C. V. RAMAN POLYTECHNIC

Lecture Notes

Subject name- Refrigeration and Air conditioning

Semester-5th , Branch- Mechanical Engineering

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Compressors

The compressor is the main moving component of the vapour-compression system. It provides the system with the force to draw the vapour from the evaporator, to force it into the condenser by creating a high pressure and to maintain circulation of the refrigerant. The compressor's work begins by its creating a low-pressure region on the low side of the system, which allows the low-temperature vapour to flow from the evaporator through the suction line to the compressor. The compressor then compresses the low-temperature vapour, raising its vapour pressure and temperature. This high-temperature and high-pressure vapour, containing the heat absorbed from the evaporator and during compression, is discharged to the condenser. The heat then flows from the hot vapour into the cooler air or water around the condenser.

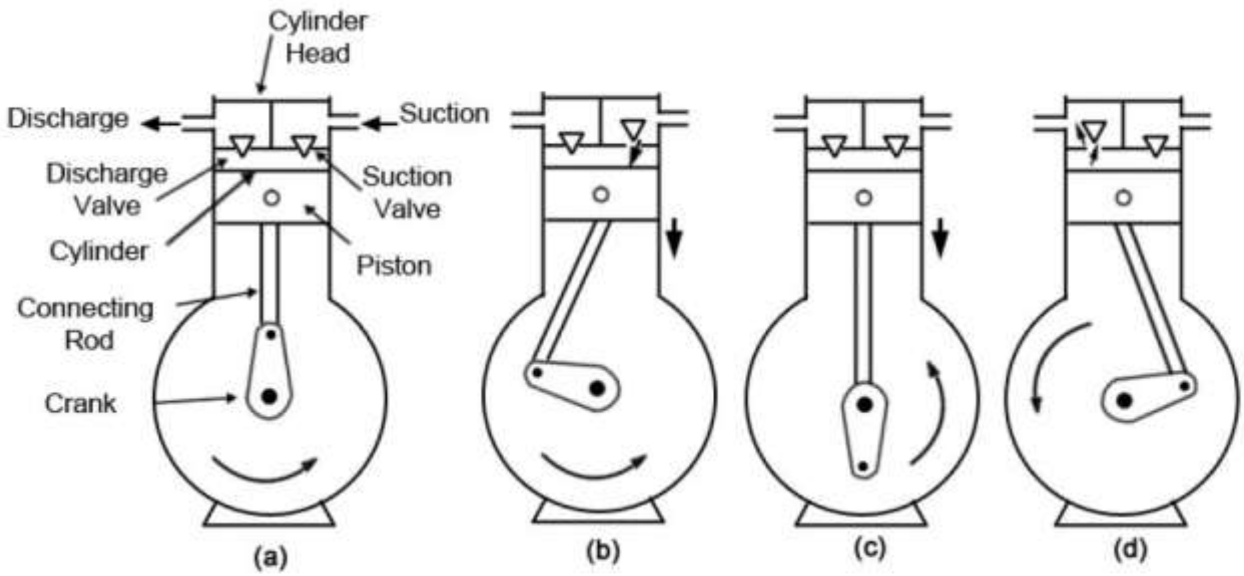
1. Reciprocating compressor

The compressor in which vapour refrigerant is compressed by reciprocating motion of the piston are called reciprocating compressor.

- Piston and cylinder arrangement to provide compressive force - like IC engines.
- Reciprocating motion of the piston due to external power compresses the refrigerant inside the cylinder.
- These compressors used for refrigerants which have low volume per kg such as ammonia, R-717, R-12, R-22, R-40.
- In single acting reciprocating compressor, the suction, compression and discharge of refrigerant takes place in one revolution of crank shaft. In double acting reciprocating compressor, the suction, compression takes place on both side of piston

Working principle of single stage single acting reciprocating compressor

The reciprocating compressor basically consists of a cylinder with a piston fitting closely inside. When the piston moves downwards, a low pressure is produced above it in the cylinder as the refrigerant left in the clearance space expands. When the pressure becomes less than the suction line pressure, the pressure in the suction line forces the suction valve open and vapour enters the cylinder. The flow continues till the piston touches the bottom dead centre. The suction valve closes due to spring action at this point. When the piston moves upwards, the vapour is compressed and, when its pressure is greater than the pressure in the discharge line, the discharge valve is forced open and the high pressure high temperature refrigerant is discharged.



Different parts of the Reciprocating compressor

Piston : The piston is generally made of cast-iron. Piston it fitted with close tolerance in cylinder. The function of the piston is only to compress the refrigerant in an enclosed cylinder.

Crank shaft: Crank shaft is a moving lever. When it is used with the connecting rod it moves with the reciprocating motion.

Connecting rod: Connecting rod is used for connecting the piston and crank shaft. One end is connected to the piston by means of hardened, ground and highly polished steel wrist pin. The wrist pin upper end of the connecting rod have an oscillating or reciprocating motion while the lower end of the connecting rod combines a reciprocating and rotary motion.

Suction and discharge valve: The valve that controls the flow of refrigerant from the suction line into cylinder head is known as suction valve. The valve that discharges the compressed gas towards the discharged line is called discharged valve.

2. Rotary compressor

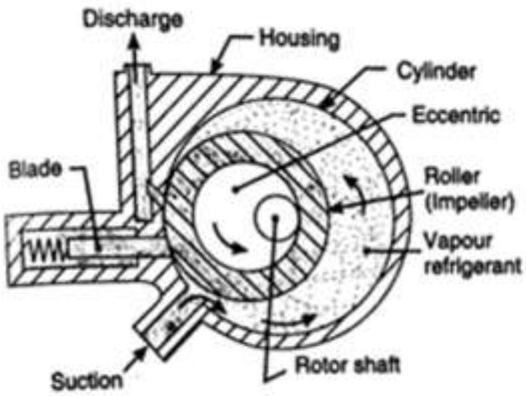
In rotary compressors, the vapour refrigerant from the evaporator is compressed due to the movement of blades. The clearance in this type of compressor is negligible, thus, possesses high volumetric efficiency. Common type refrigerants used are R-12, R-22, R-114 and ammonia.

Two types

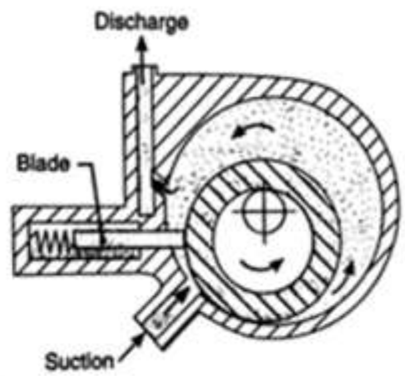
A. Single stationary blade type rotary compressor

This consists of a stationary cylinder, a roller (or impeller) and a shaft. The shaft has an eccentric on which the roller is mounted. A blade is set into the slot of a cylinder in such a manner that it always maintains contacts with the roller by means of a spring. The blade moves in and out of the slot to follow the rotor when it rotates. When the shaft rotates, the roller also rotates so that it always touches the cylinder wall.

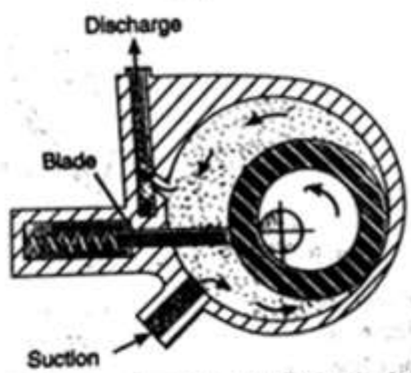
Figure (a) shows the completion of intake stroke (i.e. the cylinder is full of low pressure and temperature vapour refrigerant) and the beginning of compression stroke. When the roller rotates, the vapour refrigerant ahead of the roller is being compressed and the new intake from the evaporator is drawn into the cylinder, as shown in figure (b). As the roller turns mid position as shown in figure (c), more vapour refrigerant is drawn into the cylinder while the compressed refrigerant is discharged to the condenser. At the end of compression stroke as shown in figure (d), most of the compressed vapour refrigerant is passed through the discharge port to the condenser. A new charge of refrigerant is drawn into the cylinder. This, in turn is compressed and discharged to the condenser. In this way, the low pressure and temperature refrigerant is compressed gradually to a high pressure and temperature.



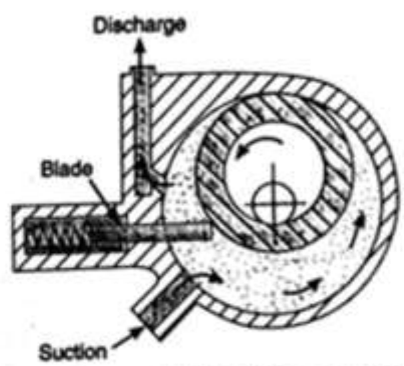
(a) Completion of intakes stroke and beginning of compression.



(b) Compression stroke continued and new intake stroke started.



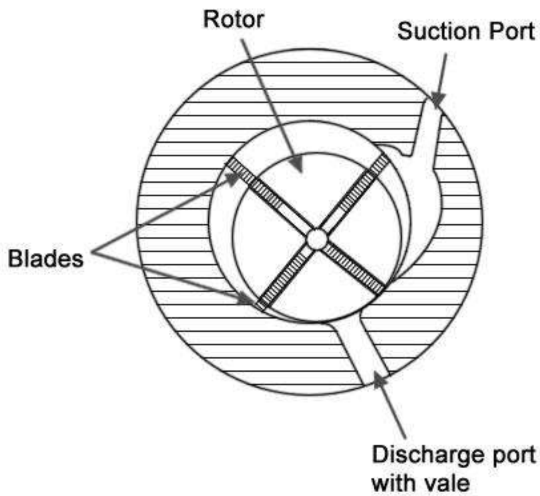
(c) Compression continued and new intake stroke continued.



(d) Compressed vapour discharged to condenser and new intake stroke continued.

B. Rotating blade type rotary compressor

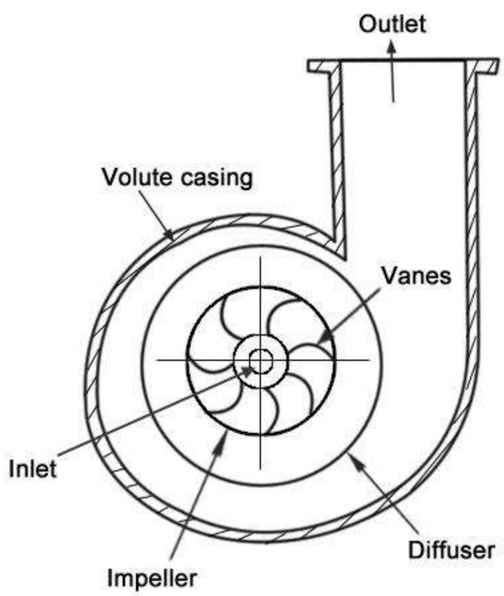
This compressor consists of a cylinder and a slotted rotor containing a number of blades. The centre of the rotor is eccentric with the centre of the cylinder. The blades are forced against the cylinder wall by the centrifugal action during the rotation of the motor. The low pressure and low temperature vapour refrigerant from the evaporator is drawn through the suction port. When the rotor turns, the vapour refrigerant entrapped between the two adjacent blades is compressed and discharged through the discharge port to the condenser.



Rotating Blade type rotary Compressor

3. Centrifugal compressor

This compressor increases the pressure of low pressure vapour refrigerant to a high pressure vapour refrigerant by means of centrifugal force. The centrifugal compressor is generally used for refrigerant that require large displacement and low condensing pressure, such as R-11 and R-113.



Centrifugal compressor

A single stage centrifugal compressor, in its simplest form, consists of an impeller to which a number of curved vanes are fitted symmetrically, as shown in Fig. The impeller rotates in an air tight volute casing with inlet and outlet points. The impeller draws in low pressure vapour refrigerant from the evaporator. When the impeller rotates, it pushes the vapour refrigerant from the centre of the impeller to its periphery by centrifugal force. The high speed of the impeller leaves vapour refrigerant at a high velocity at the vane tips of the impeller. The kinetic energy thus attained at the impeller outlet is converted into pressure energy when the high velocity vapour refrigerant passes over the diffuser. The volute casing collects the refrigerant from the diffuser and it further converts the kinetic energy into pressure energy before it leaves the refrigerant to the condenser.

Advantages and disadvantages of Centrifugal Compressors over reciprocating compressor

Advantages

- Since the centrifugal compressors have no valves, pistons, cylinders, connecting rod, etc., therefore the working life of these compressors is more as compared to Reciprocating compressors.
- The operation of centrifugal compressors is quiet and calm.
- The centrifugal compressors run at high speeds (3000 r.p.m. and above), therefore these can be directly connected to electric motors or steam turbines.
- Handle larger volume of vapour refrigerant as compared to reciprocating compressor
- The centrifugal compressors are especially adapted for systems ranging from 50 to 5000 tonnes. They are also used for temperature ranges between - 90°C and + 10°C.
- The efficiency of these compressors is considerably high.
- Requires less floor area

Disadvantages

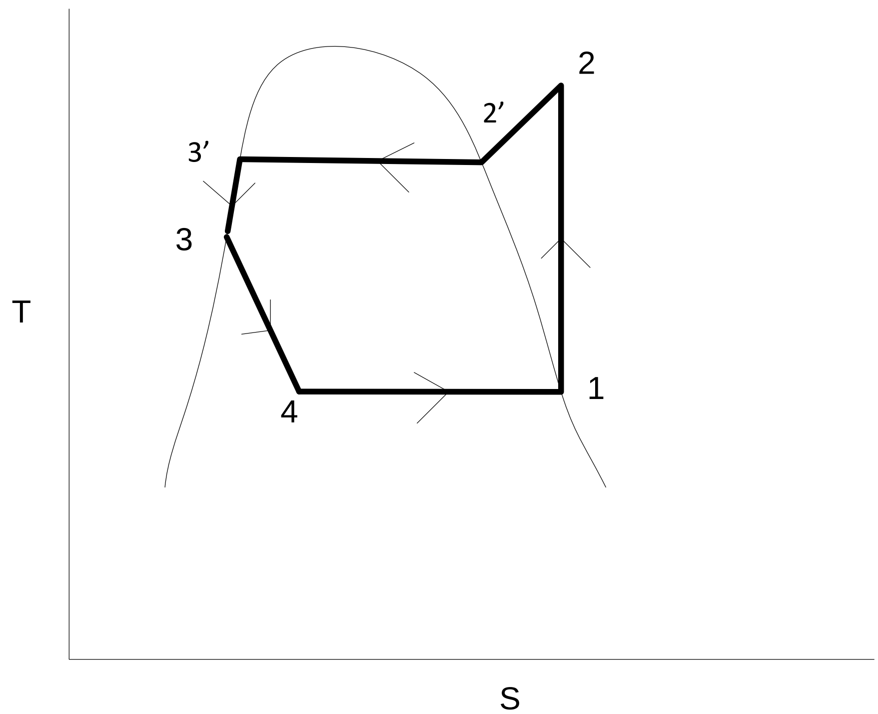
- When refrigeration load decreases below 35 percent of the rated capacity, surging occurs. Surging is the reverse flow of refrigerant from compressor to evaporator when refrigeration load decreases.
- The increase in pressure per stage is less as compared to reciprocating compressors.
- The centrifugal compressors are practical below 50 tonnes capacity load.

