



REFRIGERATION AND AIR CONDITIONING

B.TECH. VII SEMESTER
MECHANICAL ENGINEERING

PREPARED BY:

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TEXT BOOKS

1. S. C. Arora, Domkundwar, —A Course in Refrigeration and Air-conditioning
2. C. P. Arora, —Refrigeration and Air Conditioning





UNIT – I

INTRODUCTION TO REFRIGERATION AND VAPOR COMPRESSION REFRIGERAION

Introduction

- Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature.
- One of the most important applications of refrigeration has been the preservation of perishable food products by storing them at low temperatures.
- Refrigeration systems are also used extensively for providing thermal comfort to human beings by means of air conditioning.
- Air Conditioning refers to the treatment of air so as to simultaneously control its temperature, moisture content, cleanliness, odour and circulation, as required by occupants, a process, or products in the space.

Introduction

- **The subject of refrigeration and air conditioning has evolved out of human need for food and comfort, and its history dates back to centuries.**
- **The history of refrigeration is very interesting since every aspect of it, the availability of refrigerants, the prime movers and the developments in compressors and the methods of refrigeration all are a part of it.**
- **Refrigeration also defined as continued extraction of heat from a body which is kept at a temperature lower than the surrounding temperature.**

Introduction

- If we remove bucket of water from a tank, the surrounding water rushes in to fill the cavity. Similarly heat rushes in, to replace the heat removed. Therefore, the insulation is provided to prevent the rush in heat.
- Therefore, the refrigeration involves in pumping of heat from lower temperature to higher temperature but heat has a natural tendency to flow from higher temperature to lower temperature.
- According to second law of thermodynamics heat can flow from a lower temperature to higher temperature with the aid of an external agency, so refrigeration works on the principle of second law of thermodynamics.

Thermodynamic Laws:

➤ First law of thermodynamics:

When a closed system undergoes a thermodynamic cycle, the net heat transfer is equal to the net work transfer.

$$\oint \delta Q = \oint \delta W$$

(OR)

The energy can neither be created nor destroyed but it can be transferred from one form of energy into another.

Thermodynamic Laws:

➤ **Second law of thermodynamics:**

i. Kelvin-Planck statement

It is impossible to construct a device that operates in a cyclic process and produce no effect other than to receive heat from a single reservoir to convert it into equivalent amount of work. In other words it is impossible to construct an engine whose sole purpose is to convert all amount of heat into equal amount of work.

ii. Clausius statement

It states that heat cannot flow from a body at lower temperature to a body at higher temperature without any aid of external energy.

Thermodynamic Laws:

➤ **Sensible Heat:**

When a substance is heated and its temperature rises as the heat is added, the increase in heat is called sensible heat.

➤ **Latent heat:**

The amount of heat required to change the phase of a substance from one state to another with no change in temperature is called latent heat.

Latent heat of ice = 335 KJ/Kg, it means 1 kg of ice requires 335 KJ of heat to change into water at 0°C & atmospheric pressure. This heat is called latent heat of fusion or melting.

Thermodynamic Laws:

Latent heat of water = 2257 KJ/Kg, it requires 2257 KJ of heat to become gas at 100⁰C & atmospheric pressure. This heat is called latent heat of vaporization or condensation.

➤ Specific heat:

The amount of heat required to raise the temperature of 1⁰K of unit mass of any substance KJ/Kg K.

Substance	Specific Heat
Water	4.187
Ice	2.110
Steam	2.094
Air	1.0

UNIT OF REFRIGERATION

➤ **Unit of refrigeration is TR (ton of refrigeration)**

It is defined as the amount of refrigeration effect produced by uniform melting of one ton of ice at 0°C with in 24 hours.

$$\begin{aligned}
 1 \text{ TR} &= 1000 \text{ Kg of ice} \\
 &= 1000 \times 335 \text{ KJ/Kg} && \text{: LH of ice} = 335 \text{ KJ/Kg} \\
 &= 335000 \text{ KJ / 24 hrs.} \\
 &= 335000 / (24 \times 60) \text{ KJ/min.} \\
 &= 232.6 \text{ KJ/min. (or)} \\
 &= 3.8 \text{ KW}
 \end{aligned}$$

