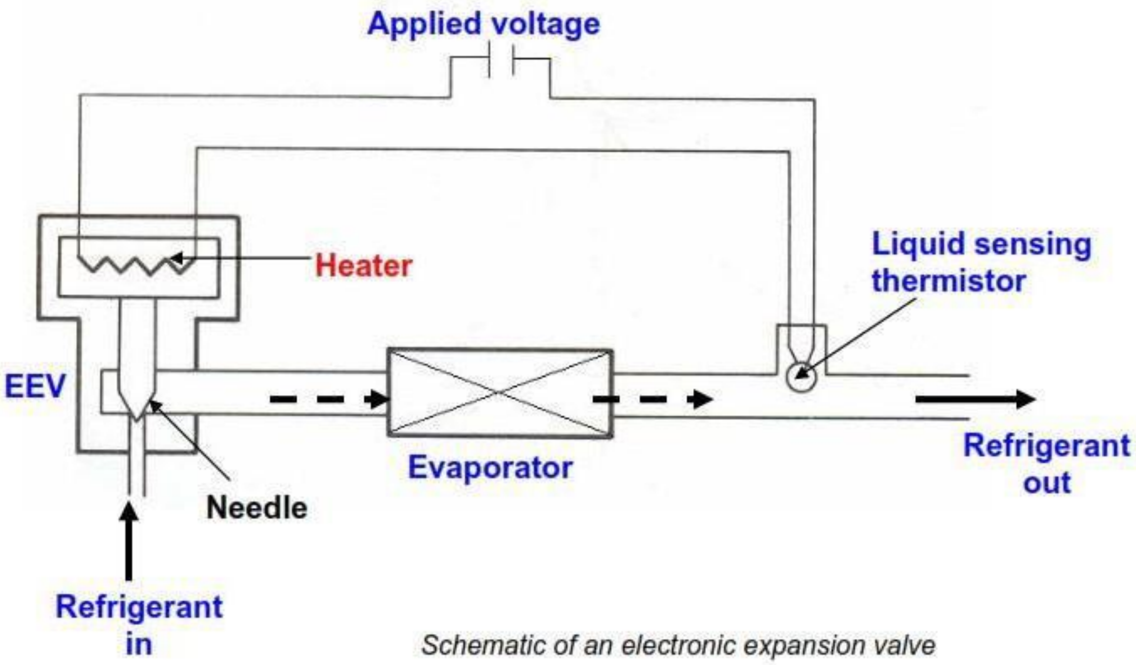
Figure shows the schematic of a high-side float valve. As shown in the figure, a high-side float valve maintains the liquid level constant in a float chamber that is connected to the condenser on the high pressure side. When the load increases, more amount of refrigerant evaporates and condenses. As a result, the liquid level in the float chamber rises momentarily. The float then opens the valve more to allow a higher amount of refrigerant flow to cater to the increased load, as a result the liquid level drops back to the original level. The reverse happens when the load drops. Since a high-side float valve allows only a fixed amount of refrigerant on the high pressure side, the bulk of the refrigerant is stored in the low-pressure side (evaporator). Hence there is a possibility of flooding of evaporator followed by compressor slugging. However, unlike lowside float valves, a high-side float valve can be used with both flooded as well as direct expansion type evaporators.



Schematic of a high-side float valve

Electronic Type Expansion Valve

The schematic diagram of an electric expansion valve is shown in Fig. As shown in the figure, an electronic expansion valve consists of an orifice and a needle in front it. The needle moves up and down in response to magnitude of current in the heating element. A small resistance allows more current to flow through the heater of the expansion valve, as a result the valve opens wider. A small negative coefficient thermistor is used if superheat control is desired. The thermistor is placed in series with the heater of the expansion valve. The heater current depends upon the thermistor resistance that depends upon the refrigerant condition. Exposureof thermistor to superheated vapour permits thermistor to selfheat thereby lowering its resistance and increasing the heater current. This opens the valve wider and increases the massflow rate of refrigerant. This process continues until the vapour becomes saturated and some liquid refrigerant droplets appear. The liquid refrigerant will cool the thermistor and increase its resistance. Hence in presence of liquid droplets the thermistor offers a large resistance, which allows a small current to flow through the heater making the valve opening narrower. The control of this valve is independent of refrigerant and refrigerant pressure; hence it works in reverse flow direction also. It is convenient to use it in year-round-air-conditioning systems, which serve as heat pumps in winter with reverse flow. In another version of it the heater is replaced by stepper motor, which opens and closes the valve with a great precision giving a proportional control in response to temperature sensed by an element.



Schematic of an electronic expansion valve

unit – IV

Vapour Absorption Refrigeration Systems

Introduction

The vapour absorption refrigeration system is one of the oldest method of producing refrigerating effect. The principle of vapour absorption was first discovered by Michael Faraday in 1824 while performing a set of experiments to liquify certain gases. The first vapour absorption refrigeration machine was developed by a French scientist Ferdinand Carre in 1860. This system may be used in both the domestic and large industrial refrigerating plants. The refrigerant, commonly used in a vapour absorption system, is ammonia.

The vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression systems, in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle. We have discussed inthe previous chapters that the function of a compressor, in a vapour compression system, is to withdraw the vapour refrigerant from the evaporator. It then raises its temperature and pressure higher than the cooling agent in the condenser so that the higher pressure vapours can reject heat in the condenser. The liquid refrigerant leaving the condenser is now ready to expand to the evaporator conditions again.

In the vapour absorption system, the compressor is replaced by an absorber,a pump, a generator and a pressure reducing valve. These components in vapour absorption system perform the same function as that of a compressor in vapour compression system. In this system, the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by the weak solution of the refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by some external source. During the heating process, the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquefied. The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

Simple Vapour Absorption System -

The simple vapour absorption system, as shown in Fig. 3.1, consists of an absorber, a pump, a generator and a pressure reducing valve to replace the compressor of vapour compression system. The other components of the system are condenser, receiver, expansion valve and evaporator as in the vapour compression system.

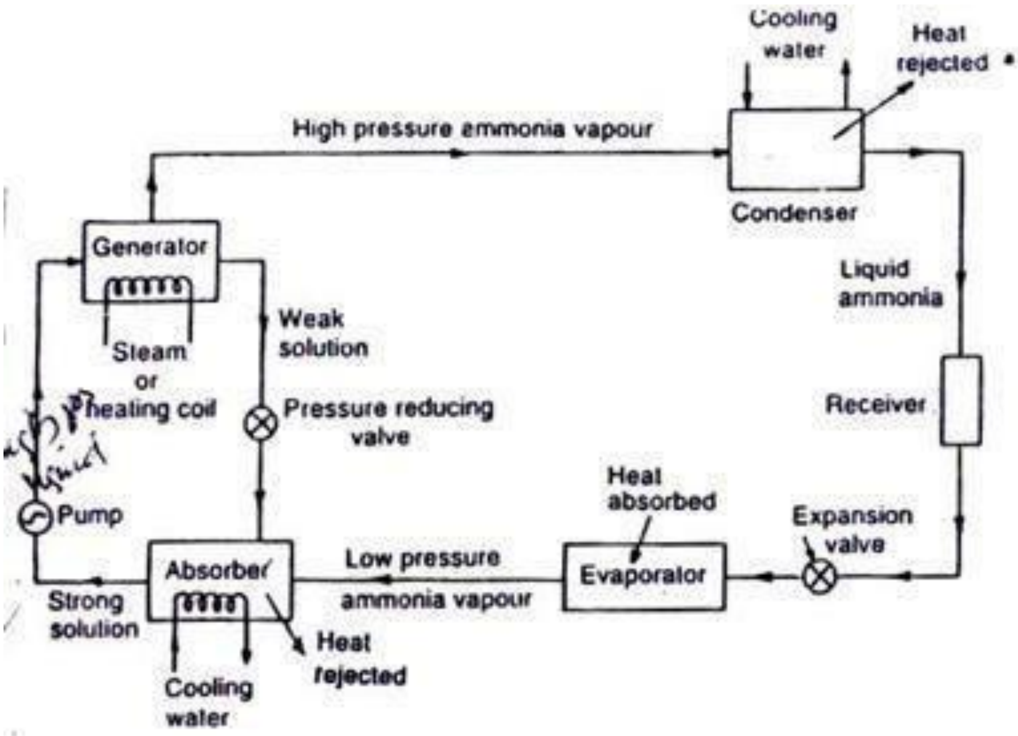


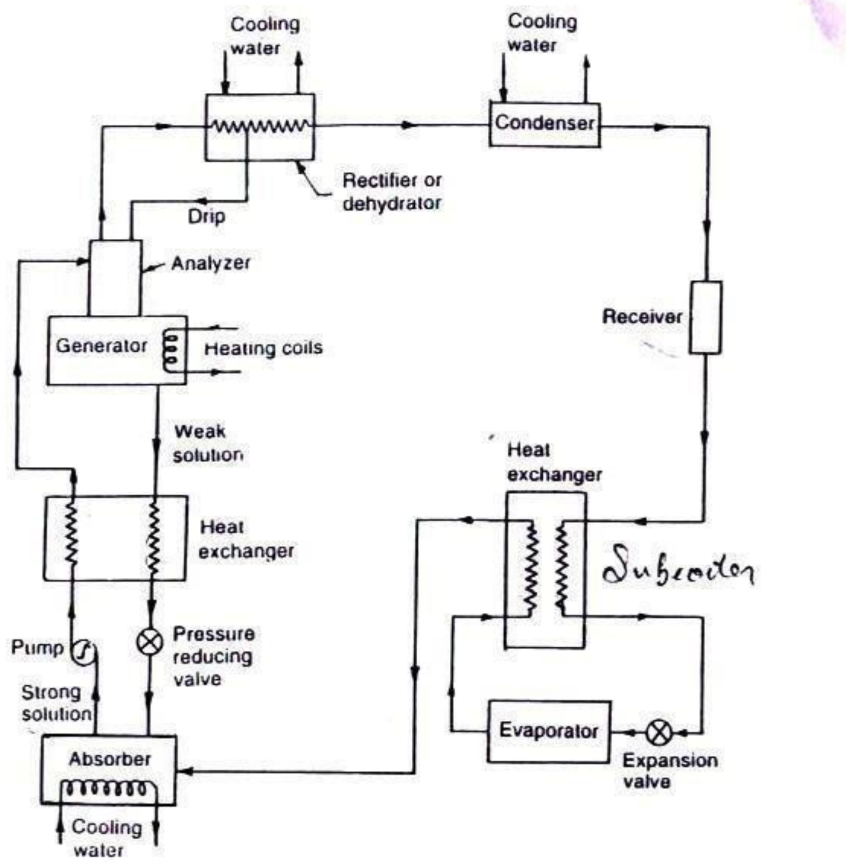
Fig 3.1 Simple vapour absorbtion system

. In this system, the low pressure ammonia vapour leaving the evaporator enters the absorber where it is absorbed by the cold water in the absorber. The water has the ability to absorb very large quantities of ammonia vapour and the solution thus formed, is known as aqua-ammonia. The absorption of ammonia vapour in water lowers the pressure in the absorber which in turn draws more ammonia vapour from the evaporator and thus raises the temperature of solution. Some form of cooling arrangement (usually water cooling) is employed in the absorber to remove the heat of solution evolved there. This is necessary in order to increase the absorption capacity of water, because at higher temperature water absorbs less ammonia vapour. The strong solution thus formed in the absorber is pumped to the generator by the liquid pump. The pump increases the pressure of the solution upto10 bar.

The *strong solution of ammonia in the generator is heated by some external source such as gas or steam. During the heating process, the ammonia vapour is driven off the solution at high pressure leaving behind the hot weak ammonia solution in the generator. This weak ammonia solution flows back to the absorber at low pressure after passing through the pressure reducing valve. The high pressure ammonia vapour from the generator is condensed in the condenser to a high pressure liquid ammonia. This liquid ammonia is passed to the expansion valve through the receiver and then to the evaporator. This completes the simple vapour absorption cycle.

Vapour Absorption System

The simple absorption system as discussed in the previous article is not very economical. In order to make the system more practical, it is fitted with an analyser, arectifier and two heat exchangers as shown in Fig. 3.2. These accessories help to improve the performance and working of the plant, as discussed below :-



vapour absorption system.

1. *Analyser.* When ammonia is vaporised in the generator, some water is also vaporised and will flow into the condenser along with the ammonia vapours in the simple system. If these unwanted water particles are not removed before entering into the condenser, they will enter into the expansion valve where they freeze and choke the pipe line. In order to remove these unwanted particles flowing to the condenser, an analyser is used. The analyser may be built as an integral part of the generator or made as a separate piece of equipment. It consists of a series of trays mounted above the generator. The strong solution from the absorber and the aqua from the rectifier are introduced at the top of the analyser and flow downward over the trays and into the generator. In this way, considerable liquid surface area is exposed to the vapour rising from the generator. The vapour is cooled and most ofthe water vapour condenses, so that mainly ammonia vapour leaves the top of the analyser. Since the aqua is heated by the vapour, less external heat is required in the generator.

2. *Rectifier*. In case the water vapours are not completely removed in the analyser, a closed type vapour cooler called rectifier (also known as dehydrator) is used. It is generally water cooled and may be of the double pipe, shell and coil or shell and tube type. Its function is to cool further the ammonia vapours leaving the analyser so that the remaining water vapours are condensed. Thus, only dry or anhydrous ammonia vapours flow to the condenser. The condensate from the rectifieris returned to the top of the analyser by a drip return pipe.

3. *Heat exchangers*. The heat exchanger provided between the pump and thegenerator is used to cool the weak hot solution returning from the generator to the absorber. The heat removed from the weak solution raises the temperature of the strong solution leaving the pump and going to analyser and generator. This operation reduces the heat supplied to the generator and the amount of cooling required for the absorber. Thus the economy of the plant increases.

The heat exchanger provided between the condenser and the evaporator mayalso be called liquid sub-cooler. In this heat exchanger, the liquid refrigerant leaving the condenser is sub- cooled by the low temperature ammonia vapour from the evaporator as shown in Fig. 7.2. This sub-cooled liquid is now passed to the expansion valve and then to the evaporator.

In this system, the net refrigerating effect is the heat absorbed by the refrigerant in the evaporator. The total energy supplied to the system is the sum of work done by the pump and the heat supplied in the generator. Therefore, the coefficient of performance of the system is given by

$$\text{C.O.P.} = \frac{\text{Heat absorbed in evaporator}}{\text{Work done by pump + Heat supplied in generator}}$$

Advantages of Vapour Absorption Refrigeration System over Vapour Compression Refrigeration System

Following are the advantages of vapour absorption system over vapour compression system:

In the vapour absorption system, the only moving part of the entire system is a pump which has a small motor. Thus, the operation of this system is essentially quiet and is subjected to little wear.

The vapour compression system of the same capacity has more wear, tearand noise due to moving parts of the compressor.

The vapour absorption system uses heat energy to change the condition of the refrigerant from the evaporator. The vapour compression system uses mechanical energy to change the condition of the refrigerant from the evaporator.

The vapour absorption systems are usually designed to use steam, eitherat high pressure or low pressure. The exhaust steam from furnaces and solar energy may also be used. Thus this system can be used where the electric power is difficult to obtain or is very expensive.

The vapour absorption systems can operate at reduced evaporator pressure and temperature by increasing the steam pressure to the generator, with littledecrease in capacity. But the capacity of vapour compression system drops rapidly with lowered evaporator pressure.

The load variations does not effect the performance of a vapour absorption system. The load variations are met by controlling the quantity of aqua circulated and the quantity of steam supplied to the generator.

The performance of a vapour compression system at partial loads is poor.

In the vapour absorption system, the liquid refrigerant leaving the evaporator has no bad effect on the system except that of reducing the refrigerating effect. In the vapour compression system, it is essential to superheat the vapour refrigerant leaving the evaporator so that no liquid may enter the compressor.

The vapour absorption systems can be built in capacities well above 1000tonnes of refrigeration each which is the largest size for single compressor units.

The space requirements and automatic control requirements favour theabsorption system more and more as the desired evaporator temperature drops.

Coefficient of Performance of an Ideal Vapour: Absorption Refrigeration System:

We have discussed earlier that in an ideal vapour absorption refrigeration system
,

(a) the heat (Q_G) is given to the refrigerant in the generator,

(b) the heat (Q_C) is discharged to the atmosphere or cooling water from the condenser and absorber.

(c) the heat (Q_E) is absorbed by the refrigerant in the evaporator, and

(d) the heat (Qp) is added to the refrigerant due to pump work.

Neglecting the heat due to pump work (Qp), we have according to First Lawof Thermodynamics,

$$Q_C = Q_G + Q_E \qquad \text{... (i)}$$

Let T_G = Temperature at which heat (Q_G) is given to the generator,

T_C = Temperature at which heat (Q_C) is discharged to atmosphere or cooling water from the condenser and absorber, and

T_E = Temperature at which heat (Q_E) is absorbed in the evaporator.

Since the vapour absorption system can be considered as a perfectly reversible system, therefore the initial entropy of the system must be equal to the entropy of the system after the change in its condition.

$$\therefore \frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_C}{T_C} \qquad \text{...(ii)}$$

$$= \frac{Q_G + Q_E}{T_C} \qquad \text{... [From equation (i)]}$$

$$\text{or} \quad \frac{Q_G}{T_G} - \frac{Q_G}{T_C} = \frac{Q_E}{T_C} - \frac{Q_E}{T_E}$$

$$Q_G\left(\frac{T_C - T_G}{T_G \times T_C}\right) = Q_E\left(\frac{T_E - T_C}{T_C \times T_E}\right)$$

$$Q_G = Q_E\left[\frac{T_E - T_C}{T_C \times T_E}\right]\left[\frac{T_G \times T_C}{T_C - T_G}\right]$$

$$= Q_E\left[\frac{T_C - T_E}{T_C \times T_E}\right]\left[\frac{T_G \times T_C}{T_G - T_C}\right]$$

$$= Q_E\left(\frac{T_C - T_E}{T_E}\right)\left(\frac{T_G}{T_G - T_C}\right) \qquad \text{... (iii)}$$

Maximum coefficient of performance of the system is given by

$$(\text{C.O.P.})_{max} = \frac{Q_E}{Q_G} = \frac{Q_E}{Q_E\left(\frac{T_C - T_E}{T_E}\right)\left(\frac{T_G}{T_G - T_C}\right)}$$

$$= \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right) \qquad \text{...(iv)}$$

$E\Big(\;\; T_G \;\;\Big)$

It may noted that,

1. The expression $\left(\dfrac{T_E}{T_C - T_E}\right)$ is the C.O.P. of a Carnot refrigerator working between the temperature limits of T_E and T_C.