4. Hermetic compressor

When compressor and motor operates on same shaft and enclosed in a common casing, these are known as hermetic compressor. These compressors may operate on reciprocating or rotary principle. These are widely used in domestic refrigerators, home freezers and window AC.

Refrigerant condensers

Condensers and evaporators are basically heat exchangers in which the refrigerant undergoes a phase change. In condensers the refrigerant vapour condenses by rejecting heat to an external fluid, which acts as a heat sink. 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 22.1 shows the variation of refrigeration cycle on T-s diagram. In the figure, the heat rejection process is represented by 2-2'-3'-3. It can be seen that process 2-2' is a de-superheating process, during which the refrigerant is cooled from a temperature T_2 to the saturation temperature corresponding condensing pressure, $T_{2'}$. Process 2'-3' is the condensation process, during which the temperature of the refrigerant remains constant as it undergoes a phase change process. Process 3'-3 is a sub cooling process, during which the refrigerant temperature drops from T3' to T3.



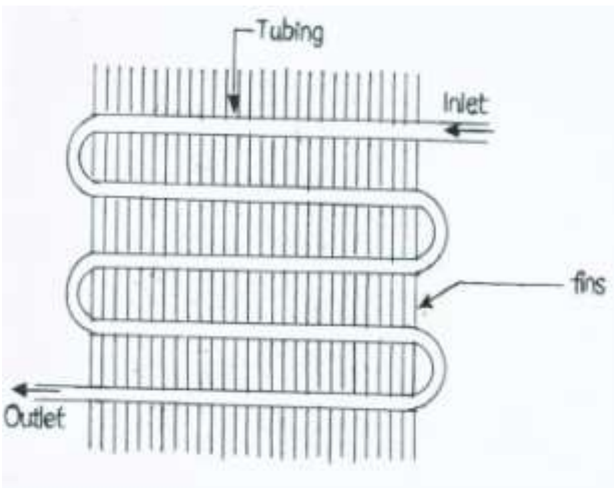
Classification of condensers:

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

1. Air cooled condensers
2. Water cooled condensers, and
3. Evaporative condensers

a. Air-cooled condensers:

In air-cooled condensers air is the external fluid, i.e., the refrigerant rejects heat to air flowing over the condenser. it consists of steel or copper tubing through which refrigerant flows. Copper tubes are generally preferred due to its good heat transfer ability. Steel tubes used for ammonia refrigerant system. The tubes are provided with plate type fins to increase the surface area for heat transfer. The fins are made of aluminium. The air cooled condenser may have tubes up to 6 or 7 rows. More than 8 rows of tubing are not efficient because air temperature will get too close to the condenser temperature and heat absorption rate of air decreases. 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 done by natural convection. As the air comes in contact with the warm condenser tubes, it absorbs heat from the refrigerant and temperature of air increases. The warm air got lighter and rises up taking away heat. The cold air from the surrounding takes the place to take away the heat from the condenser. The rate of heat transfer in natural convention type condenser is low.

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. Forced convection type condensers are commonly used in window air conditioners, water coolers and packaged air conditioning plants. These are either 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 remote mounted type, is either vertical or roof mounted horizontal type. They can be located either inside or outside the building. This system is used for capacity above 10 tonnes. For above 125 tonnes two or more condensers are used.

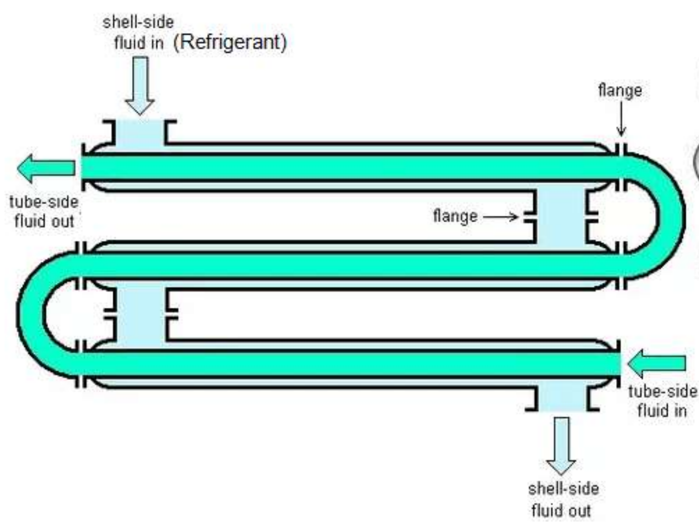
2. Water Cooled Condensers:

In water cooled condensers water is the external fluid. These are commonly used in commercial and industrial application. The water cooled condensers uses either of the following two water systems: 1. Waste water system, 2. Re-circulated water system.

In waste water system, the water circulated in the condenser is discharged into sewer. This system is used where large quantities of waste water are available. In re-circulated water system, the same water circulated on condenser again and again after cooling. This system requires some water cooling system such as cooling tower or spray ponds. The warm water from the condenser is passed through cooling tower/spray pond, cooled there by self evaporation and then re-circulated in condenser. Additional make up water is required to replace the water that evaporates from the cooling tower.

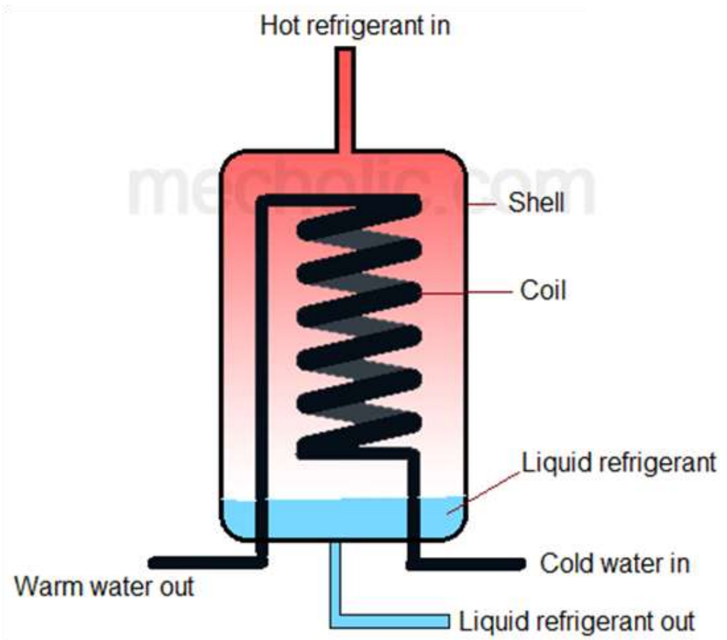
Water cooled condensers can be further classified into:
1. Double pipe or tube-in-tube type
2. Shell-and-coil type
3. Shell-and-tube type

a. **Double Pipe or tube-in-tube type:**
Double pipe condensers are normally used up to 10 TR capacities. In these condensers the cold water flows through the inner tube, while the refrigerant enters at the top. The water absorbs the heat from the refrigerant and liquid refrigerant flows at the bottom. The refrigerant in the tubes rejects a part of its heat to the surroundings by free convection and radiation. The water in this type of system may flow in either direction. If the water flows in the same direction of refrigerant then it is called **parallel flow system**, when the water flow is opposite to the refrigerant then called **counter flow system**. In parallel flow system the temperature difference will be maximum at the inlet side and will be minimum at outlet side. I.e. the heat transfer rate decrease as it passes through the condenser. Thus, counter flow condenser is preferred in type of water-cooled condenser.



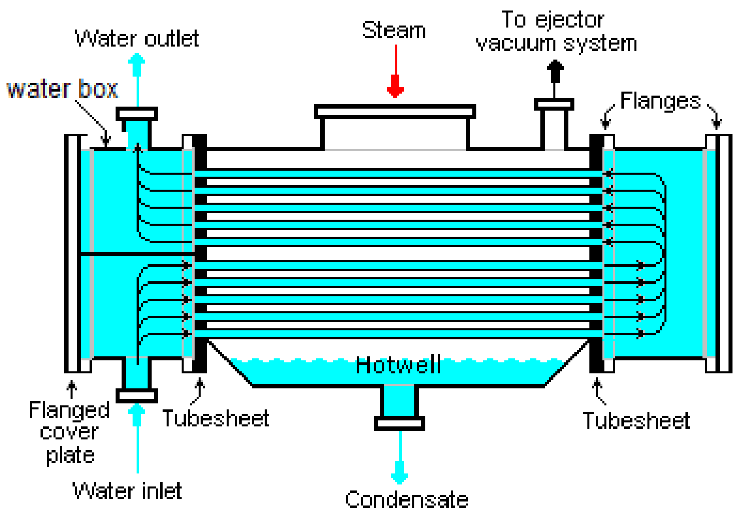
b. Shell-and-coil type

The refrigerant flows through the shell and water flows through multiple coils. In smaller capacity condensers, refrigerant flows through coils while water flows through the shell. These type condensers may be either vertical or horizontal. The hot vapour refrigerant enters at the top of the shell and surrounds the water coil. The vapour condenses when it comes in contact with coil with cooling water supply and collects at the bottom of the shell. Counter flow water system is mostly preferred as it is more efficient than parallel flow water system. The coil inside the shell is allowed to expand and contract with temperature rise and fall. This spring action coil helps it to withstand temperature strain.

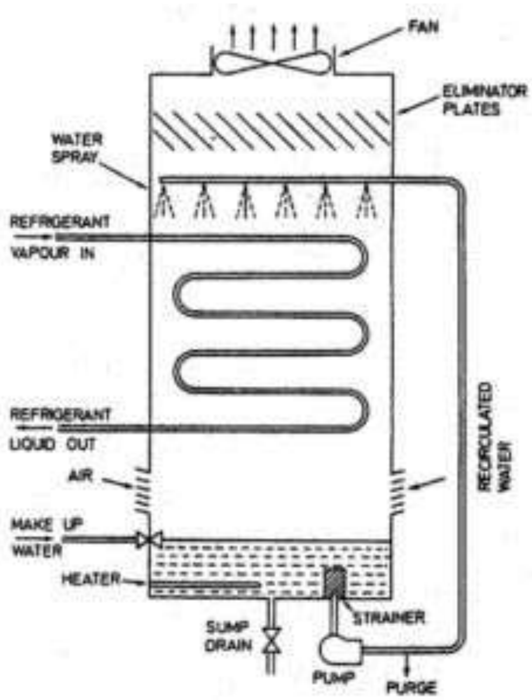


C. Shell-and-tube type

Shell and tube is the most common type of condenser in large chemical processing plants. In this type of condenser number of straight water tubes are enclosed a large cylindrical shell. The shell may be with or without fins. The common materials for shell are steel and copper. In ammonia refrigerating system steel tube is used because ammonia corrodes the copper. The water tubes are extended to the groove of tube sheet to achieve vapour tight fit. Intermediate support is provided to avoid bending of water tube. The hot refrigerant enters the shell at top. Refrigerant reject heat to the water when it contacts with water tubes. Finally, the condensed refrigerant drops to the bottom of shell.



3. Evaporative condensers



It uses both water and air for cooling of the refrigerant. In this system the water is pumped from sump to spray header and sprayed through nozzles over the condenser coils. The heat transfers from the refrigerant to the water droplets through the tube walls. A fan also used at the top of the condenser which draws the surrounding air from the bottom of the condenser. The air causes water droplets on the surface of the coil evaporates and absorbs latent heat of evaporation from the remaining water to cool it. In this way the refrigerant rejects its latent heat and condenses into liquid. The cold water drops down is collected at the sump where it is re-circulated. The eliminator is provided above the spray header to stop the water particle escaping with air.