But in actual practice it is considered as 210 KJ/min. or 3.5 KW

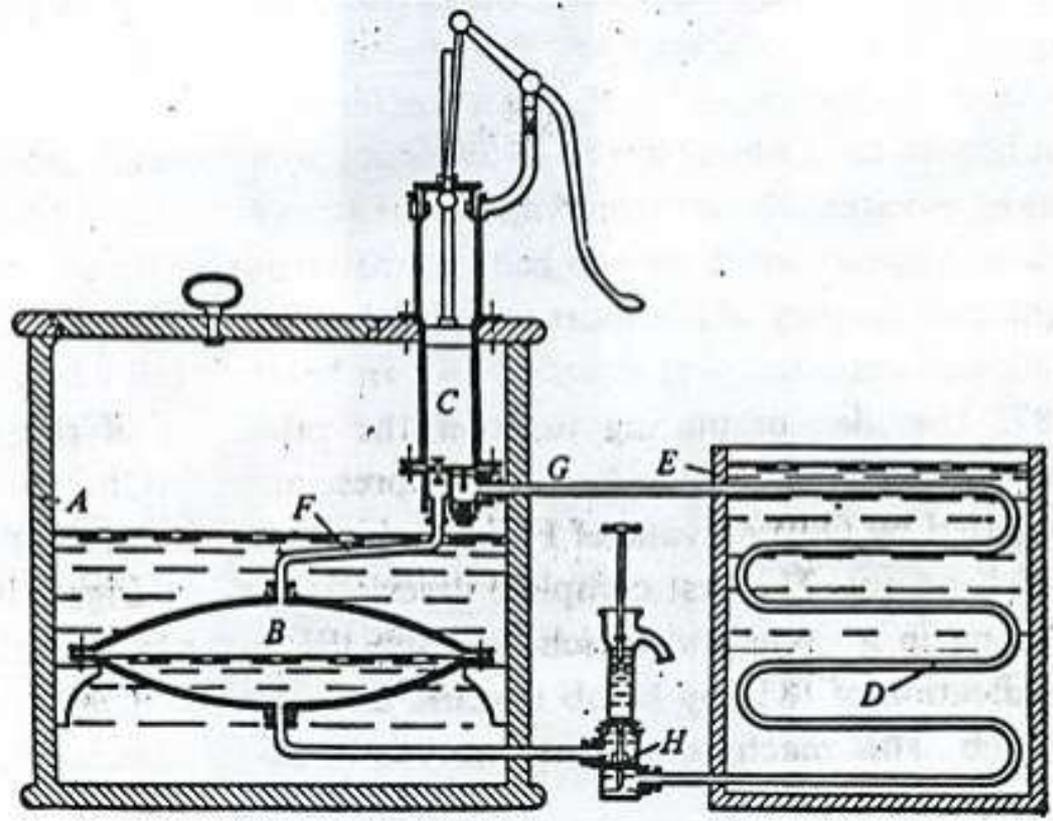
Natural Refrigeration

- In olden days refrigeration was achieved by natural means such as the use of ice or evaporative cooling. In earlier times, ice was either:
 1. Transported from colder regions,
 2. Harvested in winter and stored in ice houses for summer use or,
 3. Made during night by cooling of water by radiation to stratosphere.

Artificial Refrigeration

- Refrigeration as it is known these days is produced by artificial means. Though it is very difficult to make a clear demarcation between natural and artificial refrigeration, it is generally agreed that the history of artificial refrigeration began in the year 1755, when the Scottish professor William Cullen made the first refrigerating machine, which could produce a small quantity of ice in the laboratory.
- Based on the working principle, refrigeration systems can be classified as vapour compression systems, vapour absorption systems, gas cycle systems etc.

Apparatus described by Jacob Perkins in his patent specification of 1834.