2. The expression $\left(\dfrac{T_G - T_C}{T_G}\right)$ is the efficiency of a Carnot engine working between the temperature limits of T_G and T_C.

Thus an ideal vapour absorption refrigeration system may be regarded as a combination of a Carnot engine and a Carnot refrigerator. The maximum C.O.P. may be written as

$$(C.O.P.)_{max} = (C.O.P)_{carnot} \times \eta_{carnot}$$

In case the heat is discharged at different temperatures in condenser and absorber, then

$$(C.O.P.)_{max} = \left[\frac{T_E}{T_C - T_E}\right]\left[\frac{T_G - T_C}{T_G}\right]$$

where T_A = Temperature at which heat is discharged in the absorber.

. In a vapour absorption refrigeration system, heating, cooling and refrigeration takes place at the temperatures of 100 °C, 20 °C and _5° C respectively. Find the maximum C.O.P. of the system.

Solution. Given: $T_G = 100$ °C $= 100 + 273 = 373$ K ; $T_C = 20$ °C $= 20 + 273 = 293$ K ; $T_E = -5°$ C $= -5 + 273 = 268$ K

We know that maximum C.O.P. of the system

$$= \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right) = \left(\frac{268}{293 - 268}\right)\left(\frac{373 - 293}{373}\right) = 2.3 \textbf{ Ans.}$$

Example. In an absorption type refrigerator, the heat is supplied to NH_3 generator by condensing steam at 2 bar and 90% dry. The temperature in the refrigerator is to be maintained at - 5° C. Find the maximum C.O.P. possible.

If the refrigeration load is 20 tonnes and actual C.O.P. is 10% of the maximum C.O.P ., find the mass of steam required per hour. Take temperature of the
atmosphere as 30^{o} C.

Solution. Given: p = 2 bar; x = 90% = 0.9; T_E = -5°C = -5 + 273 = 268 K ; Q = 20 TR; Actual C.O.P. = 70% of maximum C.O.P. ; T_C = 30° C = 30 + 273 = 303K

Maximum C.O.P.

From steam tables, we find that the saturation temperature of steam at apressure of 2 bar is

T_G = 120.2° C = 120.2 + 273 = 393.2 K

We know that maximum C.O.P.

$$= \left[\frac{T_E}{T_C - T_E}\right]\left[\frac{T_G - T_C}{T_G}\right] = \left[\frac{268}{303 - 268}\right]\left[\frac{393 - 303}{393.2}\right] = 1.756 \textbf{ Ans.}$$

Mass of steam required per hour

We know that actual C.O.P.

= 70% of maximum C.O.P. = 0.7 × 1.756 = 1.229

∴ Actual heat supplied

$$= \frac{\text{Refrigeration load}}{\text{Actual C.O.P.}} = \frac{20 \times 210}{1.229} = 3417.4 \text{ kJ/min}$$

Assuming that only latent heat of steam is used for heating purposes,therefore from steam tables, the latent heat of steam at 2 bar is

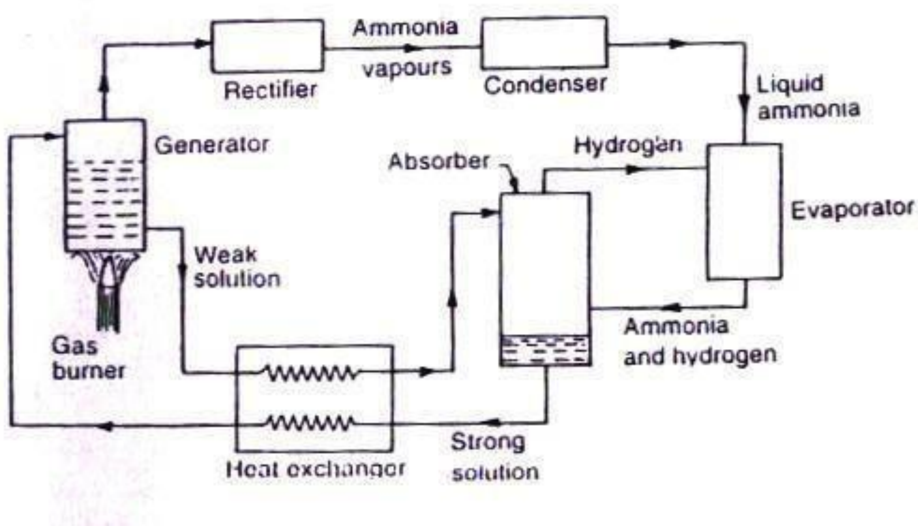
h_{fg} = 2201.6 kJ/kg

∴ Mass of steam required per hour

$$= \frac{\text{Actual heat supplied}}{x \times h_{fg}} = \frac{3417.4}{2201.6} = 1.552 \text{ kg/min} = 93.12 \text{ kg/h} \textbf{ Ans.}$$

Domestic Electrolux (Ammonia Hydrogen) Refrigerator

he domestic absorption type refrigerator was invented by two Swedish engineers Carl Munters and Baltzer Von Platan in 1925 while they were studying for their under-graduate course of Royal Institute of Technology in Stockholm. The idea was first developed by the 'Electrolux Company' of Luton, England.



Domestic electrolux type refrigerator.

This type of refrigerator is also called three-fluids absorption system. The main purpose of this system is to eliminate the pump so that in the absence of moving parts. the machine becomes noise-less. The three fluids used in this sytem are ammonia, hydrogen and water. The ammonia is used as a refrigerant because it possesses most of the desirable properties. It is toxic. but due to absence of moving parts, there is very little changes for the leakage and the total amount of refrigeration used is small. The hydrogen being the lightest gas. is used to increase the rate of evaporation of the liquid ammonia passing through the evaporator. The hydrogen is also non-corrosive and insoluble in water. This is used in the low-pressure side of the system. The water is used as a solvent because it has the ability to absorb ammonia readily. The principle of operation of a domestic electolux type refrigerator.

The strong ammonia solution from the absorber through heat exchanger is heated in the generator by applying heat from an external source usually a gas burner.During this heating process, ammonia vapours are removed from the solution and passed to the condenser. A rectifirer or a water separator fitted before the condenser removes water vapour carried with the ammonia vapours. so that dry

ammonia vapours are supplied to the condenser. These water vapours, f not removed, they will enter into the evaporator causing freezing and choking of the machine . The hot weak solution left behind in the generator flow to the absorber through the heat excl anger. This hot weak solution while passing through the exchanger is cooled. The heat removed by the weak solution is utilised in raising the temperature of strong solution passing through the heat exchanger. In this way, the absorption is accelerated and the improvement in the performance of a plant isachieved.

The ammonia vapours in the condenser are condensed by using external cooling source. The liquid refrigerant leaving the condenser flows under gravity to the evaporator where it meets the hydrogen gas. The hydrogen gas which is being fed to the evaporator permit the liquid ammonia to evaporate at a low pressure and temperature according to Dalton's principle. During the process of evaporation, the ammonia absorbs latent heat from the refrigerated space and thus produces cooling effect.

The mixture of ammonia vapour and hydrogen is passed to the absorber where ammonia is absorbed in water while the hydrogen rises to the top and flows hack to the evaporator. This completes the cycle. The coefficient of performance of this refrigerator is given by :

$$\text{C.O.P.} = \frac{\text{Heat absorbed in the evaporator}}{\text{Heat supplied in the generator}}$$

Notes: 1. The hydrogen gas only circulates from the absorber to the evaporator and back.

2. The whole cycle is carried out entirely by gravity flow of the refrigerant.

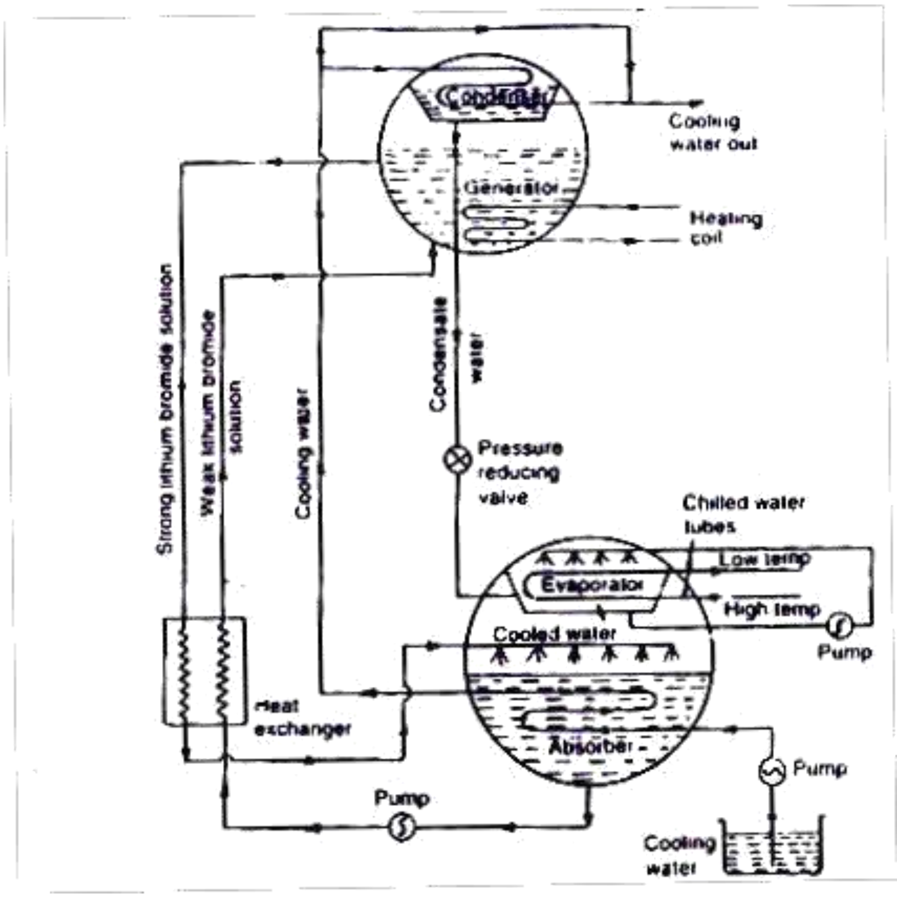
3. It can not be used for industrial purposes as the C.O.P. of the system isvery low.

Lithium Bromide Absorption Refrigeration System

The lithium-bromide absorption refrigeration system uses a solution of lithium bromide in water. In this system, the *water is being used as a refrigerant whereas lithium bromide, which is a highly hydroscopic salt, as an absorbent. The lithium bromide solution has a strong affinity for water vapour because of its very low vapour pressure. Since lithium bromide solution is corrosive, therefore inhibitors should be added in order to protect the metal parts of the system against corrosion. Lithium chromate is often uged as a corrosion inhibitor. This system is very popular for air conditioning in which low refrigeration temperatures (not below 0° C)** are required.

a lithium bromide vapour absorption system. In this system. the absorber and the evaporator are placed in one shell which operates at the same low pressure of the system. The generator and condenser are placed in another shell which operates at the same high pressure of the system. The principle of operation of this system is discussed below :

The water for air-conditioning coils or process requirements is chilled as it is pumped through the chilled-water tubes in.the evaporator by giving up heat to the refrigerant water sprayed over the tubes. Since the pressure inside the evaporator is maintained very low, therefore, the refrigerant waterevaporates. The water vapours thus formed will be absorbed by the strong lithium-bromide solution which is sprayed in the absorber. In absorbing the water vapour, the lithium bromide solution helps in maintaining very low pressure (high vacuum) needed in the evaporator, and the solution becomes weak. This weak solution is pumped by a pump to the generator where it is heated up by using steam or hot water in the heating coils. A portion of water is evaporated by the heat and the solution now becomes more strong. This strong solution is passed through the heat exchanger and then sprayed in the absorberas discussed above. The weak solution of lithium bromide from the absorber to the generator is also passed through the heat exchanger. This weak solution gets heat from the strong solution in the heat exchanger, thus reducing the quantity of steam required to heat the weak solution in the generator.

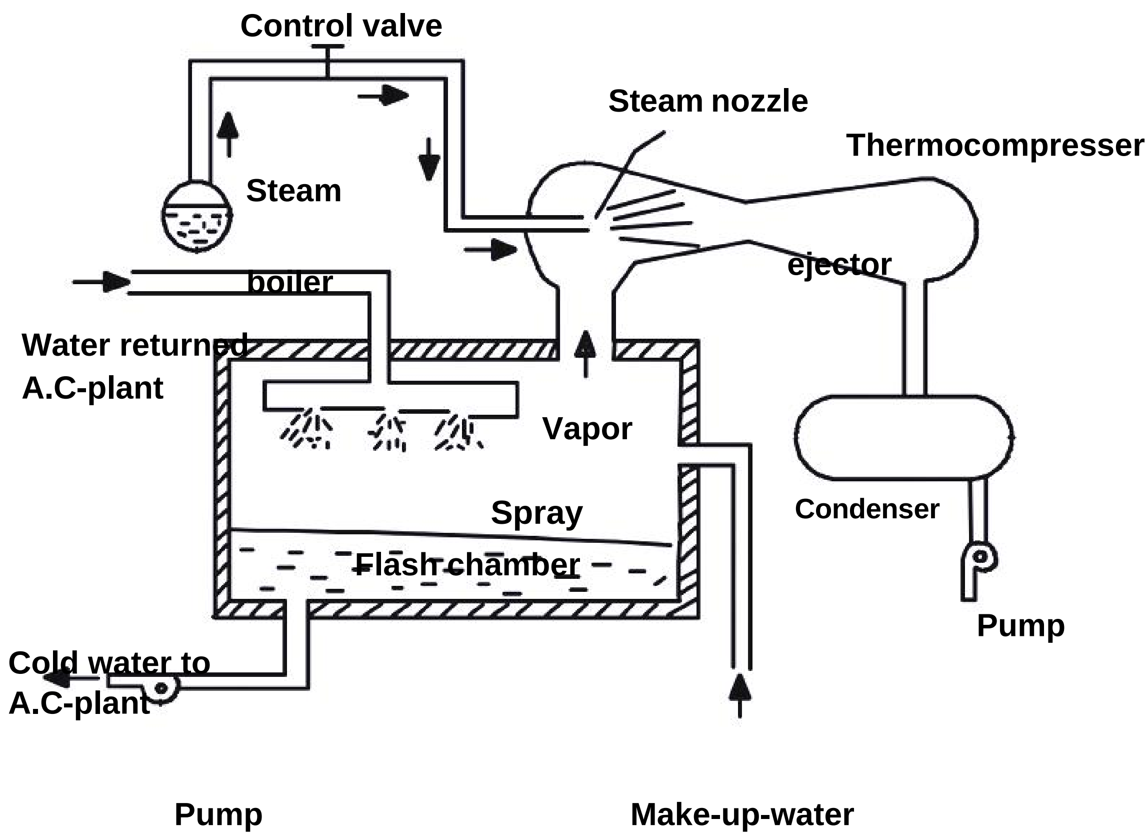


Lithium-Bromide absorption refrigeration system.

The refrigerant water vapours formed in the generator due to heating of solution are passed to the condenser where they are cooled and condensed by the cooling water flowing through the condenser water tubes. The cooling water for condensing is pumped from the cooling water pond or tower. This cooling water first enters the absorber where it takes away the heat of condensation and dilution. The condensate from the condenser is supplied to the evaporator to compensate the water vapour formed in the evaporator. The pressure reducing valve reduces the pressure ofcondensate from the condenser pressure to the evaporator pressure. The cooled water from the evaporator is pumped and sprayed in the evaporator in order to cool the water for air conditioning flowing through the chilled tubes. This completes the cycle.

Note: The pressure difference between the generator and the absorber and the gravity due to the height difference of the two shells is utilised to create the pressure for the spray.

Steam Jet Refrigeration System:



Steam jet refrigeration system

This system uses the principle of boiling the water below 100 ^{0}C. If the pressure on the surface of the water is reduced below atmospheric pressure, water can be made boil at low temperatures. Water boils at 6 ^{0}C, when the pressure on the surface is 5 cm of Hg and at 10 ^{0}C, when the pressure is 6.5 cms of Hg. The very low pressure or high vacuum on the surface of the water can be maintained by throttling the steam through jets or nozzles. The general arrangement of the system is shown in the Fig.6.8.

Consider a flash chamber contains 100 kg of water. If suddenly 1 kg of water is removed by boiling, as pressure is reduced due to throttling of steam through nozzles. Approximately 2385 kJ of heat will be removed from the water, which is equivalent to heat of evaporation of water. The fall in temperature of the remaining water will be

$$Q = m\,C_p dT$$

$$dT = \frac{2385}{99 * 4.187} = 5.7\,^{0}C$$

Evaporating one more kg of water reduces the remaining water temperature by 5.7 ^{0}C further. Thus by continuing this process, the remaining water can be made to freeze. Water is the refrigerant used in the steam jet refrigeration system. As water freezes at 0 ^{0}C, then either refrigeration has to be stopped or some device is required to pump the ice.

Operation:

High pressure steam is supplied to the nozzle from the boiler and it is expanded. Here, the water vapor originated from the flash chamber is entrained with the high velocity steam jet and it is further compressed in the thermo compressor. The kinetic energy of the mixture is converted into static pressure and mass is discharged to the condenser. The condensate is usually returned to the boiler. Generally, 1% evaporation of water in the flash chamber is sufficient to decrease the temperature of chilled water to 6 ^{0}C. The chilled water in the flash chamber is circulated by a pump to the point of application.The warm water from the load is returned to the flash chamber. The water is sprayed through the nozzles to provide maximum surface area for cooling. The water, which is splashed in the chamber and any loss of cold water at the application, must be replacedby makeup water added to the cold water circulating system.

Advantages:

It is flexible in operation; cooling capacity can be easily and quickly changed.

It has no moving parts as such it is vibration free.

It can be installed out of doors.

The weight of the system per ton of refrigerating capacity is less.

The system is very reliable and maintenance cost is less.

The system is particularly adapted to the processing of cold water used inrubber mills,, distilleries, paper mills, food processing plants, etc.

This system is particularly used in air-conditioning installations, because of the complete safety of water as refrigerant and ability to adjust quickly to load variations and no hazard from the leakage of the refrigerant.

Disadvantages:

The use of direct evaporation to produce chilled water is usually limited astremendous volume of vapor is to be handled.