❖ **Comparison between water cooled and air cooled condenser**

Water cooled condenser	**Air cooled condenser**
Complicated construction	Simple construction
Maintenance cost high	Maintenance cost low
Piping arrangement required to carry water	No requirement of piping arrangement
High fouling effect	Low fouling effect as no corrosion is there

Heat transfer capacity high	Heat transfer capacity low
No fan noise	Forced convection air condenser fan noise is there
Even distribution of water on condensing surface	Distribution of air in condenser is not uniform
Used for large capacity plant	Used for low capacity plant

***Fouling factor: The water used in water cooled condenser contains minerals and foreign material which deposits on the tubes. These are called water fouling. This insulates the tube causing reduction in heat transfer rate and water flow rate.**

- **Heat Rejection factor:** it is the ratio of load on condenser to refrigeration effect.
  HRF=Qc/RE
  Where Qc= RE+ work done at compressor
  HRF=1+(W/RE) =1+(1/COP)

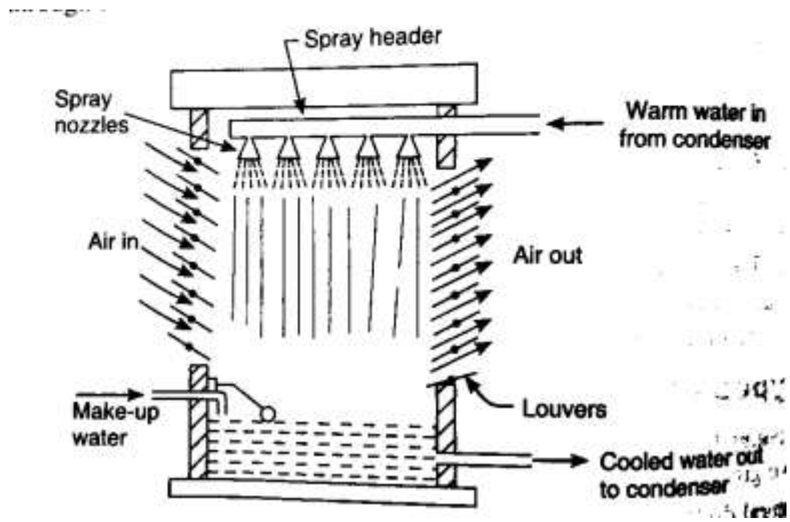
Cooling tower and spray ponds

- A cooling tower is enclosed tower like structure through which atmospheric air circulates to cool warm water by direct contact
- A spray pond consists of nozzle and piping arrangement placed over a pond or reservoir

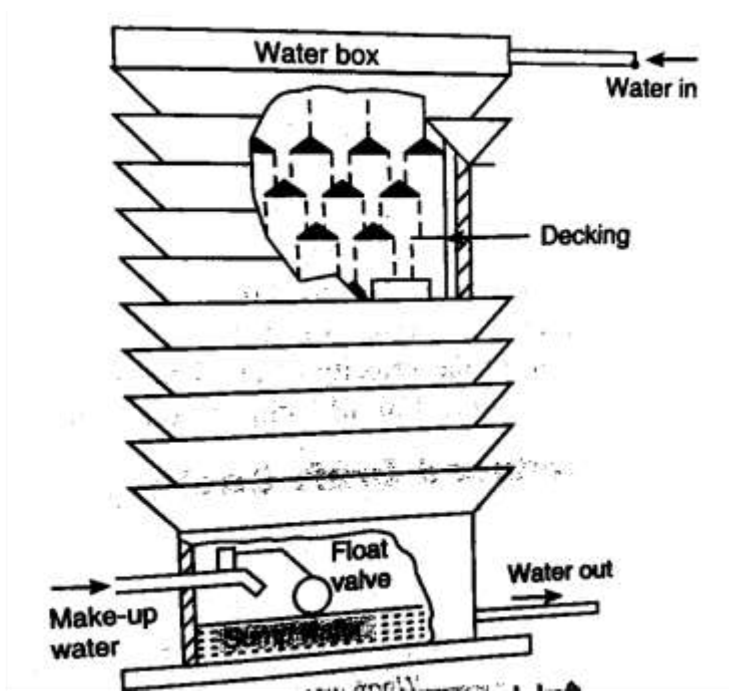
Cooling towers are divided into two main groups: natural draft cooling towers and mechanical draft cooling towers.

Natural draft cooling towers

1. **Natural Draft Atmospheric Spray Towers:** This tower should be located in open space or on the roof of the building where the movement of air is best. Hot water that needs cooling in the natural draft cooling tower is pumped in via the hot water inlet. The inlet is connected to nozzles that spray the water which provides a large surface area for heat transfer. At the bottom of the tower, the structure is open to draw in fresh air, which then flows upward and allows for direct-contact heat transfer between the warm water and the air. The hot water releases heat after coming into direct contact with the fresh air, and some of the hot water is evaporated. Cold water is collected at the bottom of the tower. The warm and moist air is discharged from the top of the tower into the atmosphere.



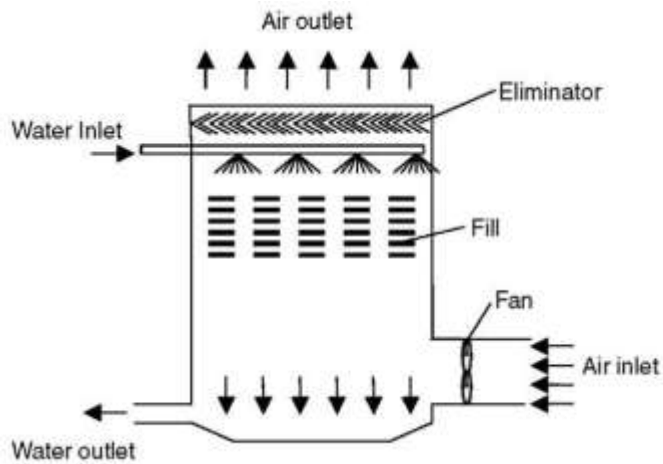
2. **Natural Draft Atmospheric splash deck type Towers:** It is similar to the atmospheric spray tower except that water-distributing troughs are used, which helps to break the water into small droplets. The object of the decks is to provide additional evaporation area. It gives 20–30% greater efficiency than the atmospheric spray tower for the same size and for the same quantity of water flow. The water splashes on the decking from the holes of the bottom of the water box placed in top of the tower. The decking helps to break the water into small droplets and slow down the fall of water to the bottom.



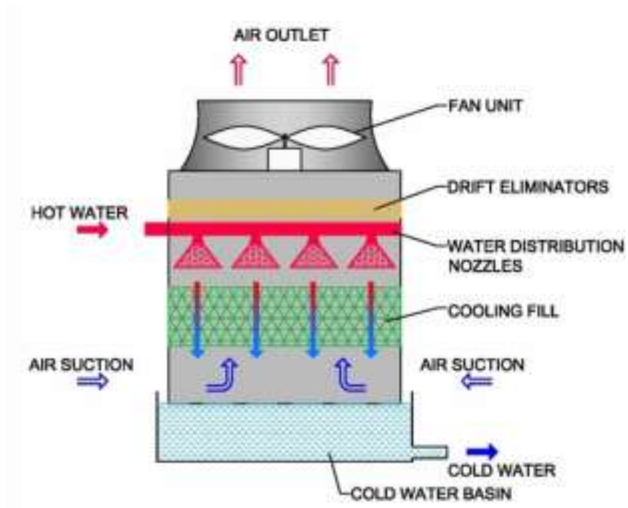
Mechanical draft cooling towers

It is similar to Natural draft cooling towers except the fan is used to force the air through them. It uses either propeller or centrifugal fans. This type of towers generally is smaller in size and increased cooling capacity than natural draft cooling towers. However, it requires additional operating cost and power requirement as fan is used.

1. **Forced draft cooling tower:** In the *forced draft cooling towers* the blower type fans are mounted on the lower side of the tower. The warm water from the condenser is sprayed through nozzle. The air is forced upward by the fan presented at the bottom of the tower. The cooling of the water takes place by means of heat transfer and evaporation.



2. **Induced draft towers:** In *induced draft towers* the fans are located at the discharge (at the top) and pull the air through the tower. Air enters the sides of the tower at low velocity through large openings and passes through the fill, whereas the hot humid air is exhausted to the atmosphere through the ventilator.



❖ **Spray pond:** Ponds are located on the ground or on the treated roofs. The water intake from the pond to the condenser is done by using some mechanical pump. The hot water coming out from the condenser is sprayed through the nozzle as fine droplets into the atmospheric air. It is thus cooled and collected at the pond for recirculation.

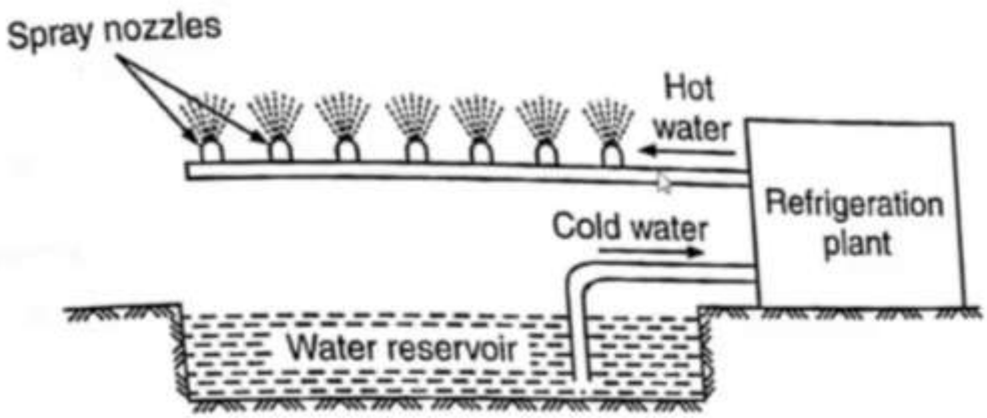


Fig. 1 Spray pond

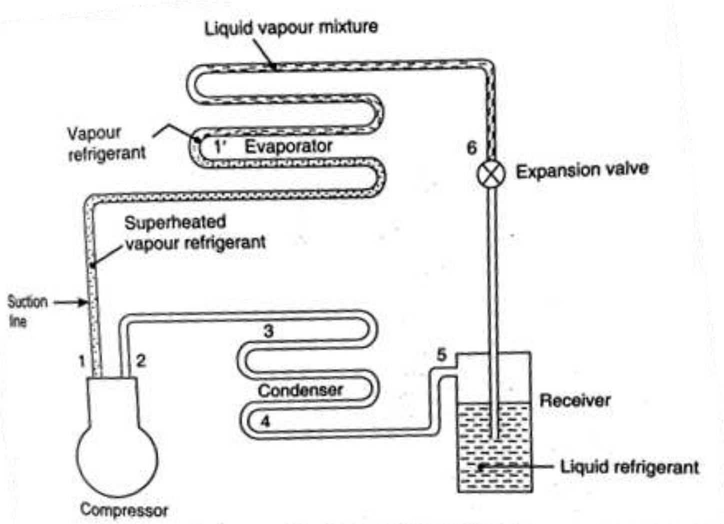
Evaporator

The evaporator works the opposite of the condenser, here refrigerant liquid is converted to gas, absorbing heat from the air in the compartment. This causes the refrigerant to absorb heat from the warm air and reach its low boiling point rapidly. The refrigerant then vaporizes, absorbing the maximum amount of heat.

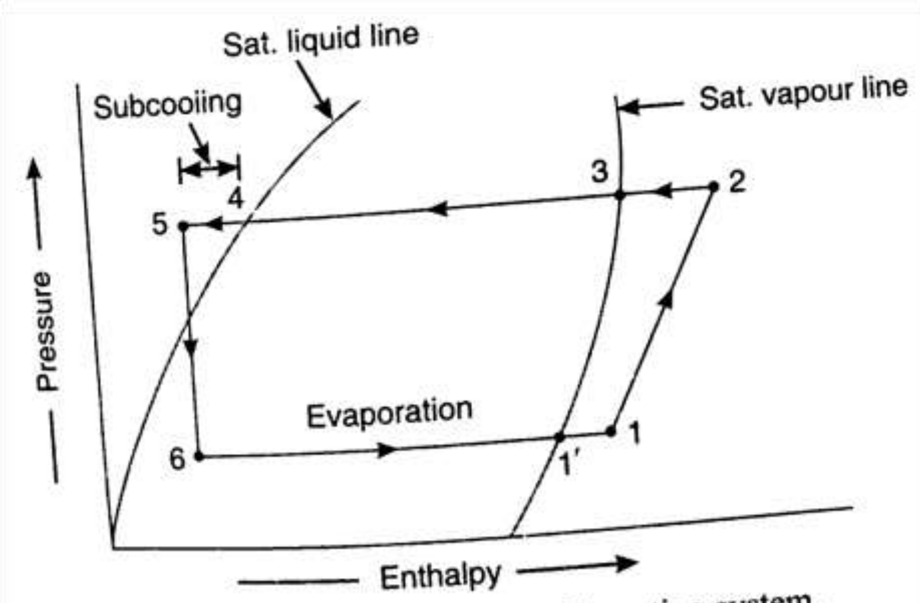
While the refrigerant is changing the phase from Liquid to vapor in the evaporator, it absorbs heat from the space/ substance kept in space to be cooled. Evaporator is kept between the Expansion valve and the Compressor.

Principle of working of an evaporator

The liquid refrigerant from the Expansion valve with low temperature and pressure enters into the Evaporator (point 6). As the liquid refrigerant passes through evaporator coil, it absorbs the heat from the evaporator coil walls and from the medium to be cooled. Due to this, the liquid refrigerant continues to boil and evaporate. Finally at point $1^{'}$, all refrigerants are evaporated and only vapour refrigerant is present in the evaporator coil. Here liquid refrigerant absorbs the latent heat. Since, the vapour refrigerant available is still colder, it keeps absorbing heat (sensible heat) and becomes super heated prior to entering to the compressor suction line (point 1).



(a) Schematic diagram of a simple refrigerating system.



(b) p-h diagram of a simple refrigerating system.

The temperature of refrigerant remains constant during evaporation process with steady increase in enthalpy. Here, latent heat is absorbed by the refrigerant and it is converted into vapour from liquid at constant temperature (6-1’). After all liquid refrigerants are evaporated, sensible heating of the refrigerant vapour is performed which increases both temperature and enthalpy and makes the vapour superheated (1’-1).

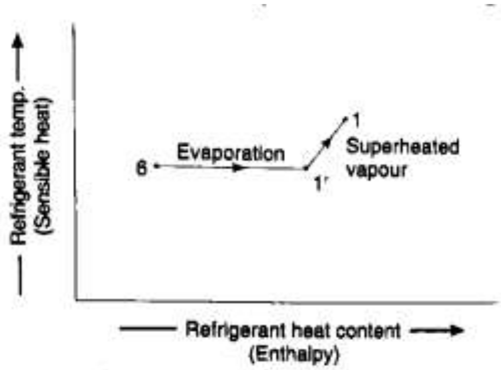


Fig. 11.2. Temperature-enthalpy diagram for an evaporator.

Types of Evaporator

1. According to types of construction
    - Bare tube coil evaporator
    - Finned tube evaporator

- Plate evaporator
- Shell and tube evaporator
- Shell and coil evaporator
- Tube-in-tube evaporator

2. According to mode of heat transfer
    - Natural convection evaporator
    - Forced convection evaporator
3. According to operating conditions
    - Frosting evaporator
    - Non-frosting evaporator
    - De-frosting evaporator
4. According to manner in which liquid refrigerant is fed
    - Flooded evaporator
    - Dry expansion evaporator

Bare tube coil evaporator

These evaporators are usually constructed of either steel pipe or copper tubings. Copper tubing is used in small evaporators where Freon is used as refrigerant where as steel pipes are used where ammonia is used. This type of evaporator is also called prime-surface evaporator. The bare tube coil evaporators are extensively used in household refrigerators because they are easier to keep clean. Its use is limited to applications where the box temperatures are under 0°C and in liquid cooling, because the accumulation of ice or frost on these evaporators has less effect on heat transfer than on those equipped with fins.