Perkins machine built by John Hague



Reversed Carnot cycle employing a gas

- **Reversed Carnot cycle is an ideal refrigeration cycle for constant temperature external heat source and heat sinks.**

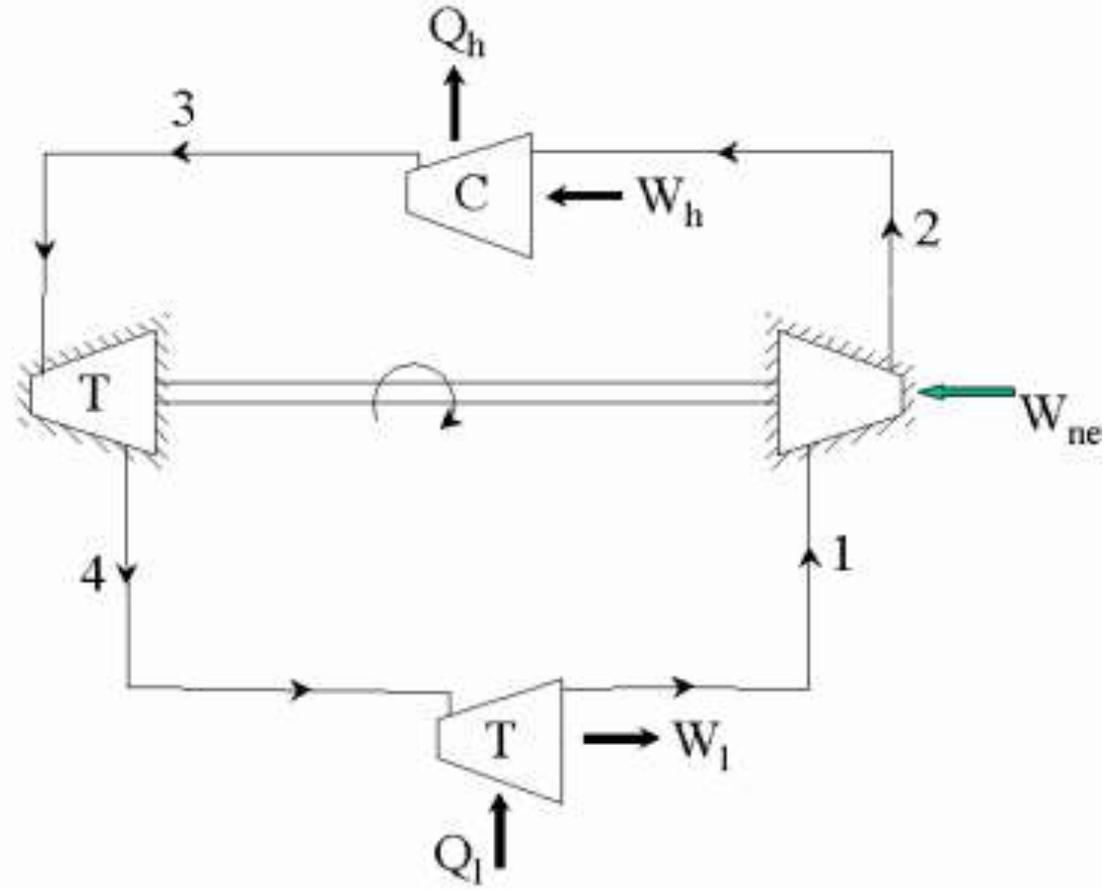
Process 1-2: Reversible, adiabatic compression in a compressor