About twice as much heat must be removed in the condenser of steam jet perton of refrigeration compared with the vapor compression system.

The system is useful for comfort air-conditioning, but it is not practicallyfeasible for water temperature below $4^{0}C$

Thermoelectric Refrigeration

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials.

This effect is commonly used in camping and portable coolers and for cooling electronic components and small instruments.

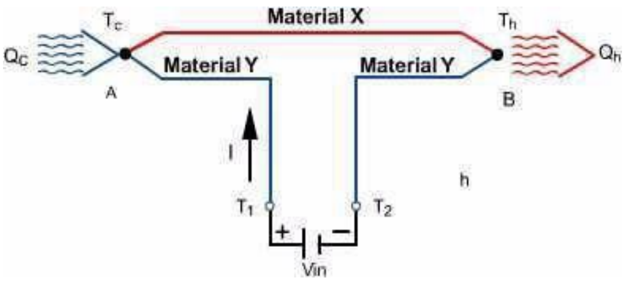
Applying a DC voltage difference across the thermoelectric module, an electric current will pass through the module and heat will be absorbed from one side and released at the opposite side. One module face, therefore, will be cooled while the opposite face simultaneously is heated.

On the other hand, maintaining a temperature difference between the two junctions of the module, a voltage difference will be generated across the module and an electrical power is delivered.

Thermoelectricity is based upon following basic principles:

1. SEEBECK EFFECT
2. PELTIER EFFECT
3. THOMSON EFFECT
4. JOULE EFFECT
5. FOURIER EFFECT

Peltier effect



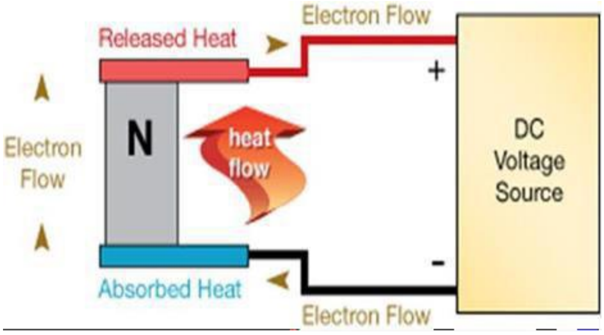
When a current is made to flow through a junction between two conductors A and B, heat may be generated (or removed) at the junction. The Peltier heat generated at the junction per unit time, Q , isequal to;

$$Q \propto I$$
$$Q = \pi_{ab} I$$
$$\pi_{ab} = \pi_a - \pi_b$$

where (π_a & π_b) is the Peltier coefficient of conductor A & B, and I is the electric current (from Ato B).

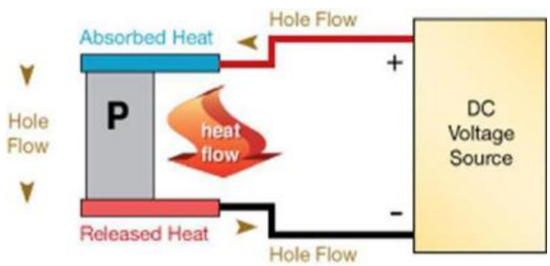
BASIC MECHANISM OF THERMOELECTRICS

Bismuth telluride (a semiconductor), is sandwiched between two conductors, usually copper. A semiconductor (called a pellet) is used because they can be optimized for pumping heat and because the type of charge carriers within them can be chosen. The semiconductor in this examples N type (doped with electrons) therefore, the electrons move towards the positive end of the battery. The semiconductor is soldered to two conductive materials, like copper. When the voltage is applied heat is transported in the direction of current flow



N-TYPE SINGLE SEMICONDUCTOR PELLET

When a p type semiconductor (doped with holes) is used instead, the holes move in a direction opposite the current flow. The heat is also transported in a direction opposite the current flow and in the direction of the holes. Essentially, the charge carriers dictate the direction of heat flow.



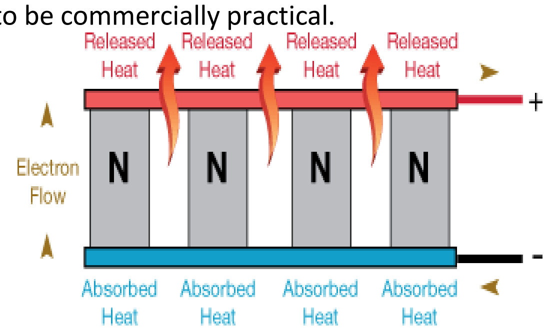
P-TYPE SINGLE SEMICONDUCTOR PELLET

Method of Heat Transport:

Electrons can travel freely in the copper conductors but not so freely in the semiconductor.As the electrons leave the copper and enter the hot-side of the p-type, they must fill a "hole" in order to move through the p-type. When the electrons fill a hole, they drop down to a lower energy level and release heat in the process.Then, as the electrons move from the p-type into the copper conductor on the cold side, the electrons are bumped back to a higher energy level and absorb heat in the process. Next, the electrons move freely through the copper until they reach the cold sideof the n-type semiconductor. When the electrons move into the n-type, they must bump up an energy level in order to move through the semiconductor. Heat is absorbed when this occurs.Finally, when the electrons leave the hot-side of the n-type, they can move freely in the copper. They drop down to alower energy level and release heat in the process.

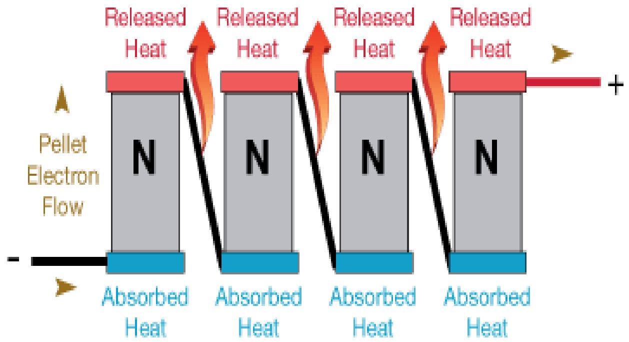
ELECTRICALLY AND THERMALLY PARALLEL MULTIPLE PELLETS

To increase heat transport, several p type or n type thermoelectric(TE) components canbe hooked up in parallel. However, the device requires low voltage and therefore, a large current which is too great to be commercially practical.



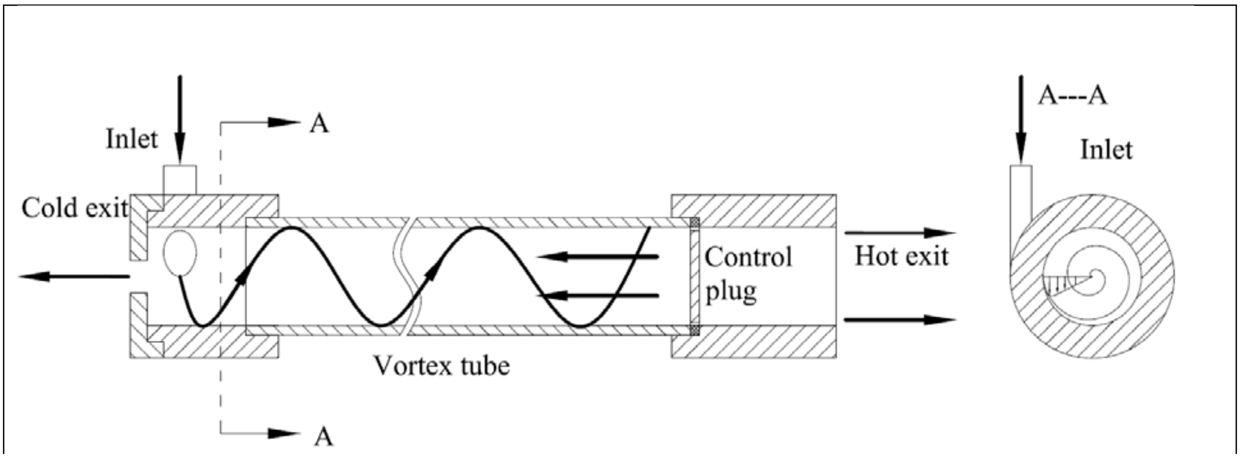
THERMALLY PARALLEL AND ELECTRICALLT IN SERIES MULTIPLE PELLETS

The TE components can be put in series but the heat transport abilities are diminished because the interconnecting between the semiconductors creates thermal shorting.



Vortex tube refrigeration system

A vortex tube is a thermal device, which generates two streams at different temperature from a single injection. Injected into the vortex tube tangentially, the compressedgas is then divided into two parts and exhausted from the exits at temperatures lower and higher than the inlet gas, respectively. In this way, cold and hot streams are generated by onlythe vortex tube without any additional components. Figure 1 shows the structure of a counter-flow vortex tube as well as the proposed flow behaviour inside the tube. Importantly, as the vortex tube contains no other part inside the tube, the separation of two streams at different temperature by the vortex tube can only be attributed by the effects of fluid dynamics. On comparison with other industry-based technologies, the significant advantages of the vortex tube, such as having no moving parts, being small, low in cost, maintenance free and having adjustable instant cold and hot streams, encourage the on-going investigations into the mechanism of this simple device, with the objective of improving the tube performance and identifying of the primary factors underlying its operation.



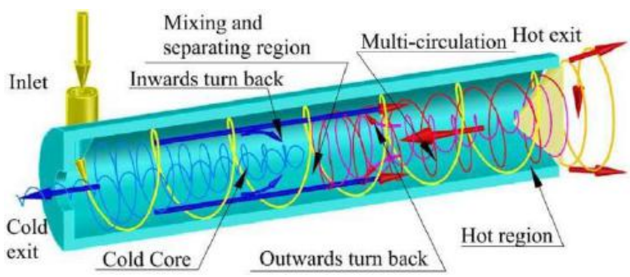
Flow structure in a counter-flow vortex tube

Several hypothesises have been proposed for the basic of the temperature separation, but a well-accepted explanation has not been forthcoming due to the complex flow mechanisms inside a vortex tube. The adiabatic compression and expansion caused by the turbulent eddies, form the basic for the temperature separation, and provide a theoretical prediction of the temperatures based on the pressures at the exits. However, compression of the working fluid cannot be considered as the reason for the temperature rise, because the pressure inside a vortex tube is always lower than the inlet pressure.

The generation of hot and cold streams in a vortex tube and is based on partial stagnation and mixture due to the nature of the multi-circulation occurring in the rear part of the tube, and thepressure gradient near the injection port.

Visualizations of theflow structure,and measurements ofthe velocity componentsinbothair-andwater-operatedvortextubes,showthattheflow to be divided intotwo streams at different temperatures.

The cooling effect in a vortex tube



Flow structure inside a counter-flow vortex tube

The cooling effect of a vortex tube is the result of the sudden expansion of the working fluid near the injection port. When the fluid is injected into the vortex tube, the main part of the fluid rotates and moves along the periphery towards the hot end. Near the injection point, theinner part of the peripheral flow turns back and moves towards the cold exit. A cold core is formed near the injection due to the pressure gradient of the forced vortex, and the temperature drops due to the decreased pressure of the working fluid in this cold core. The flow behaviour in the cold part of a vortex tube can be seen in Figure , which shows the inwards turn back of the inner flow and the cold core.

Pulse tube refrigerator

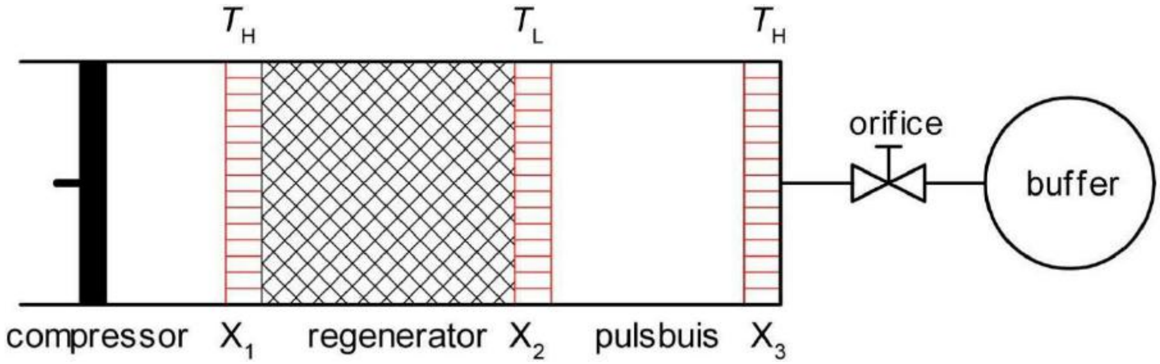
The pulse tube refrigerator (PTR) or pulse tube cryocooler is a developing technology that emerged largely in the early 1980s with a series of other innovations in the broader field of thermoacoustics. In contrast with other cryocoolers (e.g. Stirlingcryocooler and GM-refrigerators), this cryocooler can be made without moving parts in the low temperature part of the device, making the cooler suitable for a wide variety of applications.

Uses

Pulse tube cryocoolers are used in industrial applications such as semiconductor fabrication and in military applications such as for the cooling of infrared sensors. Pulse tubes are also being developed for cooling of astronomical detectors where liquid cryogens are typically used, such as the Atacama Cosmology Telescope or the Qubic experiment (an interferometer for cosmology studies). PTRs are used as precoolers of dilution refrigerators. Pulse tubes will be particularly useful in space-based telescopes where it is not possible to replenish the cryogens as they are depleted. It has also been suggested that pulse tubes could be used to liquefy oxygen on Mars.

Here the so-called Stirling-type single-orifice pulse-tube refrigerator will be treated operating with an ideal gas (helium) as the working fluid. Figure 1 represents the Stirling- type single-orifice Pulse-Tube Refrigerator (PTR). From left to right the components are:

- a compressor, with a piston moving back and forth at room temperature TH;
- a heat exchanger X_1 where heat is released to the surroundings;
- a regenerator consisting of a porous medium with a large specific heat,The porous medium can be stainless steel wire mesh, copper wire mesh, phosphor bronze wire mesh or lead balls or lead shot or (rarely) earthen materials to produce very low temperature;
- a heat exchanger X_2 where the useful cooling power is delivered at the low temperature T_L;
- a tube, often called "the pulse tube";
- a heat exchanger X_3 at room temperature where heat is released to the surroundings;
- a flow resistance (often called orifice);
- a buffer volume (a large closed volume at practically constant pressure).



The part in between X_1 and X_3 is thermally insulated from the surroundings, usually by vacuum. The cooler is filled with helium at a pressure ranging from 10 to 30 bar. The pressure varies gradually and the velocities of the gas are low. So the name "pulse" tube cooler is misleading, since there are no pulses in the system.

Operation

The piston moves periodically from left to right and back. As a result, the gas also moves from left to right and back while the pressure within the system increases and decreases. If the gas from the compressor space moves to the right it enters the regenerator with temperature T_H and leaves the regenerator at the cold end with temperature T_L, hence heat is transferred into the regenerator material. On its return the heat stored within the regenerator istransferred back into the gas.

The thermal environment of a gas element near X_2 that moves back and forth in the system changes when it passes the heat exchanger. In the regenerator and in the heat exchanger the heat contact between the gas and its surrounding material is good. Here the temperature of thegas is practically the same as of the surrounding medium. However, in the pulse tube the gas element is thermally isolated (adiabatic), so, in the pulse tube, the temperature of the gas elements varies with the pressure.

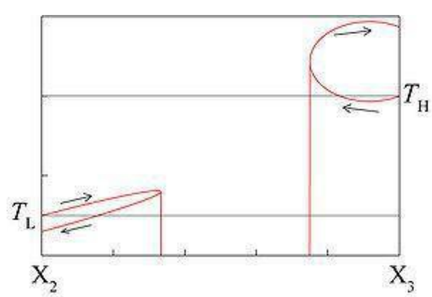


Figure 2: Left: (near X_2): a gas element enters the pulse tube with temperature T_L and leavesit with a lower temperature. Right: (near X_3): a gas element enters the tube with temperature T_H and leaves it with a higher temperature.

Look at figure 1 and consider gas molecules close to X_3 (at the hot end) which move in and out of the pulse tube.

Molecules flow into the tube when the pressure in the tube is low (it is

sucked into the tube via X_3 coming from the orifice and the buffer). At the moment of entering the tube it has the temperature T_H. Later in the cycle the same mass of gas is pushed out from the tube again when the pressure inside the tube is high. As a consequence its temperature will be higher than T_H. In the heat exchanger X_3 it releases heat and cools down to the ambient temperature T_H.

At the cold end of the pulse tube there is the opposite effect: here gas enters the tube viaX_2 when the pressure is high with temperature T_L and return when the pressure is low with a temperature below T_L. They take up heat from X_2: this gives the desired cooling effect.

UNIT-V

Psychrometry and Air Conditioning

Concept of Psychrometry and Psychrometrics

Air comprises of fixed gases principally, nitrogen and oxygen with an admixture of water vapour in varying amounts. In atmospheric air water is always present and its relative weight averages less than 1% of the weight of atmospheric air in temperate climates and less than 3% by weight under the most extreme natural climatic conditions, it is nevertheless one of most important factors in human comfort and has significant effects on many materials. Its effect on human activities is in fact altogether disproportionate to its relative weights. The art of measuring the moisture content of air is termed Psychrometry. The science which investigates the thermal properties of moist air, considers the measurement and control of the moisture content of air, and studies the effect of atmospheric moisture on material and human comfort may properly be termed -**psychrometrics'**'.

DEFINITIONS

Some of the more important definitions are given below:

1. **Dry air.** The international joint committee on Psychrometric Data has adopted the following exact composition of air expressed in mole fractions (Volumetric) Oxygen 0.2095, Nitrogen0.7809, Argon 0.0093, Carbon dioxide 0.0003. Traces of rare gases are neglected. Molecular weight of air for all air conditioning calculations will be taken as 28.97. Hence the gas

$$R_{air} = \frac{8.3143}{28.97} = 0.287 \text{ kJ/kg K}$$

constant,

Dry air is never found in practice. Air always contains some moisture. Hence the common designation -air‖ usually means moist air. The term ‗dry air' is used to indicate the water free contents of air having any degree of moisture.

2. **Saturated air.** Moist air is said to be saturated when its condition is such that it can co- exist in natural equilibrium with an associated condensed moisture phase presenting a flat surface to

it. For a given temperature, a given quantity of air can be saturated with a fixed quantity of moisture. At higher temperatures, it requires a larger quantity of moisture to saturate it. At saturation, vapour pressure of moisture in air corresponds to the saturation

pressure given in steam tables corresponding to the given temperature of air.