These types of evaporators offer relatively little surface contact area as compared to other types of coil. The amount of surface area may be increased by increasing the length of tubes. But, there is a limitation in extension of length as too long tubes results in vaporise the liquid refrigerant completely earlier which leads to excess superheat. This also results in greater pressure drop between inlet and outlet of evaporator. Proper selection of tube diameter is also crucial. Too large diameter tube results in decrease in refrigerant velocity, rise in refrigerant volume in relation to the surface area of the tube. This results in incomplete vaporisation of refrigerant. Thus, liquid refrigerant may enter into the compressor and damage it. If the diameter is too small, the pressure drop will be too high and reduce the system efficiency.

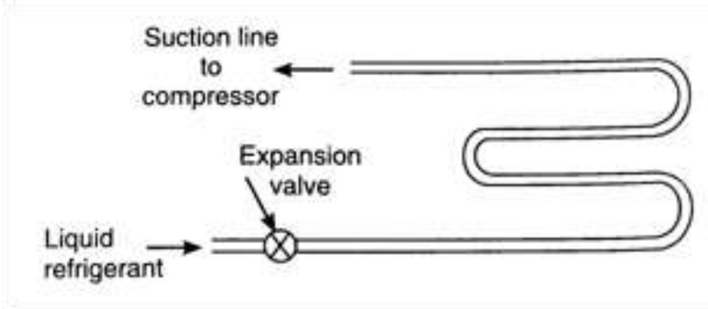


Fig. Bare tube coil evaporator

Finned tube evaporator

Finned coils are bare –tube coils upon which metal plates or fins have been installed. The fins increase the surface area of evaporator which means increased heat transfer and capacity. The size and spacing of fins depends upon the type of application. The metal fins are constructed of thin sheets of metal having good thermal conductivity. These evaporators are designed for air conditioning applications where the refrigerator temperature is above 0°C. A finned coil should not be allowed to frost as accumulation of frost between the fins reduces the heat transfer rate. Because of the rapid heat transfer of the finned evaporator, it will defrost itself on the off cycle.

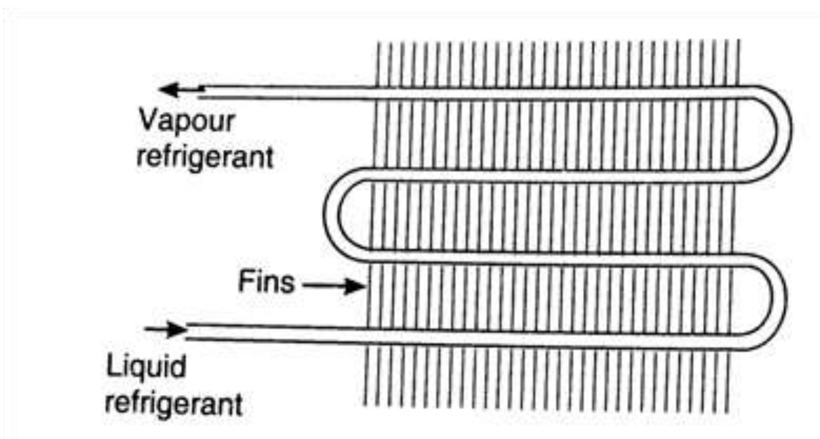


Fig. Finned tube evaporator

Shell and tube evaporator

The shell and tube types of evaporators are used in the large refrigeration and central air conditioning systems. The evaporators in these systems are commonly known as the chillers. The chillers comprise of large number of the tubes that are inserted inside the drum or the shell. Depending on the direction of the flow of the refrigerant in the shell and tube type of chillers, they are classified into two types: dry expansion type and flooded type of chillers. In dry expansion 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. Dry expansion type uses fins inside the tubes while flooded type uses fins outside the tube. Dry expansion type evaporators 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. These evaporators are usually used to chill water or brine.

A flooded type of shell and tube type liquid chiller where the liquid (usually brine or water) to be chilled flows through the tubes and refrigerant circulates around the tube. The refrigerant is fed through a float valve, which maintains a constant level of liquid refrigerant in the shell.

In Dry expansion type Shell-and-Tube Evaporator, refrigerant flows through the tubes and water flow through the shell. 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.

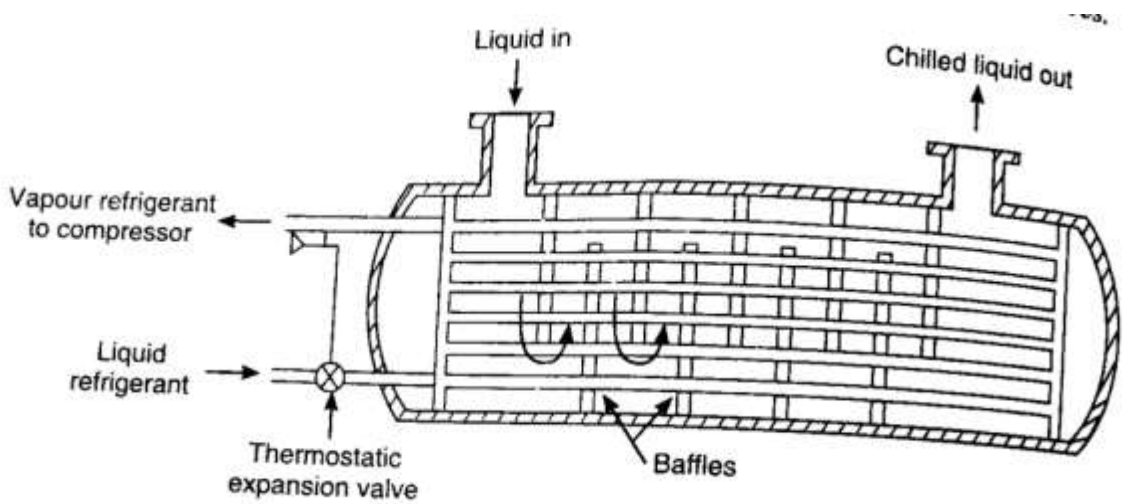


Fig. Dry expansion Shell and tube evaporator

Expansion Devices

The basic functions of an expansion device used in refrigeration systems are to:

1. Reduce pressure from condenser pressure to evaporator pressure,

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

3. It controls the flow of refrigerant according to the flow of evaporator

Types of expansion devices

- Capillary tube
- Hand operated expansion valve
- Automatic or constant pressure expansion valve
- Thermostatic expansion valve
- Low side float valve
- High side float valve

Capillary tube

A capillary tube is a long, narrow tube of constant diameter. Typical tube diameters of refrigerant capillary tubes range from 0.5 mm to 3 mm and the length ranges from 1.0 m to 6 m.

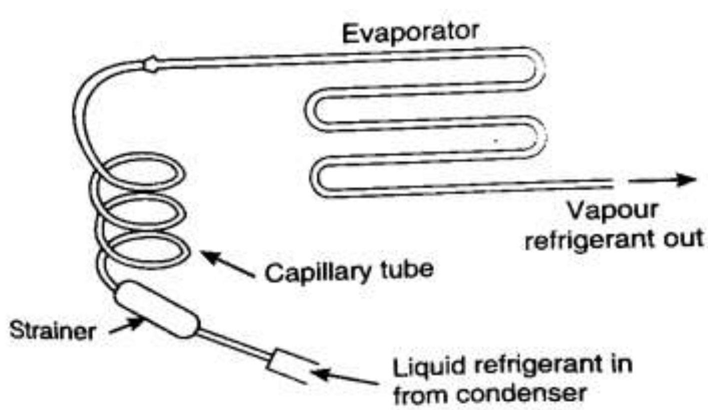


Figure. Capillary tube

The pressure reduction in a capillary tube occurs due to the following two factors:

1. When refrigerant enters into the capillary tube, due to frictional resistance offered by tube walls, its pressure drops. Frictional resistance is directly proportional to length and inversely proportional to diameter. So small diameter and longer tube produces greater pressure drop.

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 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

- Low cost
- When compressor stops, the refrigerant continues to flow to the evaporator and equalise the pressure between high side and low side of system. This decreases the starting load on compressor. Thus, a low starting motor (low cost) can be used to drive the compressor.

Automatic Expansion valve

Also known as a constant pressure expansion valve - maintain a constant pressure regardless the load on the evaporator. Used with dry expansion evaporators where load is relatively constant. This valve maintains a constant pressure throughout the varying load on the evaporator controlling the quantity of refrigerant flowing into Evaporator.

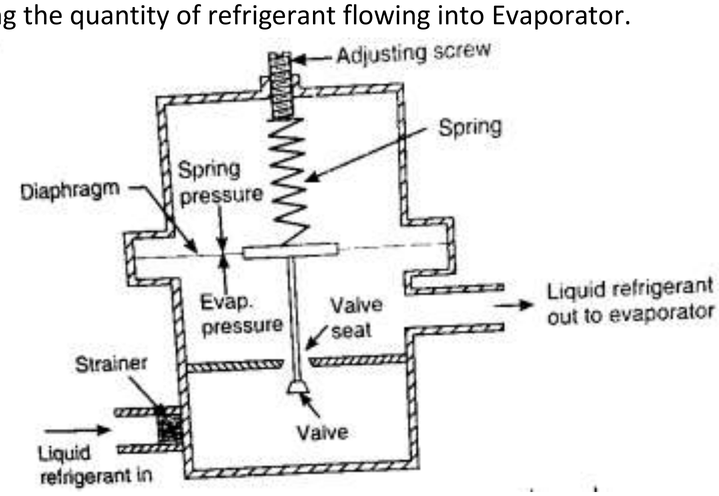


Figure. Automatic Expansion valve

- It is a diaphragm operated valve with the evaporator pressure acting on the lower side of the diaphragm and atmospheric pressure plus adjustable spring pressure acting on the upper side.

- As the compressor operates to remove the gas from the evaporator, it reduces the pressure in the evaporator and under the diaphragm. In this case, the adjusting spring pressure pushes the diaphragm down and opens the valve.
- This allows more liquid refrigerant to enter into the evaporator and thus increasing the evaporator pressure till the desired evaporator pressure is reached.
- On the other hand, if the evaporator pressure rises, the diaphragm moves upward, reduces the opening of valve and flow of refrigerant to the evaporator.
- This decrease of flow of refrigerant lowers the evaporator pressure till the desired evaporator pressure reached
- When the compressor stops, the liquid refrigerant continues to flow into the evaporator and increases the pressure in the evaporator. This increase in pressure causes diaphragm to move upward and valve got closed. It remains closed until the compressor starts again.

Thermostatic expansion valve

A thermostatic expansion valve is a throttling device which works automatically, maintaining proper and correct liquid flow.

Function of thermostatic expansion valve

- Reduces pressure of liquid refrigerant
- Keeps evaporator active
- Modulates the flow of liquid to the evaporator according to the load requirement of the evaporator

Parts of thermostatic expansion valve

- Needle valve and a seat
- Diaphragm
- Spring and adjusting screw
- Feeler or thermal bulb

The feeler bulb is installed at the suction line, thus, it will be at same temperature as the refrigerant at that point. Any changes in temperature at the feeler bulb, it will change the pressure in the feeler bulb. Under normal condition, the feeler bulb pressure is balanced by the spring pressure and evaporator pressure acting at the bottom the diaphragm. The force tending to open the valve depends upon the feeler bulb pressure. The force tending to close the valve depends upon the spring pressure and evaporator pressure.

When the load on the evaporator increases, it causes liquid refrigerant to boil faster. The temperature of the feeler bulb increases due to the early vaporisation of refrigerant. This increases the feeler bulb pressure. Thus, the diaphragm moves downward and opens the valve. More quantity of liquid refrigerant is now entered into the evaporator. This will continue when the pressure reaches the equilibrium position. On the other hand when the load decreases, less liquid refrigerant evaporates. The excess liquid refrigerant flows towards the outlet which cools the feeler tube. The feeler bulb pressure decreases due to decrease in temperature. This moves the diaphragm upward and reduces the opening of valve. In this way, the flow of liquid refrigerant to the evaporator decreases. This continues till evaporator pressure and spring maintain equilibrium with feeler bulb pressure.

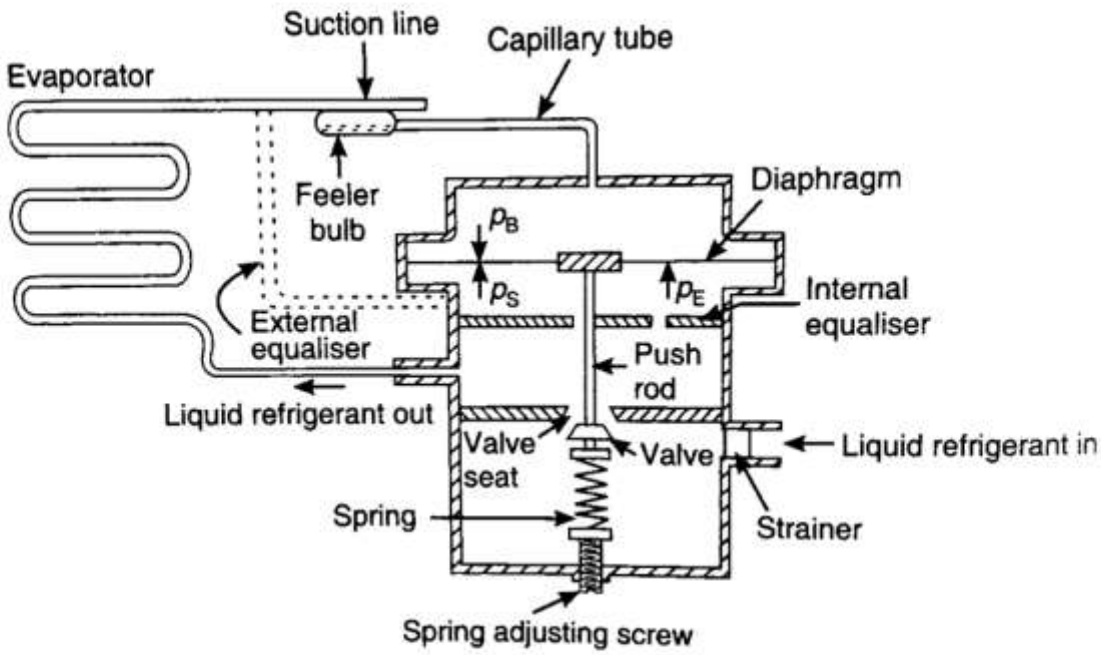


Figure. Thermostatic Expansion valve

There are two main types of thermal expansion valves: internally or externally equalized. The difference between externally and internally equalized valves is how the evaporator pressure affects the position of the needle. In internally equalized valves, the evaporator pressure against the diaphragm is the pressure at the *inlet* of the evaporator, whereas in externally equalized valves, the evaporator pressure against the diaphragm is the pressure at the *outlet* of the evaporator. In internally equalized valves, a hole is drilled in the valve body to transmit the pressure.