Process 2-3: Reversible, isothermal heat rejection in a compressor

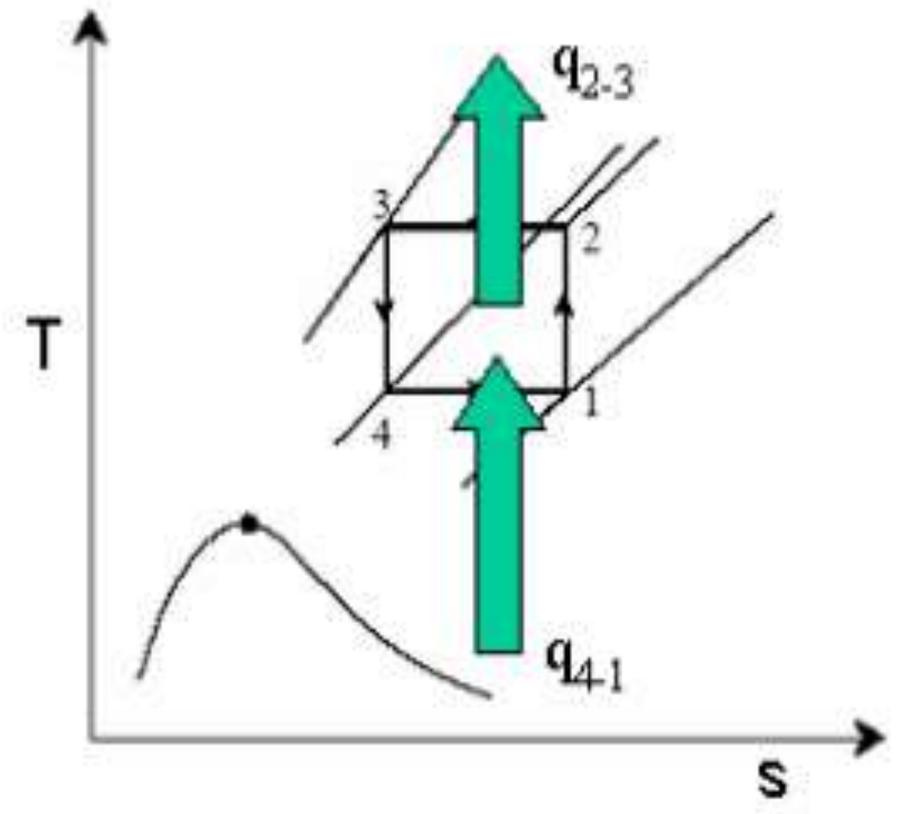
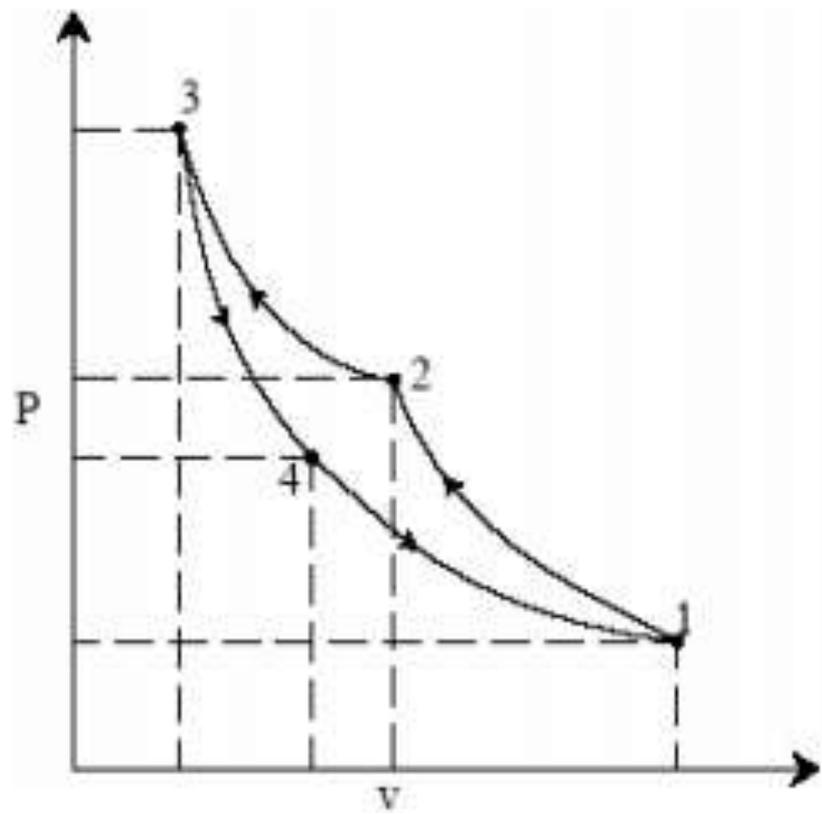
Process 3-4: Reversible, adiabatic expansion in a turbine