3. **Dry-bulb temperature (DBT).** It is the temperature of air as registered by an ordinary thermometer (t_{db}).

4. **Wet-bulb temperature (WBT).** It is the temperature registered by a thermometer when the bulb is covered by a wetted wick and is exposed to a current of rapidly moving air (t_{wb}).

5. **Adiabatic saturation temperature.** It is the temperature at which the water or ice can saturate air by evaporating adiabatically into it. It is numerically equivalent to the measured wet bulb temperature (as corrected, if necessary for radiation and conduction) (t_{db}– t_{wb}).

6. **Wet bulb depression.** It is the difference between dry-bulb and wet bulb temperatures.

7. **Dew point temperature (DPT).** It is the temperature to which air must be cooled a tconstant pressure in order to cause condensation of any of its water vapour. It is equal to steam table saturation temperature corresponding to the actual partial pressure of water vapour in the air (t_{dp}).

8. **Dew point depression.** It is the difference between the dry bulb and dew point temperatures (t_{db} – t_{dp}).

9. **Specific humidity (Humidity ratio).** It is the ratio of the mass of water vapour per unit mass of dry air in the mixture of vapour and air, it is generally expressed as grams of waterper kg of dry air. For a given barometric pressure it is a function of dew point temperature alone.

10. **Relative humidity(RH), (□).** It is the ratio of the partial pressure of water vapour in the mixture to the saturated partial pressure at the dry bulb temperature, expressed as percentage.

11. **Sensible heat.** It is the heat that changes the temperature of a substance when added to or abstracted from it.

12. **Latent heat.** It is the heat that does not affect the temperature but changes the state of substance when added to or abstracted from it.

13. **Enthalpy.** It is the combination energy which represents the sum of internal and flow energy in a steady flow process. It is determined from an arbitrary datum point for the air mixture and is expressed as kJ per kg of dry air (h).

Note. When air is saturated DBT, WBT, DPT are equal.

Psychrometric Relations

Pressure

Dalton's law of partial pressure is employed to determine the pressure of a mixture of gases. This law states that the total pressure of a mixture of gases is equal to the sum of partial pressures which the component gases would exert if each existed alone in the mixture volume at the mixture temperature. Precise measurements made during the last few years indicate that this law as well as Boyle's and Charle's laws are only approximately correct. Modern tables of atmospheric air properties are based on the correct versions. For calculating partial pressure of water vapour in the air many equations have been proposed, probably Dr. Carrier's equation is most widely used.

$$p_v = (p_{vs})_{wb} - \frac{[pt - (p_{vs})_{wb}](t_{db} - t_{wb})}{1527.4 - 1.3\, t_{wb}}$$

where

p_v = Partial pressure of water vapour,

p_{vs}= Partial pressure of water vapour when air is fully

saturated,p_t = Total pressure of moist air,

t_{db}= Dry bulb temperature (ºC),

andt_{wb}= Wet bulb temperature

(ºC).

Specific humidity W:

$$\text{Specific humidity} = \frac{\text{Mass of water vapour}}{\text{Mass of dry air}}$$

$$W = \frac{m_v}{m_a}$$

Also,

$$m_a = \frac{p_a V}{R_a T}$$

$$m_v = \frac{p_v \times V}{R_v \times T}$$

Where,

p_a= Partial pressure of dry air,

p_v= Partial pressure of water vapour,

V=Volume of mixture,

$$W = \frac{p_v \times V}{R_v \times T} \times \frac{R_a T}{p_a V} = \frac{R_a}{R_v} \times \frac{p_v}{p_a}$$

$$R_a = \frac{R_0}{M_a} \qquad \left(= \frac{8.3143}{28.97} = 0.287 \text{ kJ/kg K in SI units}\right)$$

$$R_v = \frac{R_0}{M_v} \qquad \left(= \frac{8.3143}{18} = 0.462 \text{ kJ/kg K in SI units}\right)$$

Where

R_0 = Universal gas constant,

M_a= Molecular weight of air, and

M_v = Molecular weight of water vapour.

$$W = \frac{0.287}{0.462} \cdot \frac{p_v}{p_a} = 0.622 \ \frac{p_v}{p_t - p_v}$$

$$W = 0.622 \ \frac{p_v}{p_t - p_v}$$

The masses of air and water vapour in terms of specific volumes are given by expression as

$$m_a = \frac{V}{v_a} \qquad \text{and} \qquad m_v = \frac{V}{v_v}$$

Where

v_a= Specific volume of dry air,

and v_v= Specific volume of water vapour.

$$W = \frac{v_a}{v_v}$$

Degree of saturation (μ):

$$\text{Degree of saturation} = \frac{\text{Mass of water vapour associated with unit mass of dry air}}{\text{Mass of water vapour associated with saturated unit mass of dry saturated air}}$$

$$\mu = \frac{W}{W_s}$$

W_s = Specific humidity of air when air is fully saturated

$$\mu = \frac{0.622\left(\dfrac{p_v}{p_t - p_v}\right)}{0.622\left(\dfrac{p_{vs}}{p_t - p_{vs}}\right)} = \frac{p_v(p_t - p_{vs})}{p_{vs}(p_t - p_v)}$$

$$= \frac{p_v}{p_s}\left[\frac{\left(1 - \dfrac{p_{vs}}{p_t}\right)}{\left(1 - \dfrac{p_v}{p_t}\right)}\right]$$

Where

p_{vs} = Partial pressure of water vapour when air is fully saturated (p_{vs}can be calculatedfrom steam tables corresponding to the dry bulb temperature of the air).

Relative humidity (RH)□ :

$$\text{Relative humidity, } \phi = \frac{\text{Mass of water vapour in a given volume}}{\text{Mass of water vapour in the same volume if saturated at the same temp.}}$$

$$= \frac{m}{m_{vs}} = \frac{\dfrac{p_v T}{R_v T}}{\dfrac{p_{vs} T}{R_v T}} = \frac{p_v}{p_{vs}}$$

$$\phi = \frac{p_a W}{0.622} \times \frac{1}{p_{vs}} = 1.6 \ W \ \frac{p_a}{p_{vs}}$$

Note 1. Relative humidity as compared to specific humidity plays a vital role in comfort air-conditioning and industrial air-conditioning. Relative humidity signifies the absorption capacity of air. If initial relative humidity of air is less it will absorb more moisture.

2. W, μ and ϕ cannot be conveniently measured as they require measurement of p_v and p_{vs}. The value of p_v can be obtained from the measurement of the wet bulb temperature and the value of p_{vs} can be calculated from steam tables corresponding to given air temperature.

Enthalpy of moist air

It is the sum of enthalpy of dry air and enthalpy of water vapour associated with dry air. It is expressed in kJ/kg of dry air.

$$h = h_{air} + W \, . \, h_{vapour}$$
$$= c_p t_{db} + W \, . \, h_{vapour}$$

where h = Enthalpy of mixture/kg of dry air,

h_{air} = Enthalpy of 1 kg of dry air,

h_{vapour} = Enthalpy of 1 kg of vapour obtained from steam tables,

W = Specific humidity in kg/kg of dry air, and

c_p = Specific heat of dry air normally assumed as 1.005 kJ/kg K.

Also $$h_{vapour} = h_g + c_{ps} (t_{db} - t_{dp})$$

where h_g = Enthalpy of saturated steam at dew point temperature,

and c_{ps} = 1.88 kJ/kg K.

$$\therefore \quad h = c_p t_{db} + W[h_g + c_{ps}(t_{db} - t_{dp})]$$
$$= (c_p + c_{ps} W) \, t_{db} + W(h_g - c_{ps} t_{dp})$$
$$= c_{pm} t_{db} + W(h_g - c_{ps} t_{dp})$$

Where $C_{pm} = (C_p + C_{ps}W)$ is the specific heat of humid air or humid specific heat.

The value of C_{pm} is taken as 1.021 kJ/kg dry air per K. It is the heat capacity of (1 + *W*) kg of moisture per kg of dry air.

$H_{vapour} = h_g$ at dry bulb temperature. So,

$$h = c_p t_{db} + W\, h_g.$$

However, a better approximation is given by the following relationship:

$$h_{\text{vapour}} = 2500 + 1.88 t_{db} \text{ kJ/kg of water vapour}$$

Where t_{db} is dry bulb temperature in ºC, and the datum state is liquid water at 0ºC.

$$h = 1.005\ t_{db} + W(2500 + 1.88\ t_{db}) \text{ kJ/kg dry air.}$$

PSYCHROMETRIC CHARTS

The psychrometric charts are prepared to represent graphically all the necessary moist air properties used for air conditioning calculations. The values are based on actual measurements verified for thermodynamic consistency.

For psychrometric charts the most convenient co-ordinates are dry bulb temperature of air vapour mixture as the abcissa and moisture content (kg/kg of dry air) or water vapour pressure as the ordinate. Depending upon whether the humidity contents are abcissa or ordinate with temperature co-ordinate, the charts are generally classified as Mollier chart and Carrier chart. Carrier chart having t_{db} as the abcissa and W as the ordinate finds a wide application. The chart is constructed as under:

1. The dry bulb temperature (ºC) of unit mass of dry air for different humidity contents or humidityratios are indicated by vertical lines drawn parallel to the ordinate.
2. The mass of water vapour in kg (or grams) per kg of dry air is drawn parallel to the abcissa for different values of dry bulb temperature. It is the major vertical scale of the chart.
3. Pressure of water vapour in mm of mercury is shown in the scale at left and is the absolutepressure of steam.
4. Dew point temperatures are temperatures corresponding to the boiling points of water at lowpressures of water vapour and are shown in the scale on the upper curved line. The dew points for

different low pressures are read on diagonal co-ordinates.

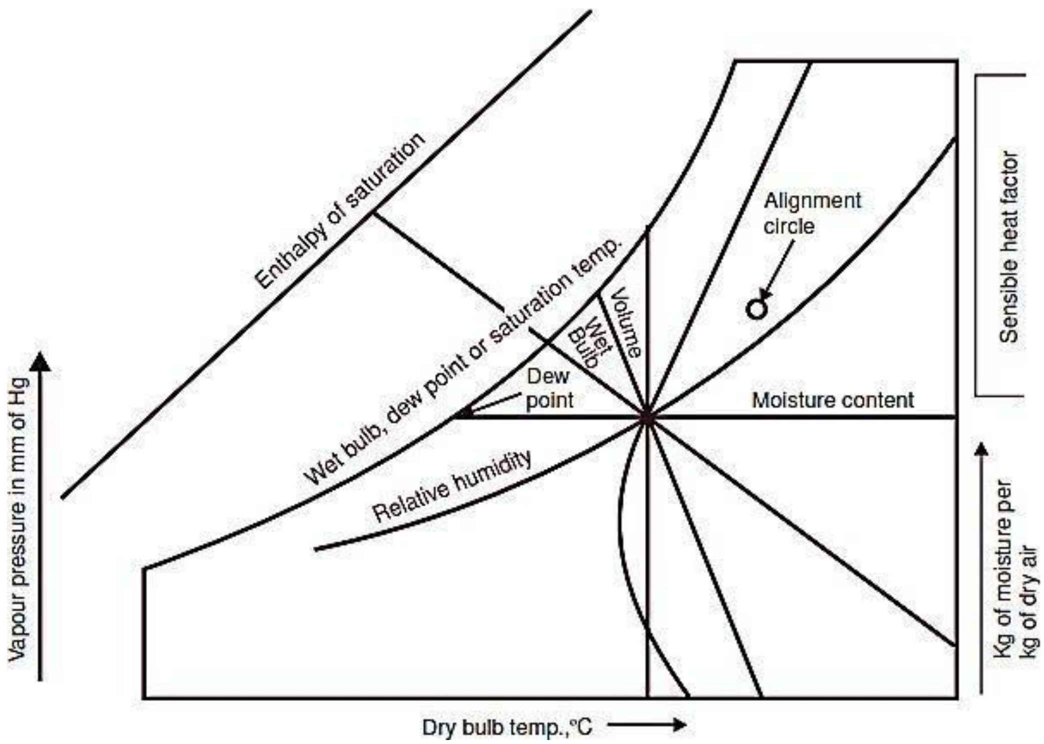


Fig.a. Skeleton psychrometric chart.

5. Constant relative humidity lines in per cent are indicated by marking off vertical distances between the saturation line or the upper curved line and the base of the chart. The relative humidity curve depicts quantity (kg) of moisture actually present in the air as a percentage of the total amount possible at various dry bulb temperatures and masses of vapour.

6. Enthalpy or total heat at saturation temperature in kJ/kg of dry air is shown by a diagonal system of co-ordinates. The scale on the diagonal line is separate from the body of the chart and is indicated above the saturation line.

7. Wet bulb temperatures are shown on the diagonal co-ordinates coinciding with heat coordinates.The scale of wet bulb temperatures is shown on the saturation curve. The diagonals run downwardsto the right at an angle of 30º to the horizontal.

8. The volume of air vapour mixture per kg of dry air (specific volume) is also indicated bya set of

diagonal co-ordinates but at an angle of 60º with the horizontal.

The other properties of air vapour mixtures can be determined by using formulae (already discussed).In relation to the psychrometric chart, these terms can quickly indicate many things about the condition of air, for example:

1. If dry bulb and wet bulb temperatures are known, the relative humidity can be read from the chart.

2. If the dry bulb and relative humidity are known, the wet bulb temperature can be deter- mined.

3. If wet bulb temperature and relative humidity are known, the dry bulb temperature can be found.

4. If wet bulb and dry bulb temperatures are known, the dew point can be found.

5. If wet bulb and relative humidity are known, dew point can be read from the chart.

6. If dry-bulb and relative humidity are known, dew point can be found.

7. The quantity (kg) of moisture in air can be determined from any of the following combinations:

(i) Dry bulb temperature and relative humidity;

(ii) Dry bulb temperature and dew point;

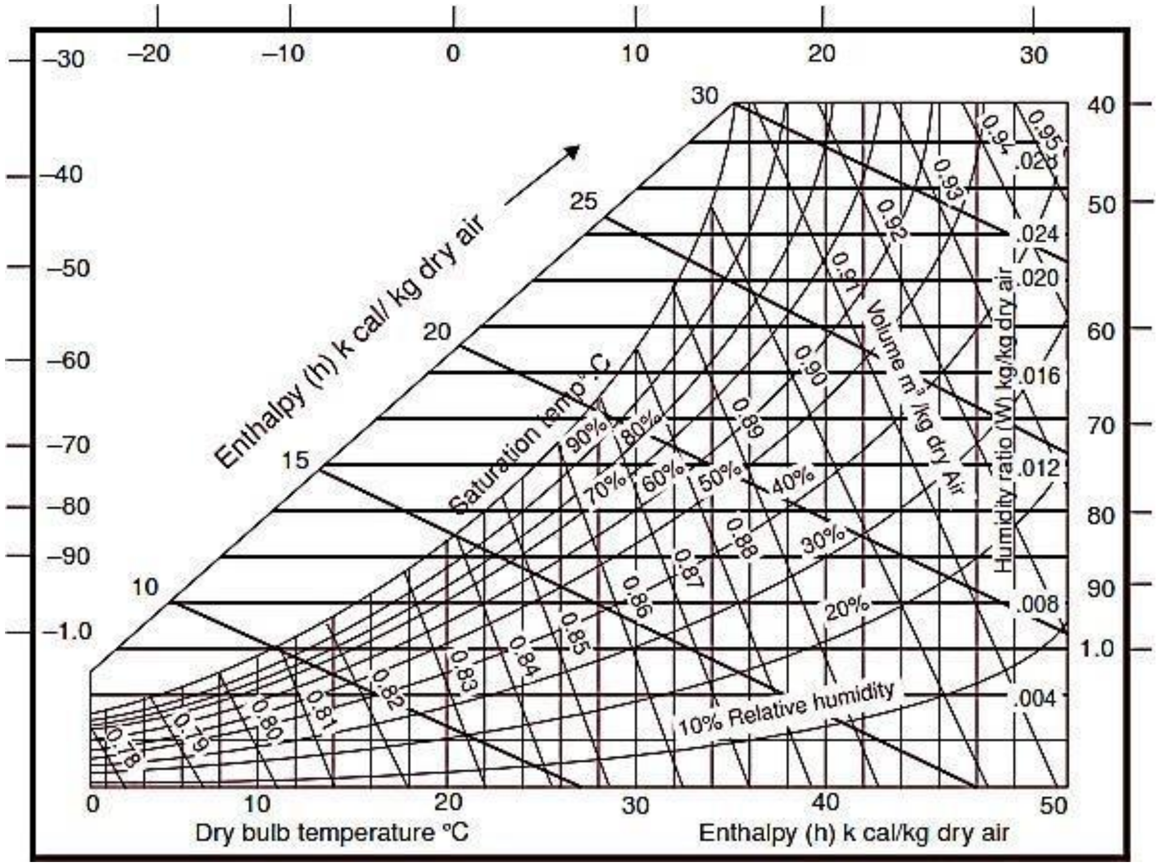
(iii) Wet bulb temperature and relative humidity;

(iv) Wet bulb temperature and dew point temperature;

(v) Dry bulb temperature and wet bulb temperature; and

(vi) Dew point temperature alone.

Figs. a an b show the skeleton psychrometric chart and lines on carrier chart respectively.



.Carrier chart.

PSYCHROMETRIC PROCESSES

In order to condition air to the conditions of human comfort or of the optimum control of anindustrial process required, certain processes are to be carried out on the outside air available. The processes affecting the psychrometric properties of air are called **psychrometric processes.** These processes involve mixing of air streams, heating, cooling, humidifying, dehumidifying, adiabatic saturation and mostly the combinations of these. The important psychrometric processes are enumerated and explained in the following text:

Mixing of air streams

Sensible heating

Sensible cooling

4. Cooling and dehumidification
5. Cooling and humidification
6. Heating and dehumidification
7. Heating and humidification.