The standard thermostatic expansion valve works well on evaporators having low pressure drop. If the pressure drop is high (above 0.14 bar), then, the pressure at the outlet of the evaporator will be less by the amount equal to the pressure drop. In such case, feeler bulb pressure should rise to maintain equilibrium with inlet evaporator pressure and spring pressure. The rise in feeler bulb pressure increases the temperature and the degree of superheat. Thus, the flow of refrigerant to the evaporator reduces. In externally equalized valves, the pressure at the bottom of the diaphragm is equal to outlet evaporator pressure. Thus, the dis-advantages of evaporator pressure drop are overcome. In this case, a small diameter equalizer tube connects the diaphragm with the evaporator outlet.

Application of refrigeration system and air conditioning

1. Cold storage

The cold storage is a building designed to store certain goods like food stuffs, fruits, vegetables and dairy product within well defined temperature range and relative humidity. The temperature and humidity condition maintained inside a cold storage depend upon the type of product stored inside. Vegetables require the maintenance temperature of around 0°C to 5°C with high RH of 80 to 90%, for milk 4°C to 5°C, -25°C to -30°C for quick freezing of fish. The refrigeration does not improve the quality of food product, it only slow down the deterioration.

Advantages of cold storage

- Substances such as potato, butter can be stored when it is plentifully available and can be supplied when needed.
- Transportation of perishable goods from distant places
- It reduces spoilage of products

It is of two types depending upon the requirement

- Long term ware houses with product in frozen or unfrozen state
- Short term ware houses or retail storage with products usually not frozen

Advantages of quick frozen food

- Limits the growth of bacteria
- Reduces the size of the ice crystal formed
- Reduces the separation of water from the cell

It is done by using cold air blast, brine spray or contact evaporators

Types of cooling plants for cold storage

1. Brine coils placed parallel to and near the centre of ceiling
2. Unit condenser with condensing unit outside

3. Small ceiling mounted unit.

1. Brine coils placed parallel to and near the centre of ceiling: In this arrangement, a central brine pump supplies chilled brine to these coil situated in various rooms of a large cold storage central plant. Thermal air circulation from the coils is employed. No fan is used.

2. Unit condenser with condensing unit outside: In this type of cooling plant the cooling coil is placed inside the store and is supplied with direct refrigerant or secondary refrigerant. Room air enters the coil at the bottom, passes over the coils, cools down and that chilled air is blown to the room.

3. Small ceiling mounted unit. : These units consist of cooling coil backed by an electric fan. The fan blows the chilled air horizontally or vertically down.

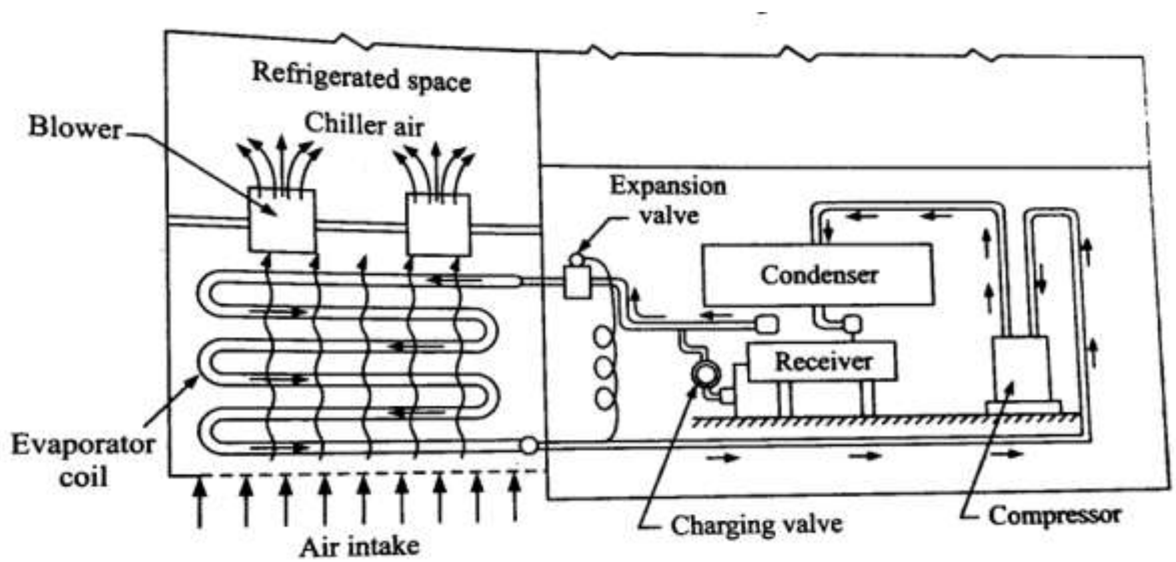


Figure. Cold storage plant

2. Water cooler

The purpose of water cooler is to make water available at a constant temperature irrespective of ambient temperature. Water coolers are used to produce cold water at about 7°C to 13°C. The temperature of cold water is controlled with the help of a thermostat switch set within 7°C to 13°C.

Water cooler may be classified as

1. Instantaneous type water cooler: In this type of water cooler, the evaporator consists of two separate cylindrically wound coils made of copper or stainless steel tube, where the cooling coil

is wrapped round the pipe line such that by the time water reaches the tank it is cooled to desired temperature. it is subdivided into

- bottle type cooler
- Pressure type cooler
- Self contained or remote type cooler

Storage type water cooler

- Bottle type cooler: In this type, water to be cooled is stored in a bottle or reservoir. For filling, glass tumblers or faucet are provided. The dripping water from the faucet is collected in the waste water basin. Its usual size is 25 litres and is suitable for places where plumbing installations is expensive and drains are available.

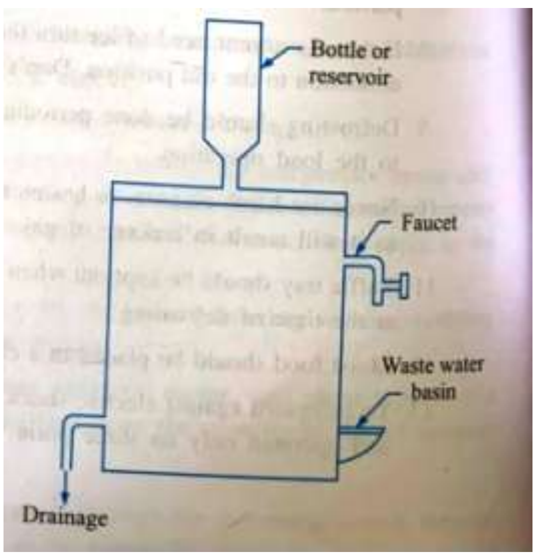


Figure. Bottle type cooler

- Pressure type cooler: In this type of water cooler, the water is supplied under pressure. For filling glass tumblers or faucets are provided. The city main water enters the cooler through inlet connection. It then passes through the pre-cooler. The pre cooling is done by the waste water of the cooler. As waste water temperature is low, it is made use of cooling the supply water by passing through a pipe coil wrapped around the drainage line. This arrangement helps to reduce the cooling load for the cooler. The pre cooled water then enters the storage chamber and losses its heat to the refrigerant. The outlet of water pipe is connected at the bottom of the storage tank, which is fitted to a bubbler. Since the water is supplied under pressure the cold water can be obtained from the top mounted at any height of the cooler. The refrigeration system is generally mounted at the bottom of the cooler body and a cooling coil is wrapped around the water tank, where the refrigerants flow. Sometimes a helical or U shape coil is immersed in the water tank. This arrangement gives high heat transfer rate but, it is possible to form undesirable salt due to chemical reaction between water contaminants and copper surface proves to be a great disadvantages.

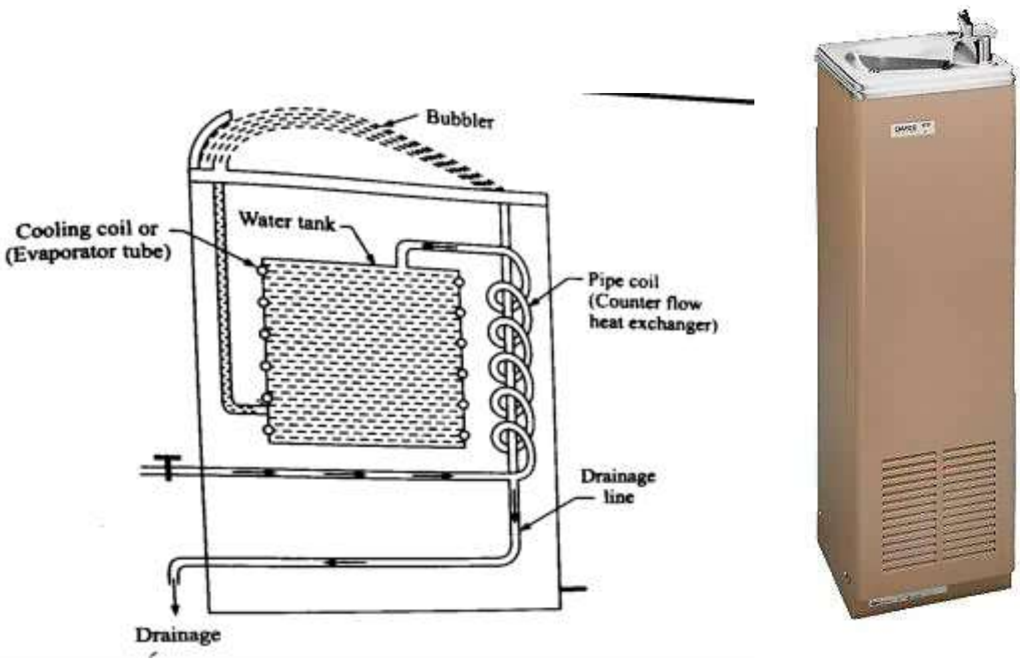


Figure. Pressure type cooler

- Self contained or remote type cooler: This type of cooler employs a mechanical refrigeration system. The water cooled from the remote cooler is supplied to desired drinking place, away from the system. This type of arrangement does not require extra space near the place of work.

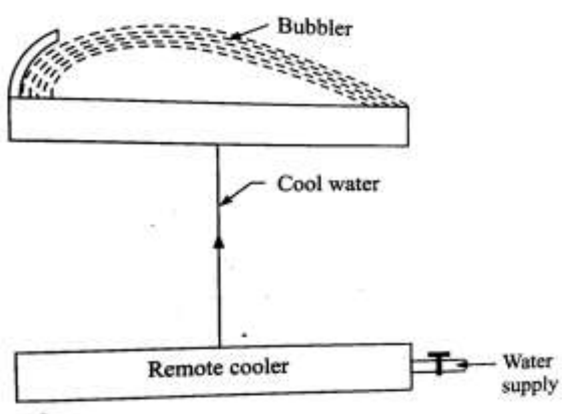


Figure. Remote type cooler

2. Storage type water cooler: Such types of coolers are used where continuous supply of water is not available. Here the water is filled in the storage tank and level of water is kept same by the use of a float valve. The storage tank is surrounded by an evaporator coil through which a low

temperature refrigerant flows and takes away the heat and cools the water. When the water is cooled to desired temperature, the thermostat operates and disconnects the power supply to the motor.

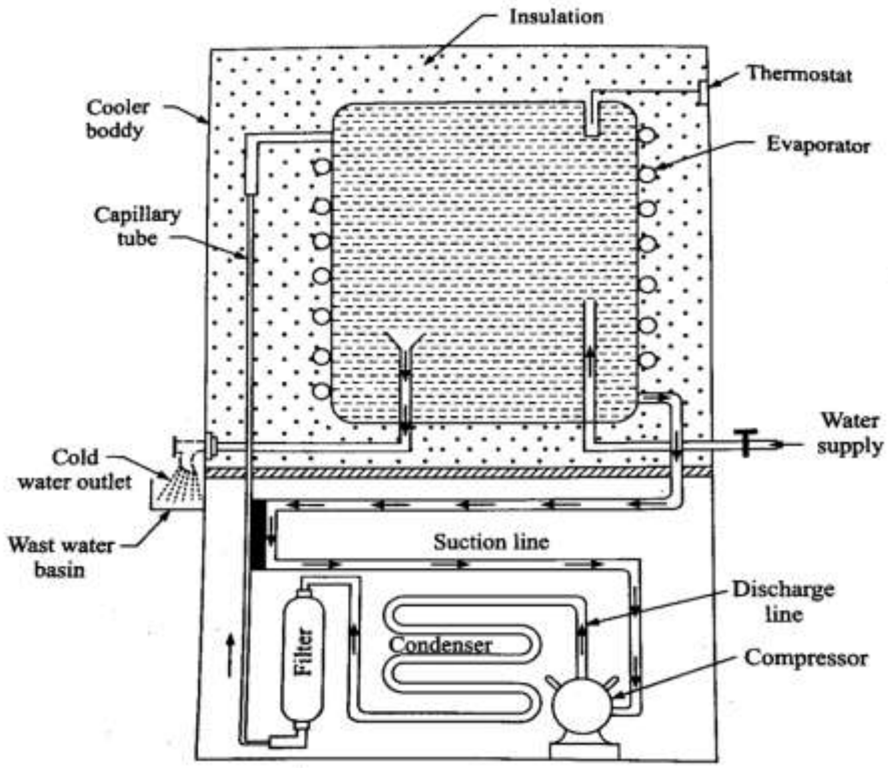


Figure. Storage type water cooler

3. Desert cooler

- Used where humidity is quite low and temperature is high.
- Uses the principle of evaporative cooling. Here the sensible heat is removed and moisture is added to the air.
- Air is allowed to pass through a spray of water. Water particle takes the heat equivalent to its latent heat and evaporates. The vapour formed is carried away with air. Thus, the air is cooled and humidified.

Main parts

- Blower/fan
- Water circulating pump
- Water wetted pads
- Water tank
- Float valve

The water is filled in the sump of the cooler from water supply mains, the level is controlled by the float valve. A water pump lifts the water and supplies it at the top of the cooler to the water distribution system. The water distribution system consists of small branches of copper pipes which delivers equal amount of water to the troughs and then to the wetted pads. The water which drops back from the pads are collected at the sump and recirculated again. The pump is generally made up of brass, stainless steel or plastic. The blower pulls the air through the wetted pads and delivers it to the space to be cooled. The air which is drawn through the pads is cooled by principle of evaporative cooling.