Process 4-1: Reversible, isothermal heat absorption in a turbine

Schematic of a reverse Carnot refrigeration system



Reverse Carnot refrigeration system in P-v and T-s coordinates

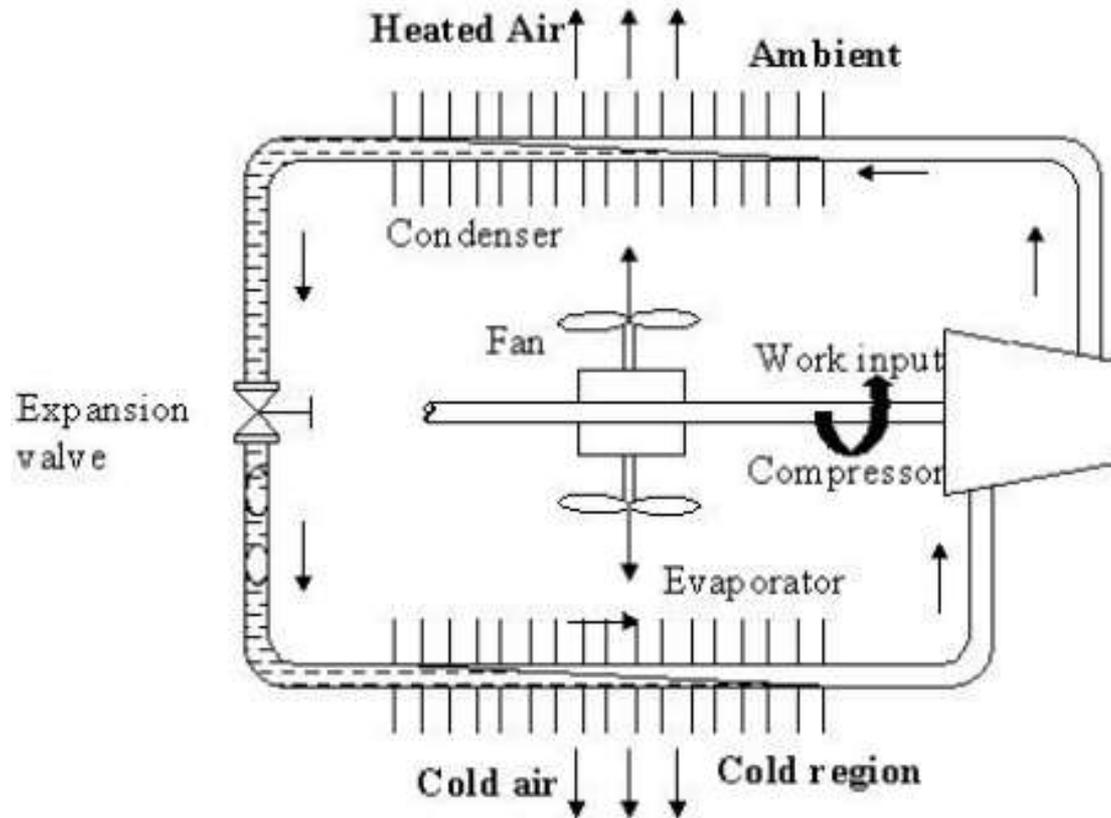


$$\text{COP}_{\text{Carnot}} = \frac{|q_{4-1}|}{|W_{\text{net}}|} = \left(\frac{T_1}{T_h - T_1} \right)$$