Mixing of Air Streams

Mixing of several air streams is the process which is very frequently used in air conditioning. This mixing normally takes place without the addition or rejection of either heat or moisture, i.e., adiabatically and at constant total moisture content. Thus we canwrite the following equations :

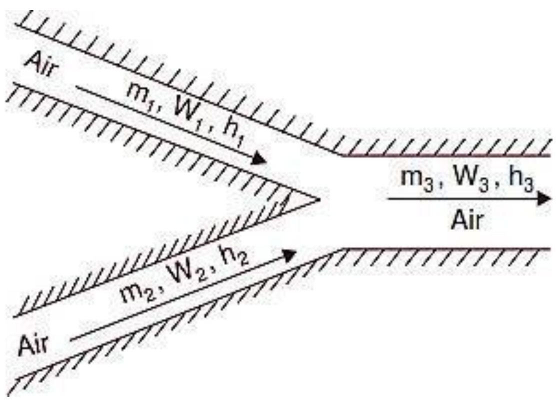
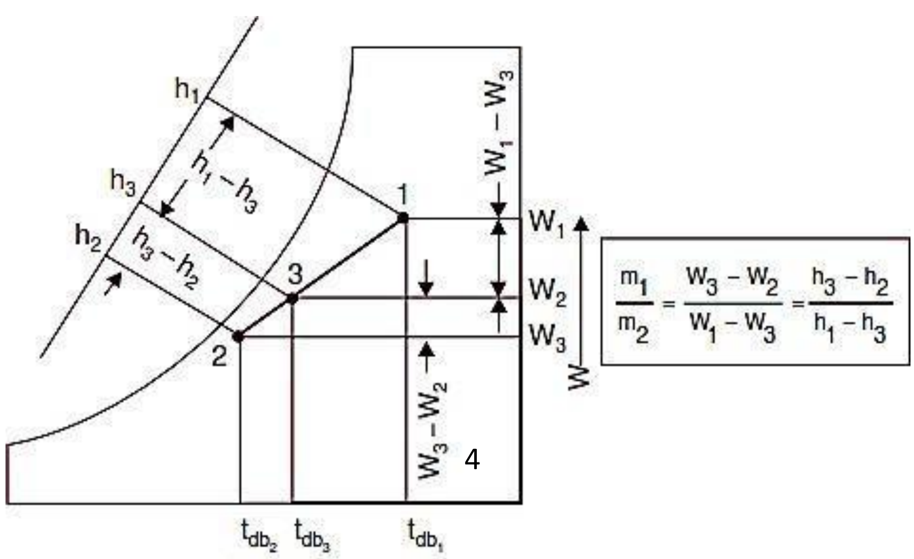


Fig. C. Mixing of air streams.

$$m_1 + m_2 = m_3$$
$$m_1W_1 + m_2W_2 = m_3W_3$$
$$m_1h_1 + m_2h_2 = m_3h_3$$



Rearranging of last two equations gives the following:

$$m_1(W_1 - W_3) = m_2(W_3 - W_2)$$
$$m_1(h_1 - h_3) = m_2(h_3 - h_2)$$
$$\frac{m_1}{m_2} = \frac{W_3 - W_2}{W_1 - W_3} = \frac{h_3 - h_2}{h_1 - h_3}$$

Where,

m = Mass of dry air at particular state points W=

Specific humidity at particular state points h =

Enthalpy at particular state points

On the psychrometric chart, the specific humidity and enthalpy scales are linear, ignoring enthalpy deviations. Therefore, the final state 3 lies on a straight line connecting the initial states of the two streams before mixing, and the final state 3 divides this line into two parts that are in the same ratio as were the two masses of air before mixing. If the air quantities are known in volume instead of mass units, it is generally sufficiently accurate to units of m^3 or m^3/min. in the mixing equations. The inaccuracy introduced is due to the difference in specific volume at two initial states. This difference in densities is small for most of the comfort air conditioning problems.

Sensible Heating

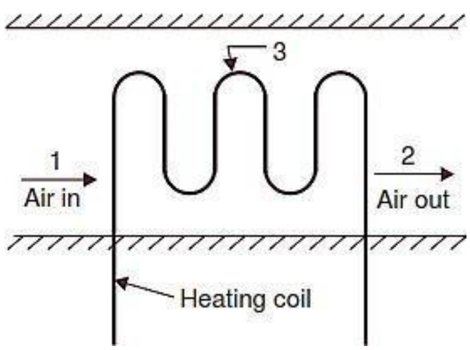
When air passes over a dry surface which is at a temperature greater than its (air) dry bulb temperature, it undergoes sensible heating. Thus the heating can be achieved by passing the air over heating coil like electric resistance heating coils or steam coils. During such a process, the specific humidity remains constant but the dry bulb temperature rises and approaches that of the surface. The extent to which it approaches the mean effective surface temperature of the coil is conveniently expressed in terms of the equivalent **by-pass factor.**

The by-pass factor (BF) for the process is defined as the ratio of the difference between the mean surface temperature of the coil and leaving air temperature to the difference between the mean surface temperature and the entering air temperature.

E, air at temperature t_{db1}, passes over a heating coil with an average surface temperature t_{db3} and leaves at temperature t_{db2}

The by-pass factor is expressed as follows :

$$BF = \frac{t_{db_3} - t_{db_2}}{t_{db_3} - t_{db_1}}$$



E. Sensible heating.

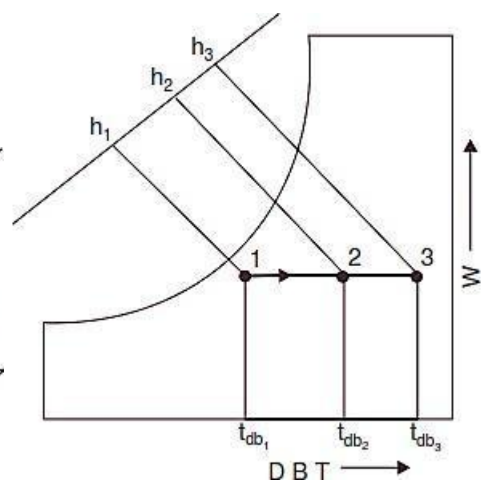


Fig.F

Or in terms of lengths on the chart (Fig. F) it is $\frac{\text{length } 2-3}{\text{length } 1-3}$

The value of the by-pass factor is a function of coil design and velocity. The heat added to the air can be obtained directly from the entering and leaving enthalpies (h_2-h_1) or it can be obtained from the humid specific heat multiplied by the temperature difference (t_{db2}-t_{db1}).

In a complete air conditioning system the preheating and reheating of air are among the familiar examples of sensible heating.

Note. By-pass factor can be considered to represent the fraction of air which does not come into contact with coil surface.

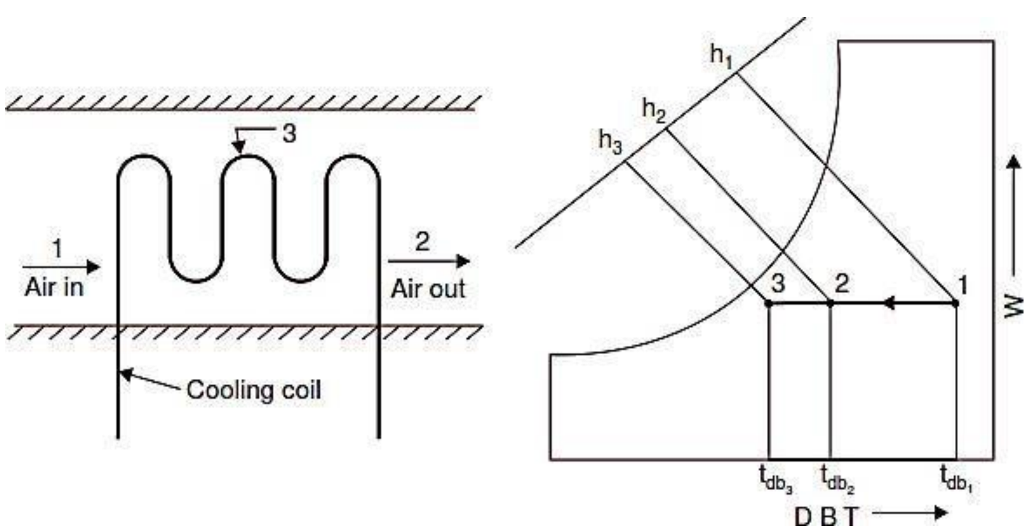
Sensible Cooling

. Air undergoes sensible cooling whenever it passes over a surface that is ata temperature less than the dry bulb temperature of the air but greater than the dew point temperature. Thus sensible cooling can be achieved by passing the air over cooling coil like evaporating coil of the refrigeration cycle or secondary brine coil.

During the process, the specific humidity remains constant and dry bulb temperature decreases, approaching the mean effective surface temperature. On a psychrometric chart the process will appear as ahorizontal line 1–2(Fig. H), where point 3 represents the effective surface temperature. For this process:

$$\text{By-pass factor BF} = \frac{t_{db_2} - t_{db_3}}{t_{db_1} - t_{db_3}}$$

The heat removed from air can be obtained from the enthalpy difference (h_1-h_2) or from humid specific heat multiplied by the temperature difference(t_{db1}-t_{db2}).

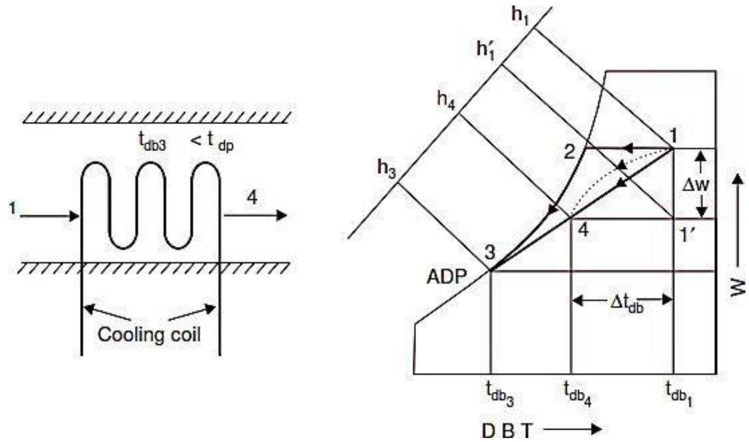


Sensible cooling.

Cooling and Dehumidification

Whenever air is made to pass over a surface or through a spray of water that is at a temperature less than the dew point temperature of the air, condensation of some of the water vapour in air will occur simultaneously with the sensible cooling process. Any air that comes into sufficient contact with the cooling surface will be reduced in temperature to the mean surface temperature along a path such as 1-2-3 , with condensation and therefore dehumidification occurring between points 2 and 3. The air that does not contact the surface will be finally cooled bymixing with the portion that did, and the final state point will somewhere on the straight line connecting points 1 and 3. The actual path of air during the path will not be straight line shown but will be something similarly to the curved dashed line 1–4.

It will result from a continuous mixing of air which is connecting a particular part of the coil and air which is by passing it. It is convenient, however to analyse the problem with the straight lineshown, and to assume that the final air state results from the mixing of air that has completely bypassed the coil with air that has been cooled to the mean effective surface temperature. If there is enough contact between air and surface for all the air to come to the mean surface temperature, theprocess is one of zero by pass. In any practical system, complete saturation is not obtained andfinal state will be a point such as 4 in Fig. I with an equivalent by pass factor equal to length 3−4 or processes involving condensation, the effective length 3−1 surface temperature, e.g t_{db3}i



Cooling and dehumidification

I is called **apparatus dew point**' (ADP). The final state point of air passing through a cooling and dehumidifying apparatus is in effect a mixture condition that results from mixing the fraction of the air, which is equal to the equivalent by- pass factor (BF) and is at initial state point and the remaining fraction which is equal to one minus by pass factor (1–BF) and is saturated at theapparatus dew point (ADP).

Total heat removed from the air is given by

$$Q_t = h_1 - h_4 = (h_1 - h_1') + (h_1' - h_4)$$
$$= Q_L + Q_S$$

where, W_L = Latent heat removed $(h_1 - h_1')$, and
Q_S = Sensible heat removed $(h_1' - h_4)$

The ratio $\frac{Q_S}{Q_L}$ *is called sensible heat factor* (SHF) Or *sensible heat ratio* (SHR)

$$\therefore \qquad \text{SHF} = \frac{Q_S}{Q_L + Q_S}$$

The ratio fixes the slope of the line 1—4 on the psychrometric chart. Sensible heat factor slope lines are given on the psychrometric chart. If the initial condition and SHF are known for the given process, then the process line can be drawn through the given initial condition at a slope given by SHF on the psychrometric chart.

The capacity of the cooling coil in *tonnes* of refrigeration is given by,

$$\text{Capacity in TR} = \frac{m_a(h_1 - h_4) \times 60}{14000},$$

Where m_a= mass of air, kg/min and h = enthalpy in kJ/kg of air.

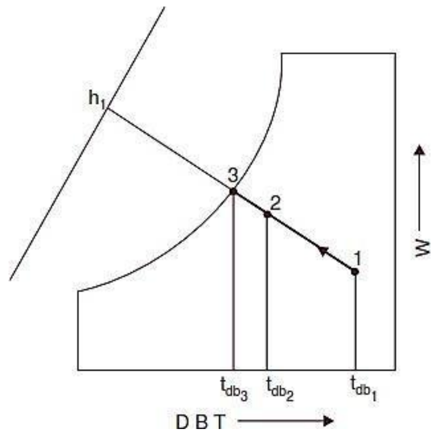
Cooling and Humidification:

If unsaturated air is passed through a spray of continuously recirculated water, the specific humidity will increase while the dry bulb temperature decreases. This is the process of **adiabatic saturation or evaporative cooling.** This process is one of constant adiabatic- saturation

temperature and for all practical purposes, one of constant wet bulb temperature. The process is illustrated as path 1-2 on Fig. J, with wet bulb temperature of air being that of point 3, which is also equilibrium temperature of the recirculated water if there is sufficient contact between air and spray, the air will leave at a condition very close to that of point 3. The concept of equivalent by pass can be applied to this process but another term is more used to describe the performance of a humidifying apparatus. It is the **'saturating'** or **'humidifying efficiency'** which is defined as the ratio of dry-bulb temperature decrease to the entering wet bulb depression usually expressed as percentage. Thus, from Fig. J, the saturating efficiency is :

$$\% \eta_{sat} = \left(\frac{t_{db_1} - t_{db_2}}{t_{db_1} - t_{db_3}} \right) \times 100$$

As a fraction, it is equal to one minus the by pass factor for the process. This adiabatic process, for all practical purposes, is line of constant enthalpy. The moisture added can be obtained from the increase in specific humidity.



Cooling and humidification.

Heating and Dehumidification:

If air is passed over a solid absorbent surface or through a liquid absorbent spray simultaneous heating and dehumidification is accompanied. In either case the dehumidification results from adsorbent or absorbent having a lower water vapour pressure than air. Moisture is condensed out ofthe air, and con sequently the latent heat of condensation is liberated, causing sensible heating of air. If these were the only energies involved, the process would be the inverse of the adiabatic saturation process. There is, however, an additional energy absorbed or liberated by the active material, termed the heat of adsorption or absorption. For the solid adsorbents used commercially, such as silica gel or activated alumina, and for the more common liquid absorbents, such as solutions of organic salts or inorganic compounds like ethylene, glycol, heat is involved and results in additional sensible heating. Thus the path lies above a constant wet bulb line on the psychrometric chart such as path 1-2 in Fig. K

Heating and Humidification:

If air is passed through a humidifier which has heated water sprays instead of simply recirculated spray, the air is humidified and may be heated, cooled or unchanged in temperature. In such a process the air increases in specific humidity and the enthalpy, and the dry bulb temperature will increase or decrease according to the initial temperature of the air and that of the spray. If sufficient water is supplied relative to the mass flow of air, the air will approach saturation at water temperature. Examples of such processes are shown on Fig. L

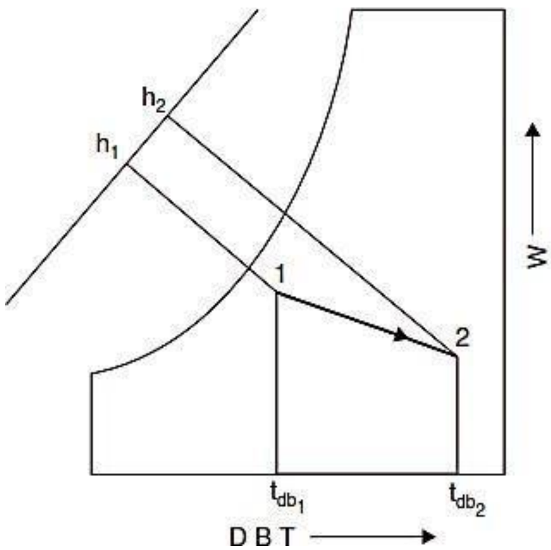


Fig. K. Heating and dehumidification.

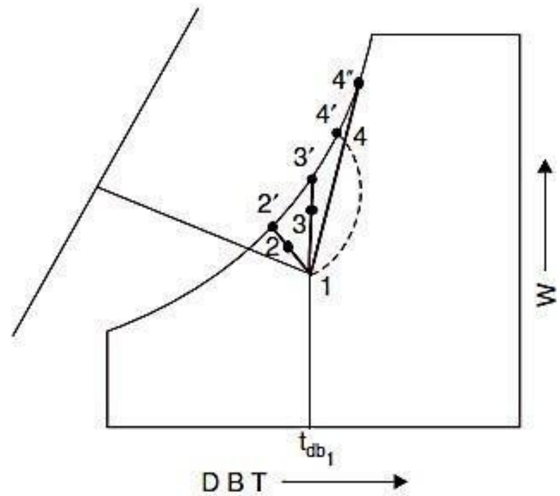


Fig. L. Heating and humidification.

Process 1-2 : It denotes the cases in which the temperature of the heated spray water is less than theair DBT

Process 1-3 : It denotes the cases in which the temperature is equal to the air DBT.

Process1-4 : It denotes the cases in which a spray temperature is greater than air DBT.

As in the case of adiabatic saturation, the degree to which the process approaches saturation can be expressed in terms of the by-pass factor or a saturating efficiency.

If the water rate relative to the air quantity is smaller, the water temperature will drop significantly during the process. The resultant process will be a curved line such as the dashed 1-4 where 4 represents the leaving water temperature.

Note. It is possible to accomplish heating and humidification by evaporation from an open pan of heated water, or by direct injection of heated water or steam. The latter is more common. The process line for it is of little value because the process is essentially an instantaneous mixing of steam and the air. The final state point of the air can be found, however by making a humidity and enthalpy balance for the process. The solution of such a problem usually involves cut-and-try procedure.

An air conditioning system is an electrical device that is purposely installed for the removal of heat and moisture from the interior of an occupied space. It is a process that is commonly used to achieve a more comfortable environment, basically for humans and other animals.