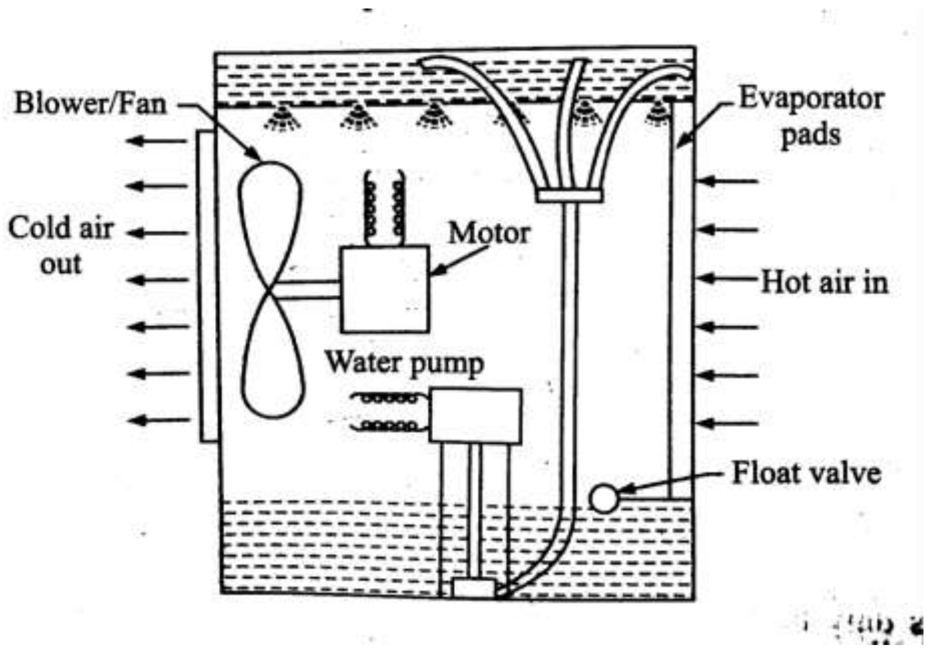


Figure. Desert cooler

4. ICE manufacture

The commercial ice is produced by freezing potable water in standard cans placed in a rectangular tank. The tank is filled with chilled brine. For increasing heat transfer rate from water to chilled brine, the brine solution is kept in constant motion by agitators. The brine temperature is maintained at -10°C to -11°C. Ammonia gas is used as the refrigerant because of its excellent thermal properties. The high pressure and high temperature ammonia vapour enters the condenser, where it is condensed to liquid ammonia by releasing its latent heat. The condensed liquid refrigerant is collected in a receiver and through expansion valve; it is supplied to the evaporator. The expansion valve reduces the pressure and temperature of the refrigerant. When the low pressure and low temperature passes through the evaporator coil surrounding the brine tank, it absorbs the latent heat from the brine solution and gets converted to vapour state. The vapour ammonia is then fed to the compressor where it is compressed and results in consequent increase in temperature and pressure of the vapour refrigerant and the cycle continues.

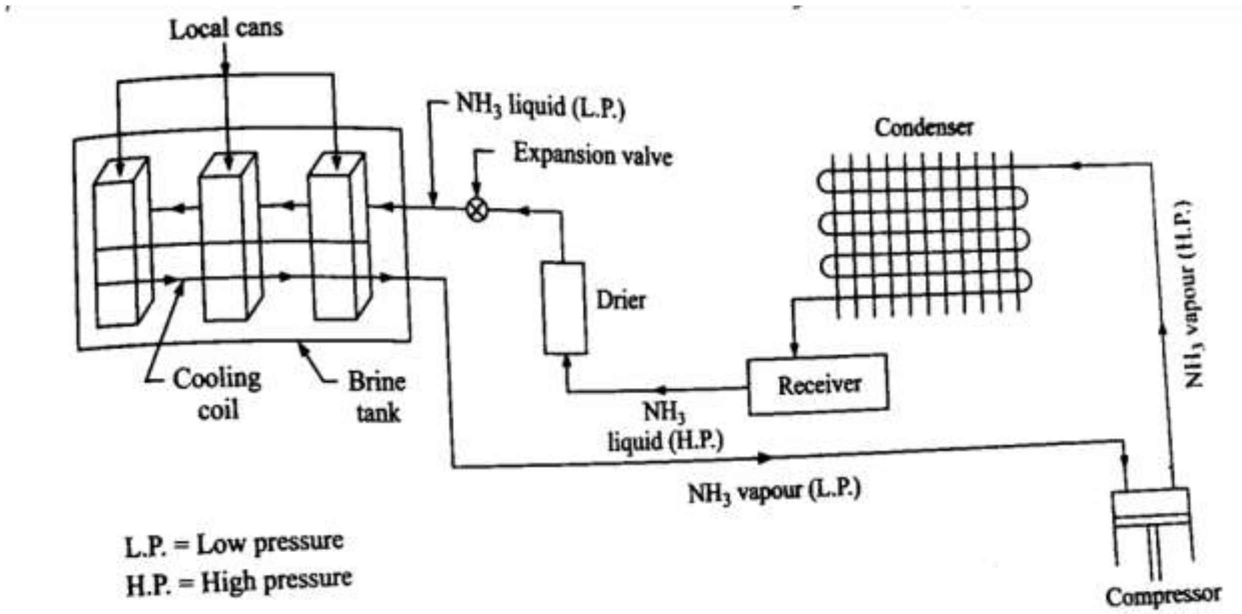


Figure. Ice manufacturing plant

The brine tanks are usually fabricated of 6 mm thick mild steel plate with tie rod welded end to end. The tank is insulated on all four sides and from the bottom. The insulated wooden lids are provided to cover the top to facilitate the removal and replacement of ice cans. The ice cans are fabricated from galvanized steel sheets and are given chromium treatment in order to prevent corrosion. In order to get transparent ice, water in the can is agitated by the use of low pressure air through the tubes suspended from the tops. Due to agitation/stirring, the dissolved impurities are collected at the centre, which should be removed and replaced with fresh water. Brine solutions taken are generally NaCl (sodium chloride) or calcium chloride (CaCl) where as NaCl is mostly preferred because of its low cost. It may be noted that the ice frozen at a temperature lower than -12°C can crack. Therefore, brine temperature is kept at a higher level; say -11°C and -10°C. The rate of freezing decreases as the thickness of the ice layer increases.

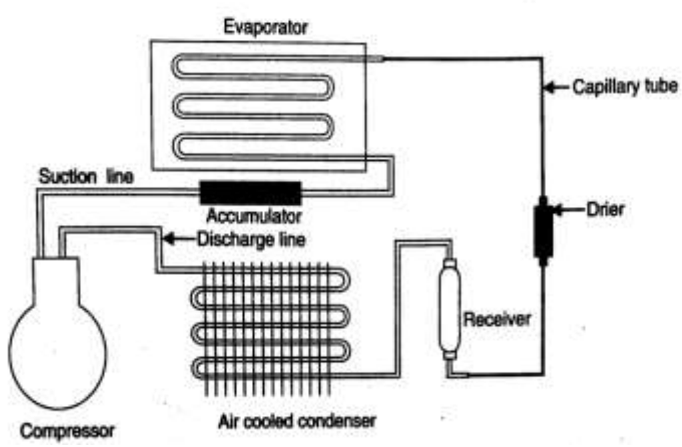
5. Domestic refrigerator

It is usually used to preserve foods. The Primary function of refrigerator is to store food at a space maintained at low temperature. Its secondary function is to form the ice cubes for domestic purpose. They are usually specified by internal gross volume and deep freezers volume. A storage temperature of 0-4 °C required for preservation of food. For frozen food, freezers are generally provided at the top or bottom portion of refrigerator space. It may be single door, double door top freezer, double door bottom freezer and side by side door freezer. These refrigerators are divided into two separate compartments, one for fresh foods and other for storage of frozen foods. With double door refrigerators, the freezer space is not subjected to wide temperature variations. This helps in maintaining a stable temperature for preservation of the frozen foods.

The mechanical vapour compression cycle as well as vapour absorption cycle may be adopted for domestic refrigerators and freezers. But, vapour compression cycle is generally preferred because of its compactness and more efficient use of electrical energy. Refrigerant used are generally R-12 or R-22. Compressor is mounted at the bottom. Condenser is mounted at the back side of the refrigerator. Capillary tube is kept in contact with evaporator inlet .Evaporator coil is wrapped around the freezer. The cooling of lower space is done by free convection. The thermostatic sensing element is provided to the evaporator coil which controls the temperature in the freezer. The refrigerator body is provided with good quality insulation in order to prevent heat transfer into the system.

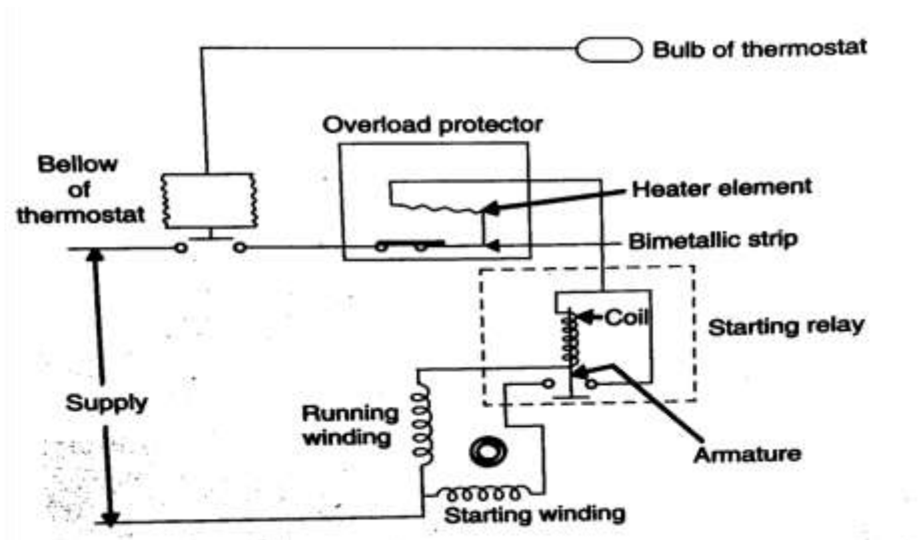
The working of the refrigerator is as follows

- The low pressure and superheated vapour refrigerant is drawn through the suction line to the compressor. The accumulator provided between the suction line and the evaporator, collects liquid refrigerant coming out of the evaporator due to incomplete evaporation. The compressor compresses the vapour to high pressure and high temperature. The compressed vapour is then flow through the discharge valve to the condenser.
- In the condenser, the vapour refrigerant at high pressure and high temperature is condensed to liquid refrigerant.
- The high pressure and high temperature liquid refrigerant is then flows through the filter and then enters to the capillary tube. The capillary tube is attached to the cold suction line. The warm refrigerant passing through the capillary tube gives some of its heat to the cold suction line vapour. This increases the heat absorbing quality of the liquid refrigerant and increases the super heat of the vapour entering the compressor. The capillary tube expands the liquid refrigerant at high pressure to the liquid refrigerant at low pressure and low temperature and supplies the required amount to the evaporator.
- In the evaporator, the liquid refrigerant gets evaporated by absorbing heat from the container and from the articles placed in the evaporative chamber and converted to vapour. It is then drawn back into the compressor and the cycle repeats.



Electrical circuit of a refrigerator

Components

- Starting relay: The starting relay is used to provide necessary starting torque required to start the motor. It disconnects the starting winding of the motor when the motor speed increases.
- Overload protector: The function of the overload protector is to protect the compressor motor winding from damage due to excessive current. It consists of a bimetallic strip. During normal working of the compressor, the contacts are closed. Whenever there is any abnormal behaviour, the bimetallic strip gets heated and bends and thereby opening the motor contacts and de energising it.
- Thermostat: Thermostat is used to control the temperature in the refrigerator. The bulb of the thermostat is clamped to the evaporator. When the desired temperature obtained, the thermostat bulb senses it, the liquid in it is compresses and operates the bellow of the thermostat and opens the compressor motor contact. When the temperature increases, the liquid in the bulb expands and the below closes the compressor motor contact. It allows the flow of current.
- 

Working:

When electric supply is given to the refrigerator, current passes through the thermostat switch, thermal overload, starting relay coil and then to the main winding of the motor. When the motor is at rest, it draws a very heavy current. When the heavy current flows through the coil of the starting relay, the coil gets energised and it pulls up the armature and closing the starting winding contact. The current flowing through the starting winding provides the starting torque and motor starts. When motor gains normal speed, the current drawn by the main winding of motor become normal. The current in the starting relay is no longer able to hold the relay and it gets released and thereby opening the starting winding contacts. In case starting relay fails to close, the motor will not start. Once it closes and not fails to open, then either thermal overload shall be trip out or fuse shall be blown off.

Defrosting in refrigerator

Since the evaporator in a refrigerator operates at a temperature below 0°C, therefore it is subjected to the accumulation of frost or ice. The frost acts as an insulation that resists the heat transfer to the evaporator and leads to further thickening of the frost. This reduces the evaporator capacity and system efficiency. Thus, the removal of frost at regular interval is necessary.

Methods:

- Manually defrosting by putting off button
- By using push button of defrost thermostat: It is provided at centre of the thermostat knob. It breaks the electrical contact till the evaporator temperature rise and defrosting takes place. This is done till the temperature rises above freezing temperature and defrosting occurs. The refrigerator returns to normal functioning automatically once the defrosting is complete.

Defrost water flows to the condensate pan provided below the evaporator of fresh food compartment. From that place it drains into a tray in the compressor compartment

6. Diary refrigeration:

The milk is known to be one of the perishable foods and if not maintained at sufficient low temperature, it gets spoiled due to bacterial growth. As the temperature of the milk is reduced, the bacterial growth decreases and practically ceases at 0°C to 5°C. But, the bacilli are not killed even at very low temperature. The bacterial content can be eliminated to a great extent by heating the milk to 62°C and holding it at that temperature for about 30 minute. Thereafter to minimize the bacterial growth, the milk is cooled to 4°C to 5°C. This process is called as pasteurization.