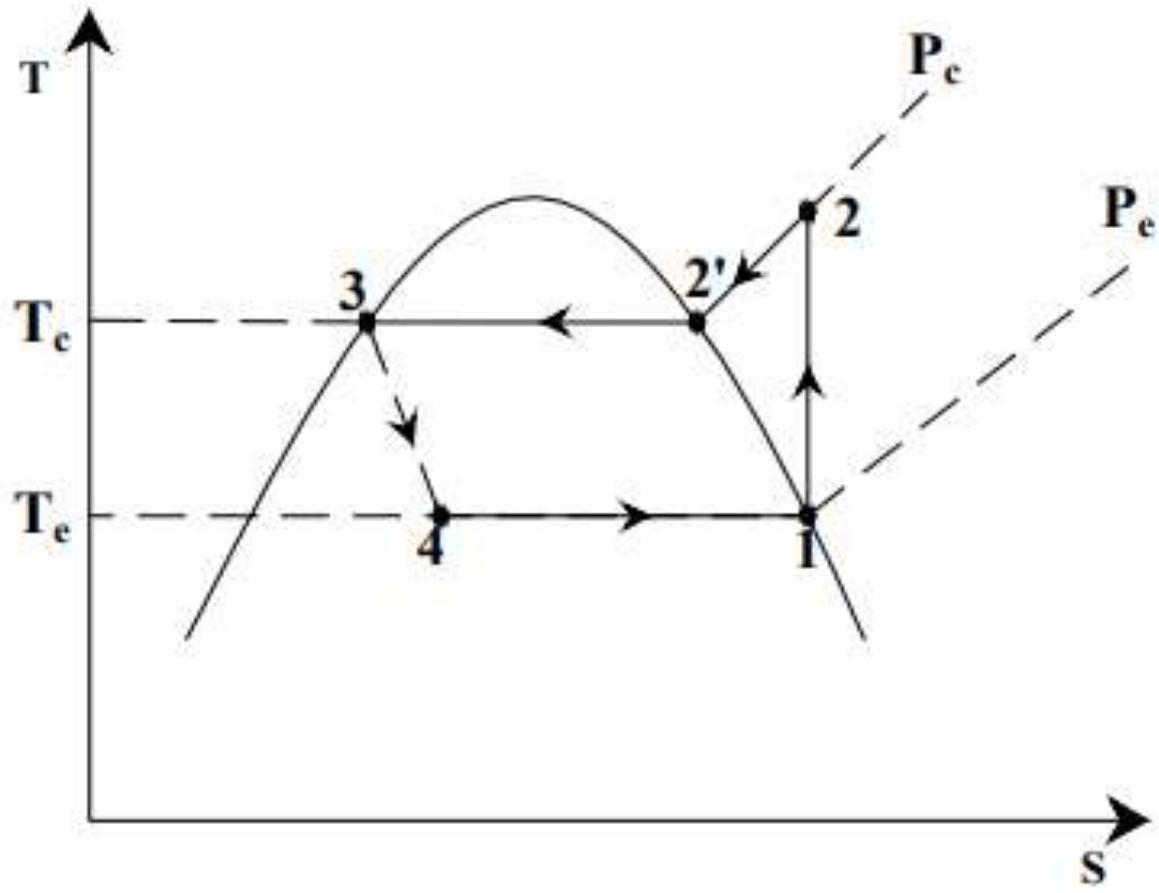
Vapour Compression Refrigeration Systems:

- The basis of modern refrigeration is the ability of liquids to absorb enormous quantities of heat as they boil and evaporate.
- Professor William Cullen of the University of Edinburgh demonstrated this in 1755 by placing some water in thermal contact with ether under a receiver of a vacuum pump.
- The evaporation rate of ether increased due to the vacuum pump and water could be frozen.
- This process involves two thermodynamic concepts, the vapour pressure and the latent heat. A liquid is in thermal equilibrium with its own vapor at a pressure called the saturation pressure, which depends on the temperature alone.