An air conditioning system is also used to cool and dehumidify rooms that contain heat-producing electronic devices, such as computer servers, and power amplifiers. It is also used in space that contains delicate products like artwork.

Cooling is generally achieved in the air conditioning system through a refrigeration cycle, but sometimes evaporation or free cooling is employed. The system can also be made based on desiccants (chemicals that eliminate moisture from the air). Most AC system stores and rejects heat in pipes called subterranean.

Functions of the air conditioning system

Below are the major functions of an air conditioning system in modern houses:

- The primary purpose of air conditioning is to create a room climate comfortable for humans.
- Some special type of conditioning system is used to cool the temperature of electric devices.
- It controls the humidity of a room as 30 to 65% is permitted while the temperature should be between 20 and 26 degrees Celsius.

- Air conditioning system affects the room air to comfort people and their productivity is not impeded.
- The condition of the air is characterized by temperature, pressure, and humidity. The air pressure is not changed.
- Air conditioning systems can be for heating, dehumidifying, cooling, and humidifying.

Components of an air conditioner

Compressor:

The compressor is the engine of the system as it works with a fluid that easily transforms the gas into a liquid. Its primary function is to convert low-pressure gas into high-pressure gas, which has a high temperature. in its working, the gap regions between molecules get narrowed down with a produced energized gas. This energized gas which is also known as a refrigerant is released from the compressor and enters the condenser.

Condenser Coil:

The condenser coil contains a fan that cools the high-pressure gas and converts it into a liquid. The product obtained is used by the evaporator to do the work. The compressor and condenser are ones placed outside of the house.

Thermostat:

The thermostat maintains the temperature of an air conditioning system as it regulates the heat energy inside and outside of it. depending on the design, a thermostat can be set manually or automatically.

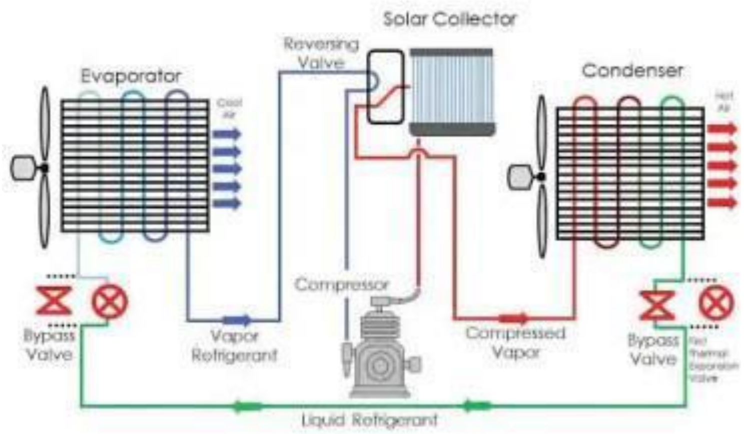
Evaporator:

Evaporators are air conditioning components found inside the house near the furnace. It’s connected to the condenser with an extremely thin pipe. The high-pressure gas is transformed into a low-pressure liquid of the air conditioner. The liquid is then converted to gas due to the decreasing pressure. The fluid or refrigerant is what takes away the heat from the and cools it off. The evaporator releases the fluid in the form of a gas in order to get compressed again by the compressor. All of these happen in a cyclic fashion.

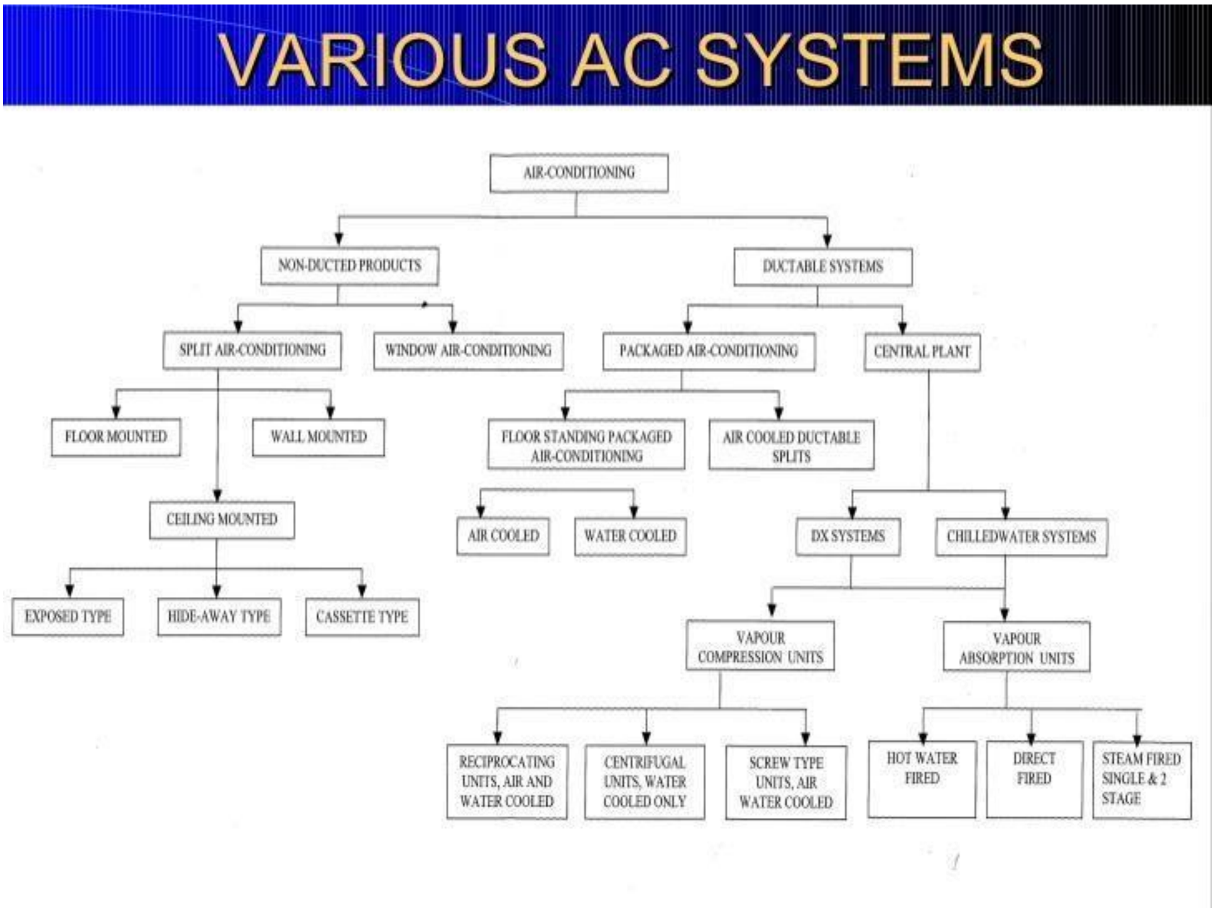
Air Handler and Blowing Unit:

These air conditioner components work together to draw the air to the evaporator and distribute cool air over the room. A duct system facilitates the passage of airflow in the room.

The complete diagram of an air conditioning system:



CLASSIFICATION OF AIR-CONDITIONING SYSTEM:



1. WINDOW AIR CONDITIONING SYSTEM

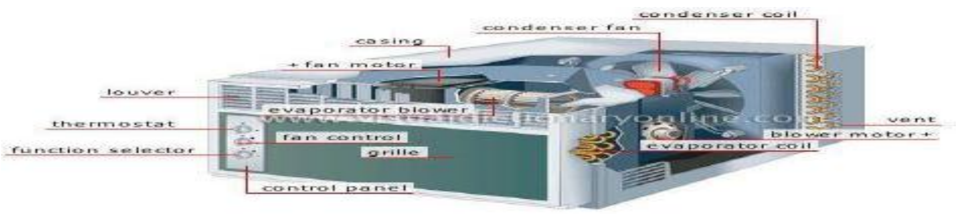
Windows air conditioners are one of the most widely used types of air conditioners because they are the simplest form of the air conditioning systems. Window air conditioner comprises of the rigid base on which all the parts of the window air conditioner are assembled. The base is assembled inside the casing which is fitted into the wall or the window of the room in which the air conditioner is fitted.

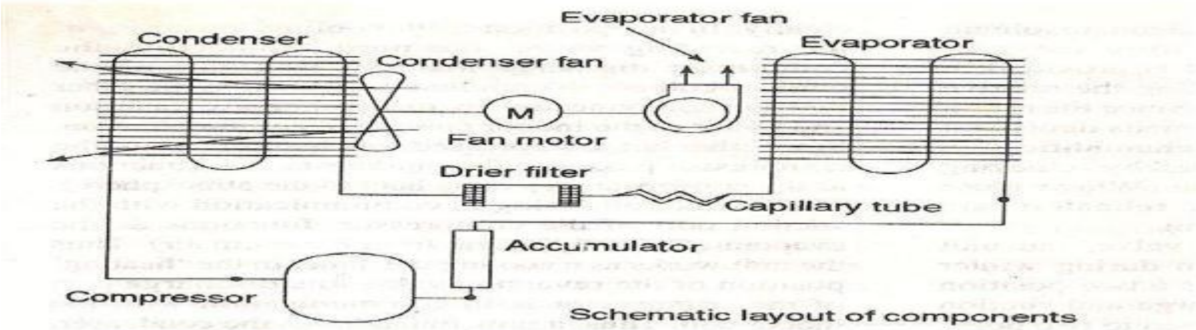
The whole assembly of the window air conditioner can be divided into two compartments: the room side, which is also the cooling side and the outdoor side from where the heat absorbed by the room air is liberated to the atmosphere. The room side and outdoor side are separated from each other by an insulated partition enclosed inside the window air conditioner assembly (refer fig 1 below).

In the front of the window air conditioner on the room side there is beautifully decorated front panel on which the supply and return air grills are fitted (the whole front panel itself is commonly called as front grill). The louvers fitted in the supply air grills are adjustable so as to supply the air in desired direction. There is also one opening in the grill that allows access to the control panel or operating panel in front of the window air conditioner.

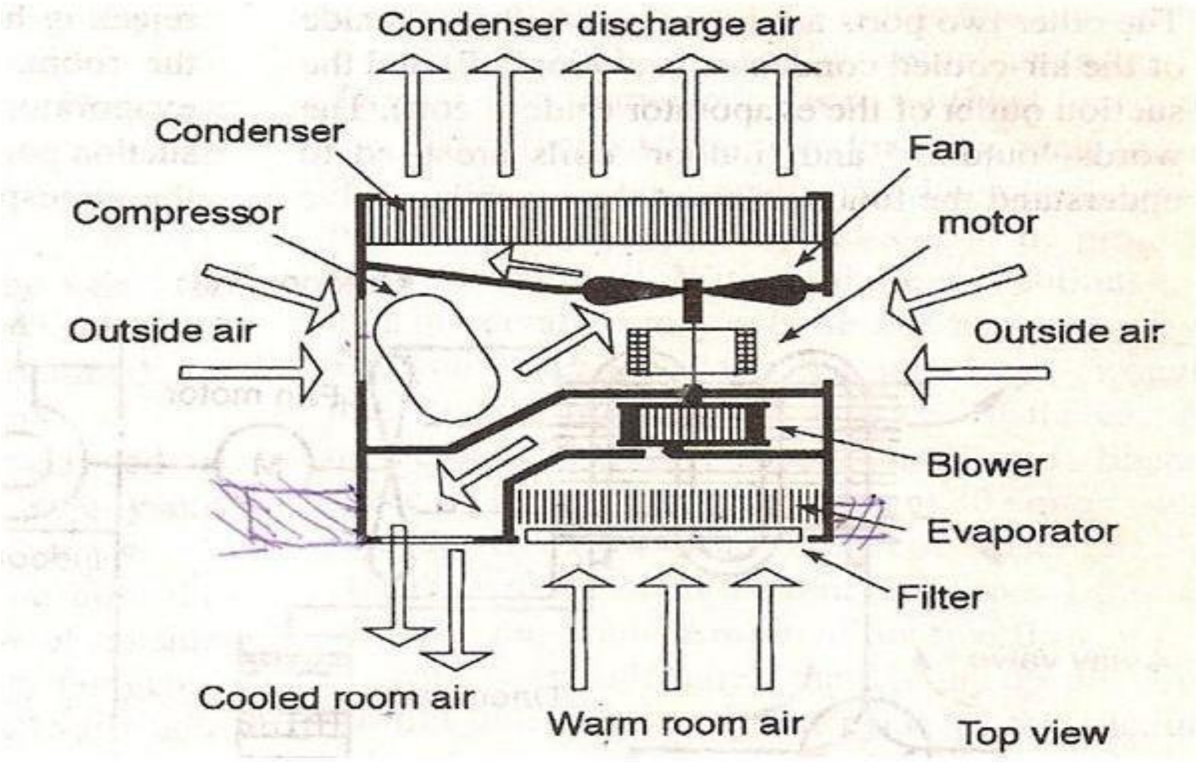
The various parts of the window air conditioner can be divided into following categories: the refrigeration system, air circulation system, ventilation system, control system, and the electrical protection system. All these have been discussed in details below along with the front panel and other parts.

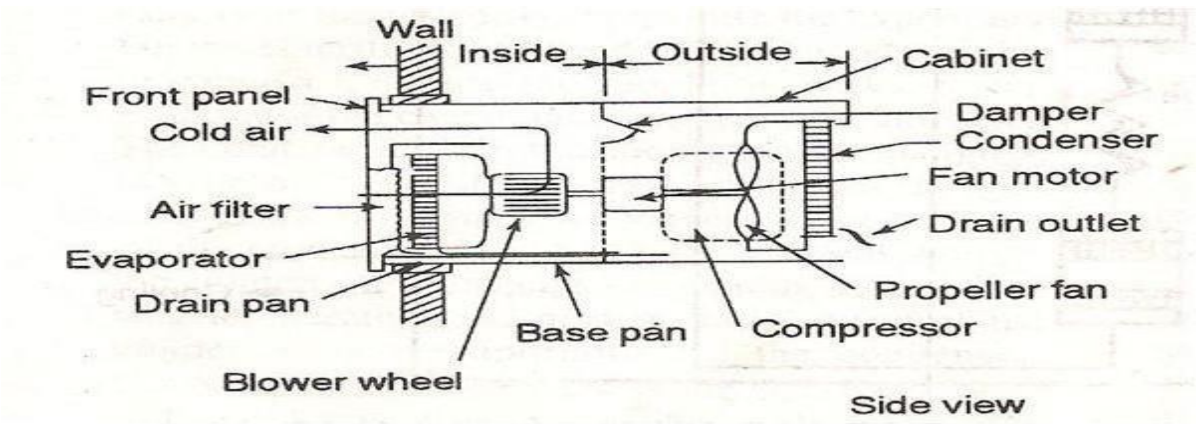
Window Air Conditioner





Schematic layout of components


Condenser discharge air
Condenser
Fan
Compressor
motor
Outside air
Outside air
Blower
Evaporator
Filter
Cooled room air
Warm room air
Top view


Wall
Inside
Outside
Cabinet
Front panel
Damper
Cold air
Condenser
Fan motor
Air filter
Drain outlet
Evaporator
Propeller fan
Drain pan
Base pan
Compressor
Blower wheel
Side view

The Refrigeration System of the Window Air Conditioner

The refrigeration system of the window air conditioner comprises of all the important parts of the refrigeration cycle. These include the compressor, condenser, expansion valve and the evaporator. All these components have been shown in fig 3 above. The refrigerant used in most of the window air conditioners is R22.

The compressor used in the window air conditioners is hermetically sealed type, which is portable one. This compressor has long life and it carries long warranty periods. In case of the maintenance problems it can be replaced easily from the company. The condenser is made up of copper tubing and it is cooled by the atmospheric air. The condenser is covered with the fins to enable faster heat transfer rate from it.

The capillary tubing made up of various rounds of the copper coil is used as the expansion valve in the window air conditioners. Just before the capillary there is drier filter that filters the refrigerant and also removes the moisture particles, if present in the refrigerant.

Like condenser, the evaporator is also made up of copper tubing of number of turns and is covered with the fins. The evaporator is also called as the cooling coil since the rooms air passes over it and gets cooled. Just in front of the evaporator there is air filter fitted in the front panel or front grill. As the room air is absorbed, it is first passed over the filter so that it gets filtered. The filtered air is then blown over the cooling coil and the chilled air is passed into the room.

The refrigerant after leaving the cooling coil enters the accumulator where it is accumulated and then it is again sucked by the compressor for recirculation over the whole cycle.

Air Circulation System of the Window Air Conditioner

The air circulation system of the window air conditioner comprises of the following parts (please refer fig 4 & 5).

1) Blower: This is the small blower that is fitted behind the evaporator or cooling coil inside the assembly of the window air conditioner system. The blower sucks the air from the room which first passes over the air filter and gets filtered. The air then passes over the cooling coil and gets chilled. The blower then blows this filtered and chilled air, which passesthrough the supply air compartment inside the window air conditioner assembly. This air is then delivered into the room from the supply air grill of the front panel.

2) Propeller fan or the condenser fan: The condenser fan is the forced draft type of propeller fan that sucks the atmospheric air and blows it over the condenser. The hot refrigerant inside the condenser gives up the heat to the atmospheric air and its temperature reduces.

3) Fan motor: The motor inside the window air conditioner assembly is located between the condenser and the evaporator coil. It has double shaft on one side of which the blower is fitted and on the other side the condenser fan is fitted. This makes the whole assembly of the blower, the condenser fan and the motor highly compact.

Control System of the Window Air Conditioners

In front of the window air conditioner there is control panel or the operating panel that carries various control buttons. This control panel can be easily accessed from the front panel of the window air conditioner. The three important parameters that are to be controlled inside the window air conditioner are the room air temperature, the flow rate of the air and the direction of the air. All these controls are discussed below and also shown in figure 1.

1) **Thermostat for controlling the room air temperature**: For controlling the temperature inside the room there is thermostat. The thermostat sensor is connected directly to the cooling coil to sense its temperature. The thermostat is also connected to the switch in control panel and it has the knob for setting the temperature. The person inside the room can easily set the temperature required by rotating this knob. In the modern window air conditioners, there is printed circuit board (PCB) to which the thermostat is connected. This PCB has remote sensor so the setting of the thermostat can be easily changed by theremote control.

2) **Air flow rate inside the room**: The motor connected to the blower is of multispeed type, so one can change the speed of the motor. As the speed of the motor changes the amount of air sucked by it and blown by it also changes and so the amount of air delivered in the room also changes. The speed of the motor can be changed by the knob provided in the control panel or by the remote control if the air conditioner has PCB fitted into it.