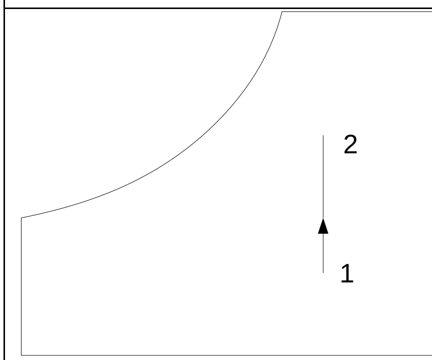
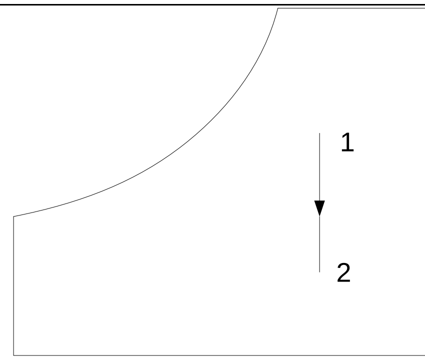
In case the heating is done by hot water, it is sprayed around the outside lining of the vat by a distributer, which gets collected in a sump at the bottom of the vat, reheated and sprayed again. In case of steam heating, the steam is allowed to flow in the space provided between lining and the casing of the vat. The heated milk is then cooled, first by cooling tower water and then by the chilled water or brine to 4°C to 5°C. The heating and cooling is done by passing the milk through heat exchanger plates. The milk flows between two plates and the hot water or cooling tower water or chilled brine is circulated through alternate pairs of plates. The direction of flow of heating or cooling fluids is opposite to that of milk to get better heat transfer.

In order to control the fat content of the milk, it is desired to churn the milk. Such milk is known as toned milk. The fat removed is processed as butter and stored at 4°C to 5°C. The cheese from the milk is stored at about 4°C.

Psychrometry and Air conditioning

❖ Humidification and Dehumidification

The addition of moisture to the air without change in its DBT is known as humidification and removal of moisture from the air without change in its DBT is called as dehumidification.

Humidification	Dehumidification
 ➢ RH increases, W increases and enthalpy increases ➢ Latent heat LH= (h2-h1)= h_{fg} (W2-W1) ➢ Humidification occurs either by direct method or indirect method. ➢ In direct method, highly atomized water is directly sprayed into the space to be cooled. ➢ In indirect method, the water is introduced to the air washer. Here the humidification occurs by spraying heated water onto the air to be conditioned.	 ➢ RH decreases, W decreases and enthalpy decreases ➢ Latent heat LH= (h1-h2)= h_{fg} (W1-W2) ➢ Dehumidification occurs either by introducing air washer or chemicals. ➢ In air washer, chilled water having temperature below the dew point temperature of entering air is sprayed on the unconditioned air. In this process the excess water vapor condenses and dehumidification occurs. A heating coil is used after the air washer as the air coming out from the air washer is in dew point temperature. ➢ For chemical dehumidification adsorbents (silica gel) or absorbents (calcium chloride) is used to absorb moisture from the unconditioned air.

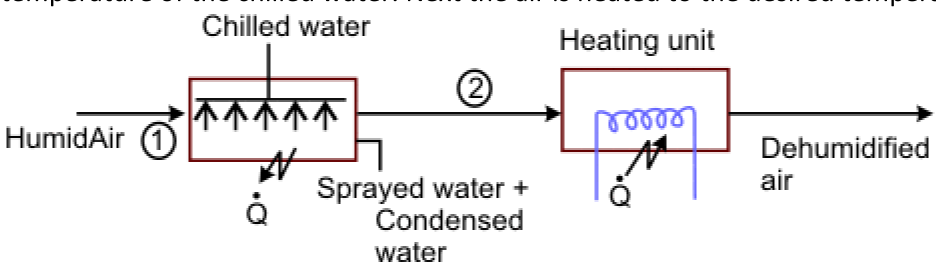
❖ **Sensible heat factor:**

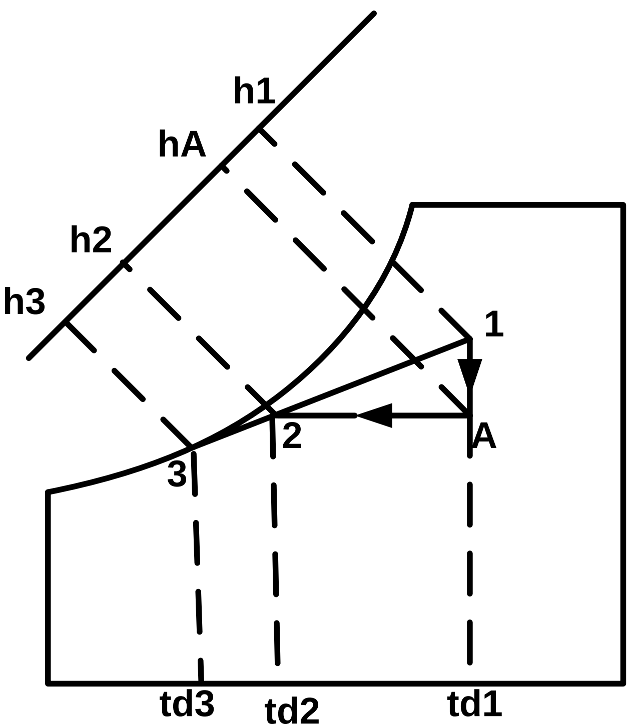
It is the ratio of sensible heat to total heat.

$$SHF=\frac{SH}{SH+LH}$$

❖ Cooling and Dehumidification

When moist air is cooled below its dew-point by bringing it in contact with a cold surface, some of the water vapor in the air condenses and leaves the air stream as liquid, as a result both the temperature and humidity ratio of air decreases. The effective temperature of cold coil is less than the dew point temperature of entering air. The effective surface temperature of coil is known as apparatus dew point (ADP). This process undergoes in a typical summer air conditioning system. In some commercial air-conditioning plants, chilled water (below the dew point temperature of the mixture) is sprayed into the air to be dehumidified. Then the air leaves with less humidity at the temperature of the chilled water. Next the air is heated to the desired temperature.





$$BPF=\frac{td2-td3}{td1-td3}=\frac{W2-W3}{W1-W3}=\frac{h2-h3}{h1-h3}$$

Total heat removed

Q=h1-h2= (h1-hA) +(hA-h2) =LH+SH

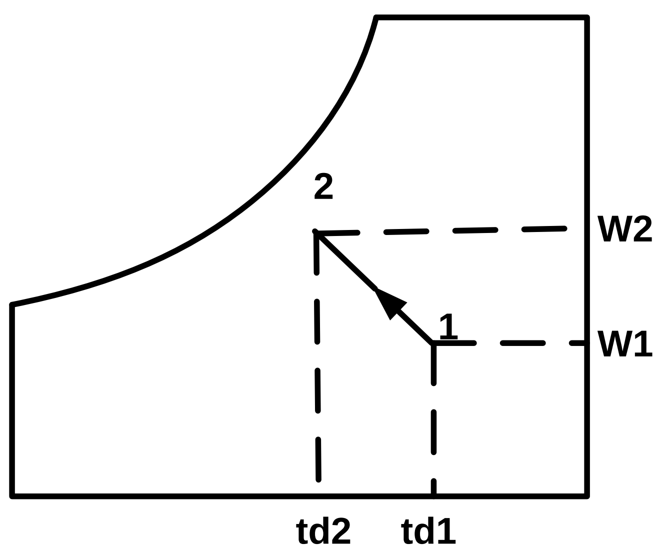
SHF= $\frac{hA-h2}{h1-h2}$

Cooling capacity = m_a(h1-h2)

Efficiency = 1- BPF = $\frac{td1-td2}{td1-td3}$

❖ Cooling and humidification (Evaporative cooling)

During this process, the air temperature drops and its humidity increases. This can be achieved by spraying cool water in the air stream. The temperature of water should be lower than the dry-bulb temperature of air but higher than its dew-point temperature to avoid condensation. It can be seen that during this process there is sensible heat transfer from air to water and latent heat transfer from water to air. Hence, the total heat transfer depends upon the water temperature. If the temperature of the water sprayed is equal to the wetbulb temperature of air, then the net transfer rate will be zero as the sensible heat transfer from air to water will be equal to latent heat transfer from water to air. If the water temperature is greater than WBT, then there will be a net heat transfer from water to air. If the water temperature is less than WBT, then the net heat transfer will be from air to water. Under a special case when the spray water is entirely recirculated and is neither heated nor cooled, the system is perfectly insulated and the make-up water is supplied at WBT, then at steady-state, the air undergoes an adiabatic saturation process, during which its WBT remains constant.



For mass balance

W2= W1+$\frac{mw}{ma}$

Where m_w= mass of water added
M_a=mass of dry air
Hw= enthalpy of water

For heat balance

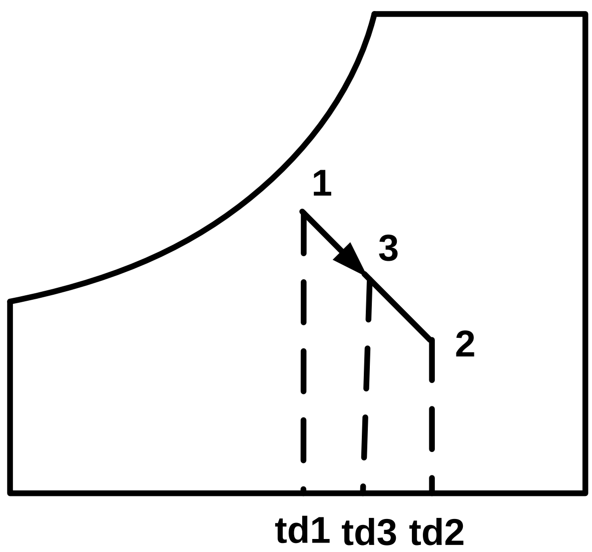
h2= h1 +$\frac{mw}{ma}$hw =h1 + (w2-w1) hw

(w2-w1) hw is neglected as it is very small. So the process is a constant enthalpy process.

❖ Heating and dehumidification

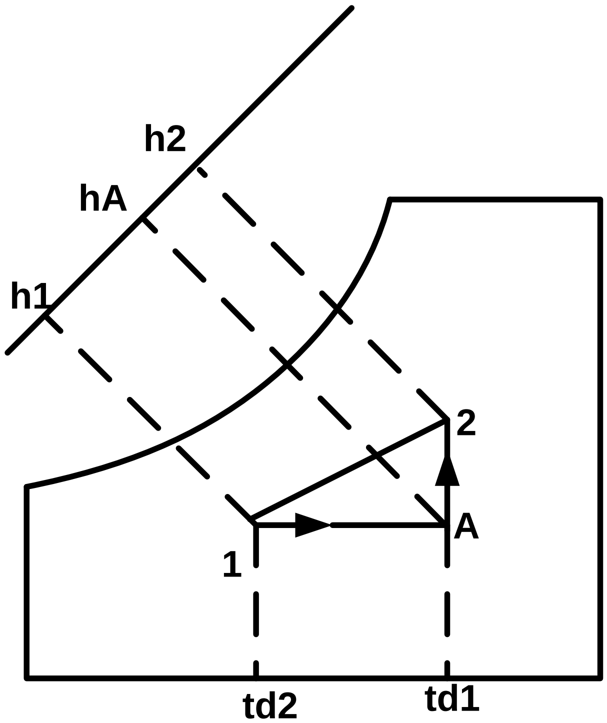
This process can be achieved by using a hygroscopic material, which absorbs or adsorbs the water vapor from the moisture. If this process is thermally isolated, then the enthalpy of air remains constant, as a result the temperature of air increases as its moisture content decreases. This hygroscopic material can be a solid or a liquid. In general, the absorption of water by the hygroscopic material is an exothermic reaction, as a result heat is released during this process, which is transferred to air and the enthalpy of air increases.

$$\eta = 1 - BPF = \frac{td3 - td1}{td2 - td1}$$



❖ Heating and humidification

This process is used in winter air conditioning system. This is normally done by first sensibly heating the air and then adding water vapour to the air stream through steam nozzles. The air is passed through humidifier having spray water temperature higher than the DBT of entering air. The heat of vaporization of water is absorbed from the spray water and it got cooled.



Total heat added to the air

Q= h2-h1 = (hA-h1) +(h2-hA) =SH+LH

SHF= $\frac{hA-h1}{h2-h1}$

Q1. 100 m3 of air per minute at 35°C DBT and 60% RH is cooled to 20°C DBT passing through a cooling coil. Find the following

a. Capacity of cooling coil in kJ/hr
b. Amount of water vapour removed per hour
c. RH of air coming out and its WBT

Ans:

Given

Pb= atmospheric pressure =1.0132 bar

At 35 degree DBT and 60%RH

Ps=0.05628 bar (from steam table at 35°C dbt)

ϕ =Pv/Ps

Pv1= 0.6 *0.05628 =0.033768 bar

Tdp corresponding to pv1 = 26.25°C (from steam table)

Find W1 = $0.622\frac{Pv}{Pb-Pv}$ $= 0.0214$ kg/kg of dry air

Find h1= 1.022*td1+ W1 (h_{fgdp} +2.3 t dp) = 89.27 kj/kg

h_{fgdp} (from steam table at dew point temperature of entering air) = 2440 KJ/Kg

Air is saturated as leaving air DBT is less than tdp of entering air

So at point 2 wbt=dbt=dpt= 20 °C

Ps2=Pv2 =0.0234 bar (from steam table corresponding to 20°C)