3) Direction of the air flow inside the room: In front panel of the window air conditioner there are horizontal lovers. Additionally, in front of the air conditioner body and attached to it are the vertical louvers. The chilled air from blown by the blower passes into the room through these louvers. The horizontal louvers in the front panel enable changing the verticalmotion direction of the air inside the room. The position of these lovers can be changed manually.

The vertical louvers enable changing the horizontal motion of the air inside the room. These louvers are connected to the small motor. The vertical louvers can be kept moving in the vertical direction so that the air flows throughout the room uniformly or they can be kept in the fixed direction so that the air flows in particular desired direction only. The operation of the motor of the vertical lovers can be controlled by the small button on the control panel of the window air conditioner (refer the figure below especially figure 5 & 6). In case of the automatic window air conditioner with PCB, the motion of the vertical lovers can be controlled by the remote. The horizontal louvers in the front panel and the vertical louvers enable fine control of the distribution of air inside the room.

Front Panel of the Window Air Conditioner

The very front covering of the window air conditioner assembly that is visible to the person is the front panel (many times called as the front grill). For novice people the front panel itself is the whole air conditioner. These days lots of importance is being given to the aesthetics of the front panel so the window air conditioner also serves as the decorative item inside the room. The front panel has two important compartments: return air and supply air compartments. These are described below (please refer the figure above, especially figure 5 & 6).

1) **Return air compartment:** The return air compartment of the front panel comprises of the return air grill and the air filter. When the blower sucks the air, it is first over the return air grill and then over the air filter. Since the return air from the room comes inside the air conditioner via this part of the front panel, it is called as return air compartment of the grill.

2) **Supply air compartment**: The supply air compartment of the front panel comprises of the horizontal louvers as described above. The horizontal louvers help changing the vertical direction of air inside the room and their position can be changed manually as per the requirement.

There is another opening in the front panel that provides access to the control panel of the window air conditioner. The front panel of the window air conditioner can be removed easily for carrying out the maintenance works. If you want to remove the filter from the front panel, one can easily slide it out from the side without removing the whole panel.

Drainage System of the Window Air Conditioner

When the room air is chilled by the cooling coil the dew from the air is accumulated on the coil. This dew drops in the bottom base of the window air conditioner and it has to be removed by some system else the water will leak inside the room. For collecting the dew, the window air conditioned is installed with slightly tilted angle toward outside due to whichall the dew water gets collected towards the back. There is small opening at the end for the drainage of this water. This opening can be left open or it can be connected to the small drain pan and the piping so that the water is drained out easily.

Electrical Protection System

The hermetically sealed compressor has motor fitted inside it. The compressor is the most important part of the air conditioning system so the motor connected to it should be protected against getting overheated and burning. Due to running of the air conditioner for long time, sometimes the winding gets overheated. To prevent the burning of the coil there is thermostat that senses the temperature of the coil. When the coil temperature reaches certain level, it trips the compressor and stops it until it gets cooled and restarts only after certain lower limit of the temperature is attained.

Air Filter

The air filter is very important part of the window air conditioner. It performs one of the most important functions of the window air conditioner, which is cleaning of the air. The air cleaner is fitted in the front of the air conditioner in the front panel. The room air first passes over the air filter and then over the cooling coil. Thus the filtered and chilled air is passed to the room. For proper working of the window air conditioner system cleaning the air filter once every two weeks is very important. If this is not done dust will get accumulated in the filter and the air will not be absorbed and supplied by the AC. Due to dirtthe temperature of the evaporator may become too low resulting in the formation of iceand ultimately complete blockage of the cooling coil.

Working of Window AC

Now that we have seen the various **parts of the window air conditioner**, let us see its working. For understanding the working of the window AC please refer the figures given below. The working of window air conditioner can be explained by separately considering the two cycles of air: room air cycle and the hot air cycle. The compartments of the room and hot air are separated by an insulated partition inside the body of the air conditioner. The setting of thermostat and its working has also been explained in the discussions below.

Working of Window AC

Room Air Cycle

The air moving inside the room and in the front part of the air conditioner where the cooling coil is located is considered to be the room air. When the window AC is started the blower starts immediately and after a few seconds the compressor also starts. The evaporator coil or the cooling gets cooled as soon as the compressor is started.

The blower behind the cooling coil starts sucking the room air, which is at high temperature and also carries the dirt and dust particles. On its path towards the blower, the room air first passes through the filter where the dirt and dust particles from it get removed.

The air then passes over the cooling coil where two processes occur. Firstly, since the temperature of the cooling coil is much lesser than the room air, the refrigerant inside the cooling coil absorbs the heat from the air. Due to this the temperature of the room air becomes very low, that is the air becomes chilled.

Secondly, due to reduction in the temperature of the air, some dew is formed on the surface of the cooling coil. This is because the temperature of the cooling coil is lower than the dew point temperature of the air. Thus the moisture from the air is removed so the relative humidity of the air reduces. Thus when the room air passes over the cooling coil its temperature and relative humidity reduces.

This air at low temperature and low humidity is sucked by the blower and it blows it at high pressure. The chilled air then passes through small duct inside the air conditioner and it is then thrown outside the air conditioner through the opening in the front panel or the grill. This chilled air then enters the room and chills the room maintaining low temperature and low humidity inside the room.

The cool air inside the room absorbs the heat and also the moisture and so its temperature and moisture content becomes high. This air is again sucked by the blower and the cycle repeats. Some outside air also gets mixed with this room air. Since this air is sent back to the blower, it is also called as the return room air. In this way the cycle of this return air or the room air keeps on repeating.

Hot Air Cycle

The hot air cycle includes the atmospheric air that is used for cooling the condenser. The condenser of the window air conditioner is exposed to the external atmosphere. The propeller fan located behind the condenser sucks the atmospheric at high temperature and it blows the air over the condenser.

The refrigerant inside the condenser is at very high temperature and it has to be cooled to produce the desired cooling effect. When the atmospheric air passes over the condenser, it absorbs the heat from the refrigerant and its temperature increases. The atmospheric air is already at high temperature and after absorbing the condenser heat, its temperature becomes even higher. The person standing behind the condenser of the window AC can clearly feel the heat of this hot air. Since the temperature of this air is very high, this is called as hot air cycle.

The refrigerant after getting cooled enters the expansion valve and then the evaporator. On the other hand, the hot mixes with the atmosphere and then the fresh atmospheric air is absorbed by the propeller fan and blown over the condenser. This cycle of the hot air continues.

Setting the Room Temperature with Thermostat

The temperature inside the room can be set by using the thermostat knob or the remote control. If your window AC has knob, you would see some numbers or the round scale round the knob that will enable setting the temperature desired in the room. If your AC has come with the remote control, then you will see the room temperature on the digital indicator placed in the control panel of the window AC. You would probably also see the temperature on the small screen of the remote control. With the buttons provided on the remote control you can easily set the temperature inside the room.

When the desired temperature is attained inside the room, the thermostat stops the compressor of the AC. After some time when the temperature of the air becomes higher again, the thermostat restarts the compressor to produce the cooling effect. One should set the thermostat at the required temperature and not keep it at very low temperature to avoid high electricity bills.

Setting the Speed of the Air

The Speed of the air can be set by the fan motor button provided on the control panel. If your AC has the remote control you can see the fan speed button on it. The motor of the blower is of multispeed that type that enable changing the speed or the flow of air insidethe room.

Important Part of the Window AC: Air Filter

The filter is a very important part of the AC since it cleans the air before it enters the room. For proper functioning of the filter it is very important to clean it every two weeks. If this is not done the filter will get choked and it won't be able to clean the air. Soon the dirt will also enter the evaporator coil and choke it. If this happens the AC will stop functioning and cleaning the evaporator becomes a very tedious process. Cleaning the filter hardly takes five minutes, do it regularly and enjoy the comforts of window AC on long-term basis.

2. SPLIT A/C

A split air conditioner consists of two main parts – a compressor located outside and an inside air outlet unit. Unlike a system that requires a series of ductwork networked throughout the ceiling, split air conditioners rely on a set of pipes to connect the outdoor to the inside air unit which is why there are referred to as a ductless mini-split air conditioner installation. Refrigerant is dispersed through the copper pipes that cycle through the systemto generate either heated or cold air.

There are two main parts of the split air conditioner. These are:

1. **Outdoor unit**: This unit houses important components of the air conditioner like the compressor, condenser coil and also the expansion coil or capillary tubing. This unit is installed outside the room or office space which is to be cooled. The compressor is the maximum noise making part of the air conditioner, and since in the split air conditioner, it is located outside the room, the major source of noise is eliminated.In the outdoor unit there is a fan that blows air over the condenser thus cooling the compressed Freon gas in it. This gas passes through the expansion coil and gets

converted into low pressure, low temperature partial gas and partial liquid Freon fluid.

2. **Indoor unit**: It is the indoor unit that produces the cooling effect inside the room or the office. This is a beautiful looking tall unit usually white in color, though these days a number of stylish models of the indoor unit are being launched. The indoor unit houses the evaporator coil or the cooling coil, a long blower and the filter. After passing from the expansion coil, the chilled Freon fluid enters the cooling coil. The blower sucks the hot, humid and filtered air from the room and it blows it over the cooling coil. As the air passes over cooling coil its temperature reduces drastically and also loses the excess moisture. The cool and dry air enters the room and maintains comfortable conditions of around 25-27 degree Celsius as per the requirements.

The temperature inside the space can be maintained by thermostat setting. The setting should be such that comfortable conditions are maintained inside the room, and there is also chance for the compressor to trip at regular intervals. If the compressor keeps running continuously without break, its life will reduce.

These days multi-split air conditioners are also being used commonly. In units for one outdoor unit there are two indoor units which can be placed in two different rooms or at two different locations inside a large room.

Since there is long distance between the indoor and the outdoor unit, there is always loss of some cooling effect; hence for the same tonnage, split air conditioners produce somewhat less cooling effect than **window air conditioners**. However, with modern insulation material this gap has been reducing between the two. In any case, there are number of instances where there is just no alternative to the split air conditioners.

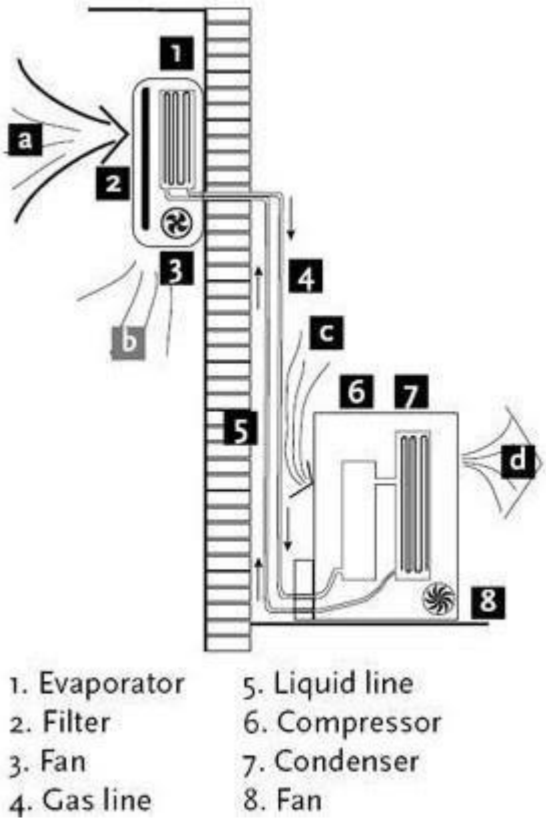
Introduction

The split air conditioner is one of the most widely used type of the air conditioners. Earlier window air conditioner was used most widely, but the split air conditioner is now catching up with it. The major reasons behind the popularity if split air conditioner are their silent operation and elegant looks. Another advantage of the split air conditioner is that you don't have to make the hole in the wall of the air conditioner and destroy the beauty of the room.

These days the indoor units of the split air conditioner are available in wide range of color and designs.

There are two main parts of the split air conditioner: the indoor unit and the outdoor unit (see fig below). The indoor unit of the split AC is installed inside the room that is to be air conditioned or cooled while the outdoor unit is installed outside the room in open space where the unit can be installed and maintained easily. Apart from these two major parts there is copper tubing connecting the indoor and the outdoor units. Let us see the various parts of the indoor and the outdoor units of the split ACs.

Parts of Split Conditioner



Outdoor Unit

As mentioned previously the outdoor unit is installed outside the room to be air conditioned in the open space. In outdoor unit lots of heat is generated inside the compressor and the condenser, hence there should be sufficient flow of the air around it. The outdoor unit is usually installed at the height above the height of the indoor unit inside the room though in many cases the outdoor is also installed at level below the indoor unit.

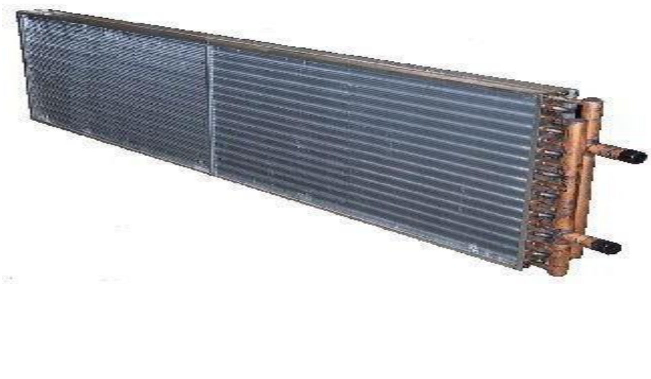
The outdoor unit contains the important parts of the split AC like compressor, condenser, expansion valve etc. Let us see these parts in more details:

1. Compressor:

The compressor is most important part of the any air conditioner. It compresses the refrigerant and increases its pressure before sending it to the condenser. The size of the compressor varies depending on the desired air conditioning load. In most of the domestic split air conditioners hermetically sealed type of compressor is used. In such compressors the motor used for driving the shaft is located inside the sealed unit and it is not visible externally. External power has to be supplied to the compressor, which is utilized for compressing the refrigerant and during this process lots of heat is generated in the compressor, which has to be removed by some means.

2. Condenser:

The condenser used in the outdoor unit of split air conditioners is the coiled copper tubing with one or more rows depending on the size of the air conditioning unit and the compressor. Greater the tonnage of the air conditioner and the compressor more are the coil turns and rows. The high temperature and high pressure refrigerant from the compressor comes in the condenser where it has to give up the heat. The tubing is made up of copper since it rate of conduction of heat is high. The condenser is also covered with the aluminum fins so that the heat from the refrigerant can be removed at more faster rate.



3. Condenser Cooling Fan:

The heat generated within the compressor has to be thrown out else the compressor will get too hot in the long run and its motor coils will burn leading to complete breakdown of the compressor and the whole air conditioner. Further, the refrigerant within the condensercoil has to be cooled so that after expansion its temperature become low enough to produce the cooling effect. The condenser cooling fan is an ordinary fan with three or four blades and is driven by a motor. The cooling fan is located in front of the compressor and the condenser coil. As the blades of the fan rotate it absorbs the surrounding air from the open space and blows it over the compressor and the condenser with the aluminum fins thus cooling them. The hot air is thrown back to the open space and the circulation of air continues unhindered.

4. Expansion Valve:

The expansion valve is usually a copper capillary tubing with several rounds of coils. In the split air conditioners of bigger capacities thermostatic expansion valve is used which is operated electronically automatically. The high pressure and medium temperature refrigerant leaves the condenser and enters the expansion valve, where its temperature and pressure drops suddenly.

Refrigerant Piping or Tubing

The refrigerant piping is made up of copper tubing and it connects the indoor and the outdoor unit (see images above). The refrigerant at low temperature and low pressure leaves the expansion valve and enters the copper tubing, which is connected to the evaporator or the cooling coil at the other end.

The distance between the indoor and the outdoor unit can be short or long depending on the distance at which the open space is available in the home or office building. The longer the distance longer is the refrigerant piping between the two. When the refrigerant flows from the indoor unit to the outdoor unit in the tubing there is some loss of the coolingeffect on the way, hence the distance between the indoor and the outdoor unit should be kept as minimum as possible. For the distance up to 15 meters there is not much appreciable loss of the cooling effect, however beyond that the losses become higher.

The refrigerant inside the tubing is at very low temperature and length of piping between and outdoor unit and indoor unit is quite long. Further, the tubing is exposed to the open atmosphere which is at very high temperature. Due to this, if the tubing is left uncovered all the cooling effect will be lost to the open atmosphere and by the time the refrigerant enters the cooling coil its temperature will already be too high and the purpose of producing the cooling effect will not be served. To avoid this, the refrigerant tubing connecting the indoor and the outdoor unit is covered with the insulation. This prevents the loss of the cooling effect to the atmosphere and low temperature refrigerant will produce the desired cooling effect inside the room.

After producing the cooling effect inside the room in the indoor unit, the refrigerant has to comeback to the outdoor unit for getting compressed and re-circulating. There is another refrigerant tubing that connects the indoor and the outdoor unit so that the refrigerant can travel from cooling coil back to the compressor. This tubing is also covered with insulation so that the refrigerant enters the compressor at minimum possible temperature to increase the refrigeration efficiency of the air conditioner. Thus there are two tubing connecting the indoor and the outdoor unit and both are covered with the insulation tape.

The refrigerant tubing are made up of copper since it is highly ductile and malleable element. The tubing can be easily manufactured from this material and they are flexible enough so they can turned into angles and coiled easily. The copper tubing used for condenser and evaporator facilitate high rate of heat conduction.

Wall Mounted Indoor Unit

It is the indoor unit that produces the cooling effect inside the room. The indoor unit of the split air conditioner is a box type housing in which all the important parts of the air conditioner are enclosed. The most common type of the indoor unit is the wall mounted type though other types like ceiling mounted and floor mounted are also used. We shall discuss all these types in separate articles, here we shall discuss the wall mounted type of the indoor unit.

These days the companies give utmost importance to the looks and aesthetics of the indoor unit. In the last couple few years the purpose of the indoor unit has changed from being a mere cooling effect producing devise to a beautiful looking cooling devise adding to the overall aesthetics of the room. This is one of the major reasons that the popularity of the split units has increased tremendously in the last few years. Let us see the various parts enclosed inside the indoor unit of the split air conditioner:

1. Evaporator Coil or the Cooling Coil:

The cooling coil is a copper coil made of number turns of the copper tubing with one or more rows depending on the capacity of the air conditioning system. The cooling coil is covered with the aluminum fins so that the maximum amount of heat can be transferred from the coil to the air inside the room.

The refrigerant from the tubing at very low temperature and very low pressure enters the cooling coil. The blower absorbs the hot room air or the atmospheric air and in doing so the air passes over the cooling coil which leads to the cooling of the air. This air is then blown to the room where the cooling effect has to be produced. The air, after producing the cooling effect is again sucked by the blower and the process of cooling the room continues.

After absorbing the heat from the room air, the temperature of the refrigerant inside the cooling coil becomes high and it flows back through the return copper tubing to the compressor inside the outdoor unit. The refrigerant tubing supplying the refrigerant from the outdoor unit to the indoor unit and that supplying the refrigerant from indoor unit to the outdoor unit are both covered with the insulation tape.

2. Air Filter:

The air filter is very important part of the indoor unit. It removes all the dirt particles from the room air and helps supplying clean air to the room. The air filter in the wall mounted type of the indoor unit is placed just before the cooling coil. When the blower sucks the hot room air, it is first passed through the air filter and then though the cooling coil. Thus the clean air at low temperature is supplied into the room by the blower.

3. Cooling Fan or Blower:

Inside the indoor unit there is also a long blower that sucks the room air or the atmospheric air. It is an induced type of blower and while is sucks the room air it is passed over the cooling coil and the filter due to which the temperature of the air reduces and all the dirt from it is removed. The blower sucks the hot and unclean air from the room and supplies cool and clean air back. The shaft of the blower rotates inside the bushes and it is connected to a small multiple speed motor, thus the speed of the blower can be changed. When the fan speed is changed with the remote it is the speed of the blower that changes.

4. Drain Pipe:

Due to the low temperature refrigerant inside the cooling coil, its temperature is very low, usually much below the dew point temperature of the room air. When the room air is passed over the cooling due the suction force of the blower, the temperature of the air becomes very low and reaches levels below its dew point temperature. Due to this thewater vapor present in the air gets condensed and dew or water drops are formed on the surface of the cooling coil. These water drops fall off the cooling coil and are collected in a small space inside the indoor unit. To remove the water from this space the drain pipe is connected from this space extending to the some external place outside the room where water can be disposed off. Thus the drain pipe helps removing dew water collected inside the indoor unit.

To remove the water efficiently the indoor unit has to be a tilted by a very small angle of about 2 to 3 degrees so that the water can be collected in the space easily and drained out.If this angle is in opposite direction, all the water will get drained inside the room. Also, theif the tilt angle is too high, the indoor unit will shabby inside the room.

5. Louvers or Fins:

The cool air supplied by the blower is passed into the room through louvers. The louvers help changing the angle or direction in which the air needs to be supplied into the room as per the requirements. With louvers one easily change the direction in which the maximum amount of the cooled air has to be passed.

There are two types of louvers: horizontal and vertical. The horizontal louvers are connected to a small motor and there position can set by the remote control. Once can set a fixed position for the horizontal louvers so that chilled air is passed in a particular direction only or one can keep it in rotation mode so that the fresh air is supplied throughout the room. The vertical louvers are operated manually and one can easily change their position as per the requirements. The horizontal louvers control flow of air in upper and downward directions of the room, while vertical louvers control movement of air in left and right directions.

Floor Air Conditioner

Floor air conditioner is another type of air conditioner unit that is commonly used in places such as restaurants, halls, motels, data centers. The reason for its name is obvious in that it is basically standing on the floor. Other types of indoor units are the wall mounted, ducted, ceiling exposed, portable and window.

These fan coil units are all located indoor. The outdoor unit or condensers are located outside the building where the heat is rejected through the vapor compression cycle.

These two units are all that are required for the air conditioning system to function. They are connected to each other through the cooper tubes which are the gas and liquid lines.

The cooling capacity of the floor air conditioner can range from 24,000 Btu/hr to 200,000 Btu/hr depending on the model. There is also the **inverter** and non-inverter type with the inverter type commanding a better performance but more costly. Here are some of the brands that you may encounter for this type of unit.

As with many air conditioners equipment, you have a choice of the type of refrigerant that is being used.

R22 is the older and most cost effective but this refrigerant is not ozone-friendly and its production has been stopped. Due to recycling program, this refrigerant is still available but will be totally phase out by 2030.

The more ozone-friendly **refrigerant** include R407C and R410A. Many manufacturers are producing these air conditioners and selling them in the market.

However, it was discovered that these refrigerants can cause global warming. A newer refrigerant that has less global warming effect is the **R32**.

Ionizer

The ionizer feature is offered by some brands. These ionizer feature helps to get rid of pollen, dust and other particles to create a cleaner air in your room.

Auto-Restart Feature

This feature is widely available in most units but it is good to confirm its availability on the floor air conditioner unit that you have chosen. It basically remembers most of the settings that you set before the power failure occurred. Once the power is restored, it will be operating in its previous settings without you having to set it all over again.

Sound Pressure

Check the specifications of the **sound level** emitted by the indoor unit and outdoor unit. The indoor unit's sound level will be heard by the people in the room and should be as low as possible for the same capacity and fan speed. For instance, the maximum sound pressure could be 52dBA and minimum of 47dBA for a 24,000 Btu/hr unit.

Column air conditioner

Floor mounted cabinet air conditioner

FLOOR MOUNTED AIR CONDITIONER

Floor mounted split air conditioners can really be subdivided in to two types. Firstly **column air conditioners** which are large, high-capacity units (up to around 45000 BTU) used where a large room is to be cooled and where there may be building reasons why several smaller outlets cannot be used. Typical applications include lobbies, reception and waiting areas. The high output of these air conditioners means that they produce a strong flow of cool air which does not allow occupants to be in close proximity to the air conditioner.

Secondly, there are smaller cabinet style air conditioners which are far smaller, more like the dimensions of a storage heater than a tall upright freezer dimensions of a column air conditioner. Typically their rated capacities are up to about 15000BTU, and they are ideal for providing high-efficiency climate control to new extensions and conservatories. These both types of air conditioners are typically installed by refrigeration engineers as they do not usually have quick connect pipes, therefore the pipe work and cabling between the inside and outside elements is installed bespoke to the building and then the system is charged with refrigerant.

CEILING CASSETTE AIR CONDITIONER

Commonplace in offices with suspended ceilings, the ceiling cassette air conditioner, sometimes known as a cartridge air conditioner, is usually designed to be fitted within a one or two ceiling tile spaces. The bulk of the unit is unseen as it is above the ceiling line and the only visible part is the decorative lower facing with its central inlet grille and 4 edge outlet louvers. The main advantage of these units is aesthetics, but also that a centrally mounted unit can deliver an increased cooling (or heating) capacity across a wide area because of the air being distributed in 4 directions. Typically, a single ceiling cassette air conditioner can do the same job as 3 or 4 wall mounted units.

There is another type of ceiling air conditioner, which is an **under ceiling air conditioner** These are used where there is no suspended ceiling to install a cassette and where there is sufficient ceiling height to suspend an under ceiling unit. As these are designed to be entirely within a room, they are made to be reasonably aesthetic, however, the under ceiling air conditioners do inevitably look like overly cumbersome items to hang from a ceiling. Generally they are designed to lift air vertically into the unit and discharge treated air horizontally along the ceiling avoiding direct discharge directly onto occupants, and some allow air discharge from four sides.

Ceiling cassette air conditioner

Advantages

The main advantages of mini splits are their small size and flexibility for zoning or heating and cooling individual rooms. Many models can have as many as four indoor air handling units (for four zones or rooms) connected to one outdoor unit. The number depends onhow much heating or cooling is required for the building or each zone (which in turn is affected by how well the building is insulated). Each of the zones will have its own thermostat, so you only need to condition that space when it is occupied, saving energy and money.

Ductless mini split systems are also often easier to install than other types of space conditioning systems. For example, the hook-up between the outdoor and indoor units generally requires only a three-inch (~8 centimeter [cm]) hole through a wall for the conduit. Also, most manufacturers of this type of system can provide a variety of lengths of connecting conduits. So, if necessary, you can locate the outdoor unit as far away as 50 feet (~15 meters [m]) from the indoor evaporator. This makes it possible to cool rooms on the front side of a building house with the compressor in a more advantageous or inconspicuousplace on the outside of the building.

Since mini splits have no ducts, they avoid the energy losses associated with ductwork of central forced air systems. Duct losses can account for more than 30% of energy consumption for space conditioning, especially if the ducts are in an unconditioned space such as an attic.

Compared with other add-on systems, mini splits offer more flexibility in interior design options. The indoor air handlers can be suspended from a ceiling, mounted flush into a drop ceiling, or hung on a wall. Floor-standing models are also available. Most indoor units have profiles of about seven inches (~18 cm) deep and usually come with sleek, high-tech-looking jackets. Many also offer a remote control to make it easier to turn the system on and off when it's positioned high on a wall or suspended from a ceiling. Split-systems can also help to keep your home safer, because there is only a small hole in the wall. Through-the-walland window mounted room air-conditioners can provide an easy entrance for intruders.

Disadvantages

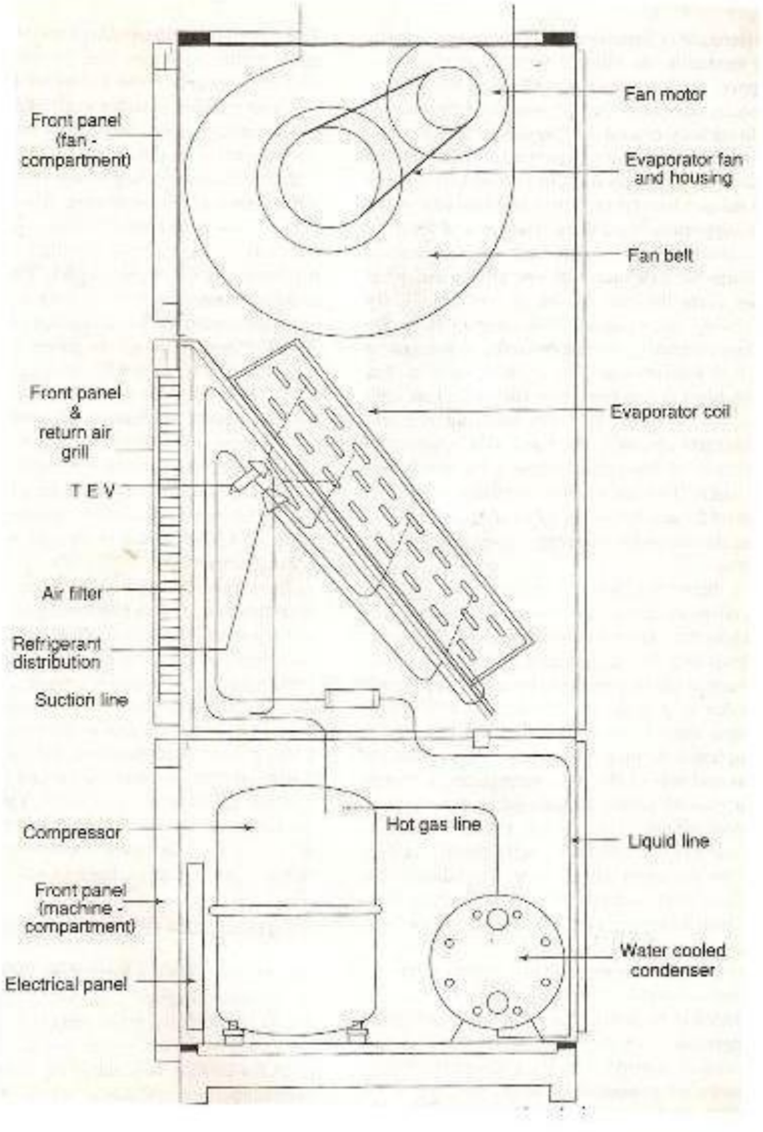
The primary disadvantage of mini splits is their cost. Such systems cost about $1,500 to $2,000 per ton (12,000 Btu per hour) of cooling capacity. This is about 30% more than central systems (not including ductwork) and may cost twice as much as window units of similar capacity.

The installer must also correctly size each indoor unit and judge the best location for its installation. Oversized or incorrectly located air-handlers often result in short-cycling, which wastes energy and does not provide proper temperature or humidity control. Too large a system is also more expensive to buy and operate.

Some people may not like the appearance of the indoor part of the system. While less obtrusive than a window room air conditioner, they seldom have the built-in look of a central system. There must also be a place to drain condensate water near the outdoor unit.

Qualified installers and service people for mini splits may not be easy to find. In addition, most conventional heating and cooling contractors have large investments in tools and training for sheet metal duct systems. They need to use (and charge for) these to earn a return on their investment, so they may not recommend ductless systems except where a ducted system would be difficult for them to install.

Packaged Air Conditioners



The window and split air conditioners are usually used for the small air conditioning capacities up to 5 tons. The central air conditioning systems are used for where the cooling loads extend beyond 20 tons. The packaged air conditioners are used for the cooling capacities in between these two extremes. The packaged air conditioners are available in the fixed rated capacities of 3, 5, 7, 10 and 15 tons. These units are used commonly in placeslike restaurants, telephone exchanges, homes, small halls, etc.

As the name implies, in the packaged air conditioners all the important components of the air conditioners are enclosed in a single casing like window AC. Thus the compressor, coolingcoil, air handling unit and the air filter are all housed in a single casing and assembled at the factory location.

Depending on the type of the cooling system used in these systems, the packaged air conditioners are divided into two types: ones with water cooled condenser and the ones with air cooled condensers. Both these systems have been described below:

Packaged Air Conditioners with Water Cooled Condenser

In these packaged air conditions the condenser is cooled by the water. The condenser is of shell and tube type, with refrigerant flowing along the tube side and the cooling water flowing along the shell side. The water has to be supplied continuously in these systems to maintain functioning of the air conditioning system.

The shell and tube type of condenser is compact in shape and it is enclosed in a single casing along with the compressor, expansion valve, and the air handling unit including the cooling coil or the evaporator. This whole packaged air conditioning unit externally looks like a box with the control panel located externally.

In the packaged units with the water cooled condenser, the compressor is located at the bottom along with the condenser (refer the figure below). Above these components the evaporator or the cooling coil is located. The air handling unit comprising of the centrifugal blower and the air filter is located above the cooling coil. The centrifugal blower has the capacity to handle large volume of air required for cooling a number of rooms. From the top of the package air conditioners the duct comes out that extends to the various rooms that are to be cooled.

All the components of this package AC are assembled at the factory site. The gas charging is also done at the factory thus one does not have to perform the complicated operations of the laying the piping, evacuation, gas charging, and leak testing at the site. The unit can be transported very easily to the site and is installed easily on the plane surface. Since all the components are assembled at the factory, the high quality of the packaged unit is ensured.

Package AC with Water Cooled Condenser

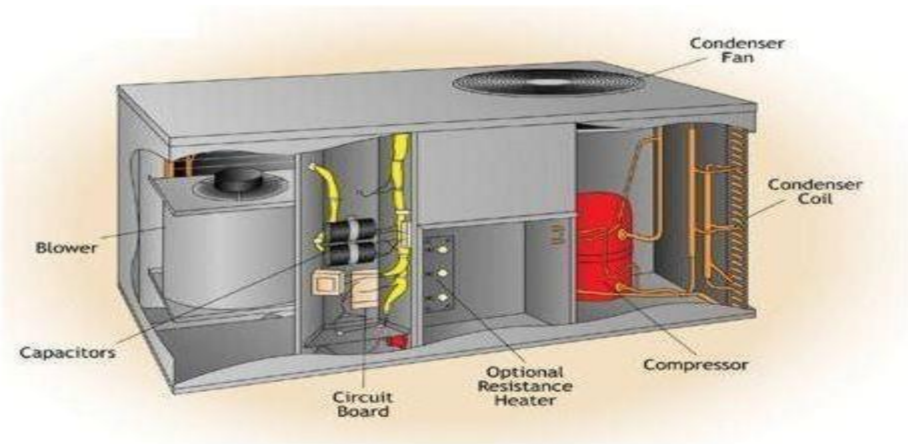
Packaged Air Conditioners with Air Cooled Condensers

In this packaged air conditioners the condenser of the refrigeration system is cooled by the atmospheric air. There is an outdoor unit that comprises of the important components like the compressor, condenser and in some cases the expansion valve (refer the figure below).

The outdoor unit can be kept on the terrace or any other open place where the free flow of the atmospheric air is available. The fan located inside this unit sucks the outside air and blows it over the condenser coil cooling it in the process. The condenser coil is made up of several turns of the copper tubing and it is finned externally. The packaged ACs with the air cooled condensers are used more commonly than the ones with water cooled condensers since air is freely available it is difficult maintain continuous flow of the water.

The cooling unit comprising of the expansion valve, evaporator, the air handling blower and the filter are located on the floor or hanged to the ceiling. The ducts coming from the cooling unit are connected to the various rooms that are to be cooled.

Package Air Conditioner Air Cooled Condenser



Central Air-Conditioning Plants

The central air conditioning plants or the systems are used when large buildings, hotels, theaters, airports, shopping malls etc are to be air conditioned completely. The window and split air conditioners are used for single rooms or small office spaces. If the whole building is to be cooled it is not economically viable to put window or split air conditioner in each and every room. Further, these small units cannot satisfactorily cool the large halls, auditoriums,receptions areas etc.

In the central air conditioning systems there is a plant room where large compressor, condenser, thermostatic expansion valve and the evaporator are kept in the large plant room. They perform all the functions as usual similar to a typical refrigeration system. However, all these parts are larger in size and have higher capacities. The compressor is of open reciprocating type with multiple cylinders and is cooled by the water just like the automobile engine. The compressor and the condenser are of shell and tube type. While in the small air conditioning system capillary is used as the expansion valve, in the central air conditioning systems thermostatic expansion valve is used.

The chilled is passed via the ducts to all the rooms, halls and other spaces that are to be air conditioned. Thus in all the rooms there is only the duct passing the chilled air and there are no individual cooling coils, and other parts of the refrigeration system in the rooms. What is we get in each room is the completely silent and highly effective air conditions system in theroom. Further, the amount of chilled air that is needed in the room can be controlled by the openings depending on the total heat load inside the room.

The central air conditioning systems are highly sophisticated applications of the air conditioning systems and many a times they tend to be complicated. It is due to this reason that there are very few companies in the world that specialize in these systems. In the modern era of computerization a number of additional electronic utilities have been added to the central conditioning systems.