Find W2 and h2

W2== $0.622\frac{Pv2}{Pb-Pv2}$ $= 0.0147$ kg/kg of dry air

h2= 1.022*td2+ W2 (h_{fgdp} +2.3 t dp2) =57.19 kj/kg

h_{fgdp} (from steam table at dew point temperature of leaving air) = 2454 KJ/Kg

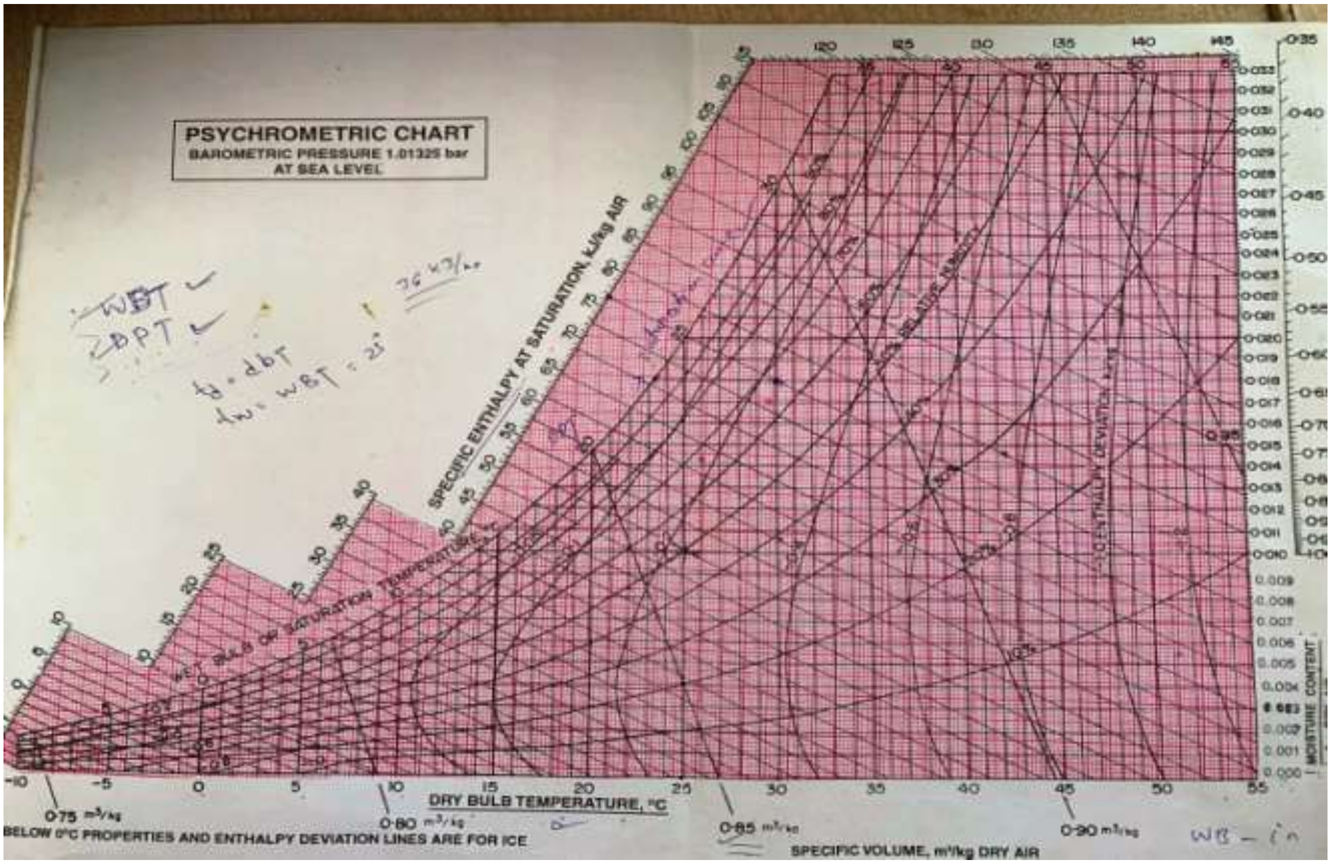
PaVa=Ma*R*td

Ma= $\frac{(1.0132 - 0.03376) * 10^5 * 100}{287 * (35 + 275)}$ = 110.8 kg/min

Capacity of cooling Q= ma (h1-h2) = 3554.46 kj/min =3554.46/210= 16.92 TR

Amount of water vapour removed Q= ma(W1-W2) =0.74 kg/min

Alternative way



From psychrometeric chart

At point 1

35°C dbt and 60% RH

W1=0.0214 kg/kg of dry air

h1=89.9 kj/kg

tdp= 26°C

Air is saturated as air leaving the coil has lower DBT than dew point temperature. Thus, humidification occurred.

So, tdp=twb=tdp at point 2 as air is saturated.

At point 2

W2= 0.0148 kg/kg of air

h2= 57 kj/kg

Air Conditioning

❖ Comfort chart

The Comfort Chart is a tool that helps operators determines how well air-handling equipment is providing thermal comfort for the building occupants or for a process within the facility. In designing winter or summer air conditioning system, the designer should be well conversant with a number of factors which physiologically affect human comfort.

The important factors are as follows: 1. Effective temperature, 2. Heat production and regulation in human body, 3. Heat and moisture losses from the human body, 4. Moisture content of air, 5. Quality and quantity of air. 6. Air motion, 7. Hot and cold surfaces

Effective Temperature : The degree of warmth or cold felt by a human body depends mainly on the following three factors:

1. Dry bulb temperature, 2. Relative humidity and 3. Air velocity.

- Too low humidity causes dryness of skin
- Too high humidity causes deposition of moisture in clothing
- High air velocity can cause un-comfort

In order to evaluate the combined effect of these factors, the effective temperature is employed. It is defined as that index which collates the combined effects of air temperature, relative humidity and air velocity on the human body. The numerical value of effective temperate is made equal to the temperature of stills (i.e 5 to 8 m/min air velocity) saturated air, which produces the same sensation of warmth as produced under the given conditions. The practical application of the concept of effective temperature is presented by the **comfort chart**. This chart is the result of research made on different kinds of people subjected to wide range of environmental temperature, relative humidity and air movement by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).

In the comfort chart, the dry bulb temperature is taken as abscissa and the wet bulb temperature of ordinates.

- The effective temperature for summer air conditioning is 21°C
- The effective temperature for winter air conditioning is 21.7°C
- In slightly cool condition comfort of human beings is not influenced by moisture from RH =30% to 90%
- With increase in temperature the comfort is influenced by moisture content.
- At tdb=25.3°C, 70% feel comfortable from RH =25% to 70%.

- It has been found that for comfort, women require 0.5ºC higher effective temperature than men.
- All men and women above 40 years of age prefer 0.5ºC higher effective temperature than the persons below 40 years of age.

Factors Affecting Optimum Effective Temperature

a. Climatic and seasonal differences: It is a known fact that the people living in colder climates feel comfortable at a lower effective temperature than those living in warmer regions. In winter the optimum effective temperature is 19ºC whereas in summer this temperature is 22ºC.
b. Clothing: Light clothing need less optimum temperature than a person with heavy clothing.
c. Age: The children need higher effective temperature than adults. Thus, the maternity halls are always kept at an effective temperature of 2 to 3ºC higher than the effective temperature used for adults.
d. Duration of stay It has been established that if the stay in a room is shorter, then higher effective temperature is required than that needed for long stay.
e. Kind of activity: When the activity of the person is heavy such as people working in a factory, dancing hall, then low effective temperature is needed than for the people sitting in cinema hall or auditorium.

Heat Production and Regulation in Human Body: The human body produces heat from the combustion of food. The rate of heat production depends upon the individual's health, his physical activity and his environment. Since the body has a thermal efficiency of 20 per cent, therefore the remaining 80 per cent of the heat must be rejected to the surrounding environment, otherwise accumulation of heat results which causes discomfort.

Moisture Content of Air: In general, for winter conditions in the average residence, relative humidity above 35 to 40 per cent is not practical. In summer comfort cooling, the air of the occupied space should not have a relative humidity above 60 per cent.

Quality and Quantity of Air: purity of air should be maintained as people do not feel comfortable while breathing contaminated air. So proper filtration, cleaning and purification of air is necessary. For general application, a minimum of 0.3 m 3 /min of outside air per person, mixed with 0.6m 3 /min of recirculated air is good.

Air Motion: The air motion which includes the distribution of air is very important to maintain uniform temperature in the conditioned space. No air conditioning system is satisfactory unless the air handled is properly circulated and distributed. Ordinarily, the air velocity in the occupied zone should not exceed 8 to 12 m/min. The air velocities in the space above the occupied zone should be very high in order to produce good distribution of air in the occupied zone.

- **Equipments used in air conditioning:**

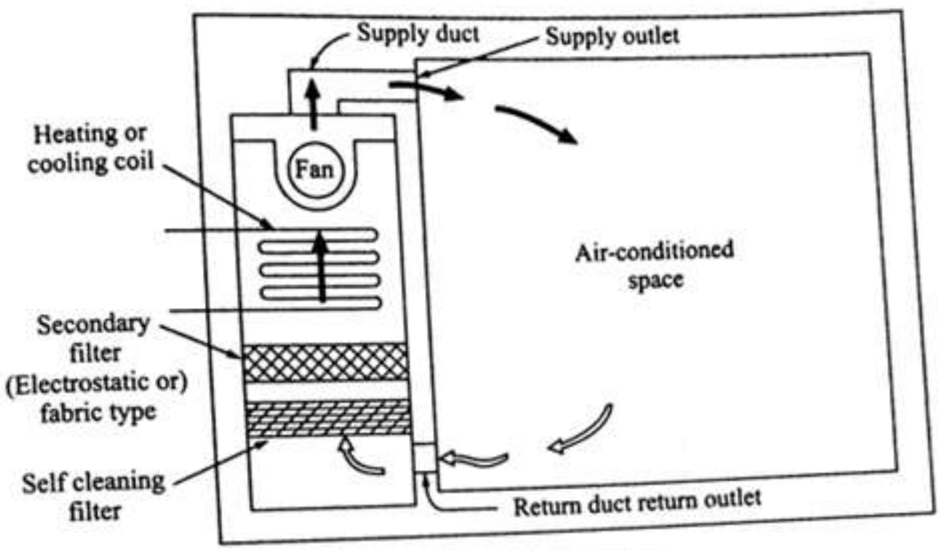


Fig. 14.1. Air-conditioning cycle.

1. **Circulation fan:** it moves air to and from the room
2. **Air conditioning unit:** it is a unit which consists of cooling and dehumidification in summer and heating and humidification in winter
3. **Supply duct:** it directs conditioned air from circulating fan to room
4. **Supply outlet:** it distribute conditioned air in the room evenly
5. **Return outlet:** it allows room air to return duct
6. **Filters:** it removes dust, dirt, bacteria from the air.

- **Classification of Air conditioning**
  1. According to purpose
     - Comfort air conditioning
     - Industrial air conditioning
  2. According to season
     - Winter air conditioning
     - Summer air conditioning
     - Year round air conditioning
  3. According to arrangement of equipment
     - Unitary air conditioning
     - Central air conditioning

Winter Air conditioning system

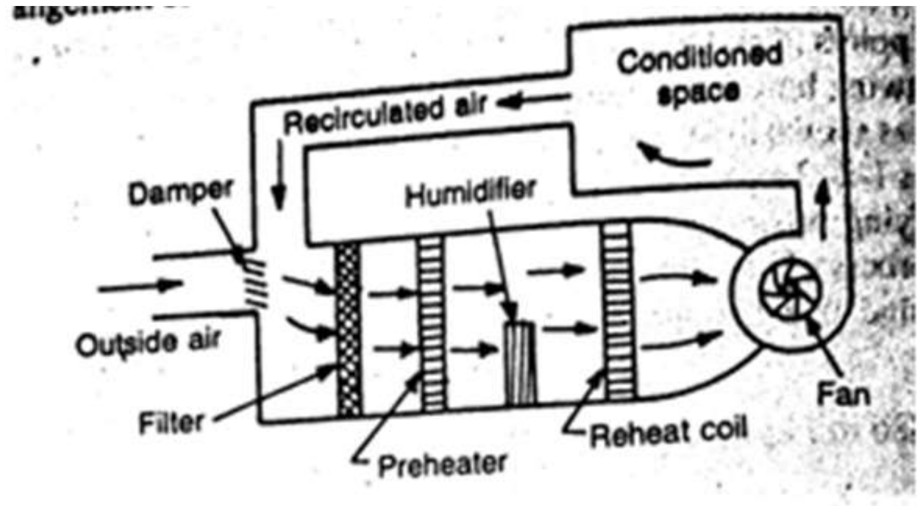


Fig. 38.3. Winter air conditioning system.

In winter AC System, the inlet air is heated by the heater, and in winter season due to less present of moisture in the air, we also need to add the moisture particle to the air, generally, a humidification system is added to maintain the moisture quantity. The outside air flows through a damper and mixes up with the recirculated air which is obtained from the conditioned space.

The mixture here passes through a filter to remove dirt, dust, and other impurities. The air now passes through a preheat coil to prevent the possible freezing of water and to control the evaporation of water in the humidifier. After that, the air is made to pass through a reheat coil to bring the air to the designed dry bulb temperature.

Now, the conditioned air is supplied to the conditioned space by a fan. From the conditioned space, a part of the air is exhausted to the atmosphere by the exhaust fans. The remaining part of the used air is again conditioned and this will repeat again and again.

Summer Air conditioning system

In this system, the air is cooled and generally dehumidified. The outside air flows through the damper and mixed with recirculated air (which is collected from the conditioned space). The mixed air passes through a filter to remove the dirt, dust and impurities.

The air is now passes through a cooling coil. The coil has a temperature much below the required dry bulb temperature of the air in the conditioned space. The cooled air passes through a perforated membrane and loses its moisture in the condensed which is collected in the sump. After that, the air is made to pass through a heating coil which heats the air slowly.

This is done to bring the air to the designed dry bulb temperature and relative humidity. Now the conditioned air is supplied to the conditioned space by a fan. From conditioned space, a part of the used air is rejected to the atmosphere by the exhaust fan. The remaining air is again conditioned and this repeated for again and again.

The outside air is sucked and made to mix with recirculated air to make for the loss of conditioned air through exhaust fan from the conditioned space.

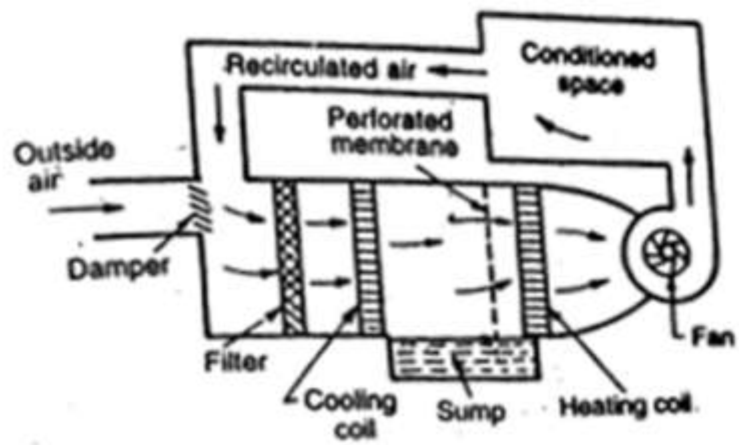


Fig. 38.5. Summer air conditioning system.