Schematic of a basic vapour compression refrigeration system



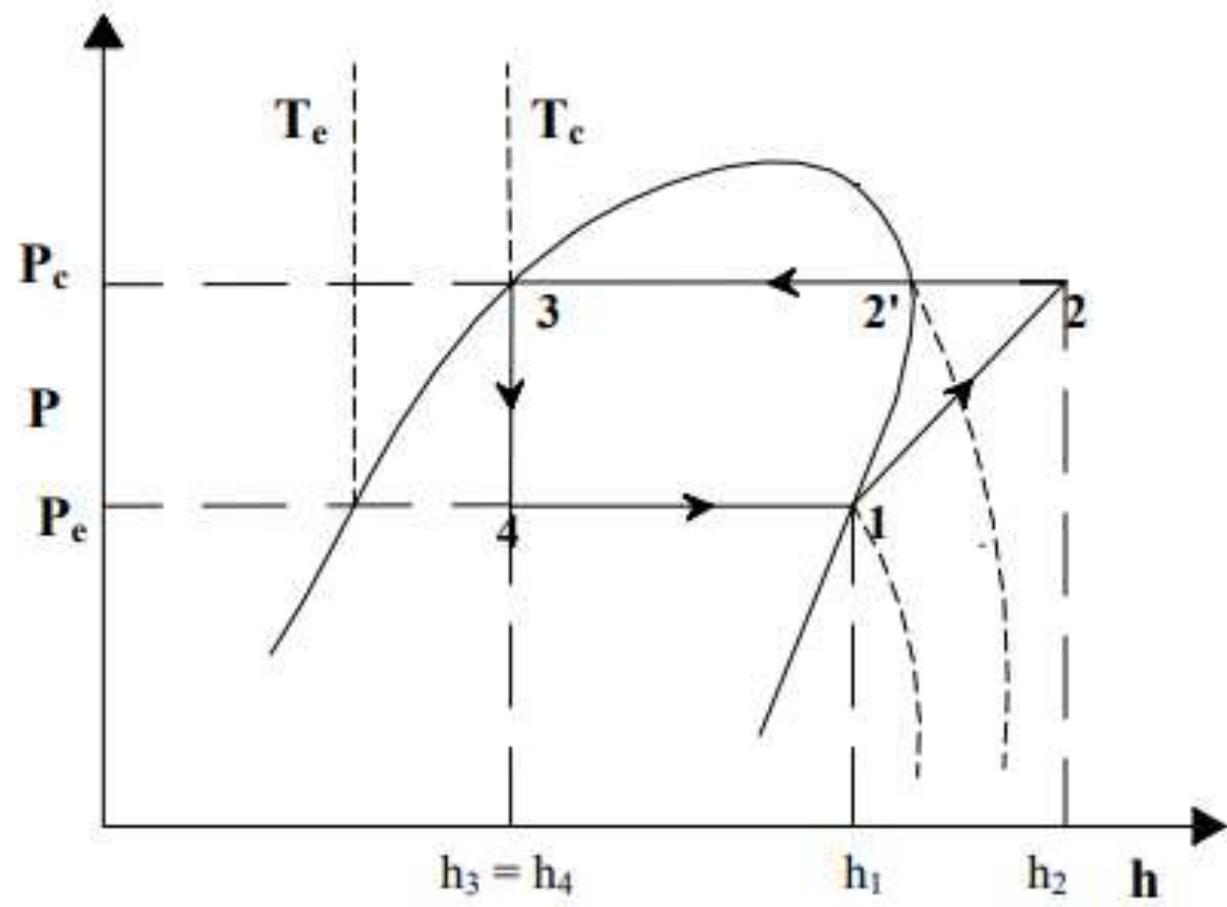
Vapour Compression Refrigeration Systems:



Standard Vapour Compression Refrigeration System (VCRS)

- **Process 1-2:** Isentropic compression of saturated vapour in compressor
- **Process 2-3:** Isobaric heat rejection in condenser
- **Process 3-4:** Isenthalpic expansion of saturated liquid in expansion device
- **Process 4-1:** Isobaric heat extraction in the evaporator

Standard vapour compression refrigeration cycle on a P-h chart



Analysis Standard Vapour Compression Refrigeration System (VCRS)

Evaporator:

- Heat transfer rate at evaporator or refrigeration capacity, is given by:

$$Q_e = m_r (h_1 - h_4)$$

- Where m_r is the refrigerant mass flow rate in kg/s, h_1 and h_4 are the specific enthalpies (kJ/kg) at the exit and inlet to the evaporator, respectively. $(h_1 - h_4)$ is known as specific refrigeration effect or simply refrigeration effect, which is equal to the heat transferred at the evaporator per kilogram of refrigerant. The evaporator pressure P_e is the saturation pressure corresponding to evaporator temperature T_e .

Analysis Standard Vapour Compression Refrigeration System (VCRS)

Compressor:

- Power input to the compressor, is given by:

$$\dot{W}_c = \dot{m}_r (h_2 - h_1)$$

- here h_2 and h_1 are the specific enthalpies (kJ/kg) at the exit and inlet to the compressor respectively. $(h_2 - h_1)$ is known as specific work of compression or simply work of compression, which is equal to the work input to the compressor per kilogram of refrigerant.

Analysis Standard Vapour Compression Refrigeration System (VCRS)

Condensor:

- Heat transfer rate at condenser, is given by

$$\dot{Q}_c = \dot{m}_r (h_2 - h_3)$$

- where h_3 and h_2 are the specific enthalpies (kJ/kg) at the e respectively.

Analysis Standard Vapour Compression Refrigeration System (VCRS)



Expansion Device:

- **Expansion device:** For the isenthalpic expansion process the kinetic energy change across the expansion device could be considerable, however, if we take the control volume, well downstream of the expansion device, then the kinetic energy gets dissipated due to viscous effects, and

$$h_3 = h_4$$



UNIT – II

VAPOR ABSORPTION AND AIR REFRIGERATION

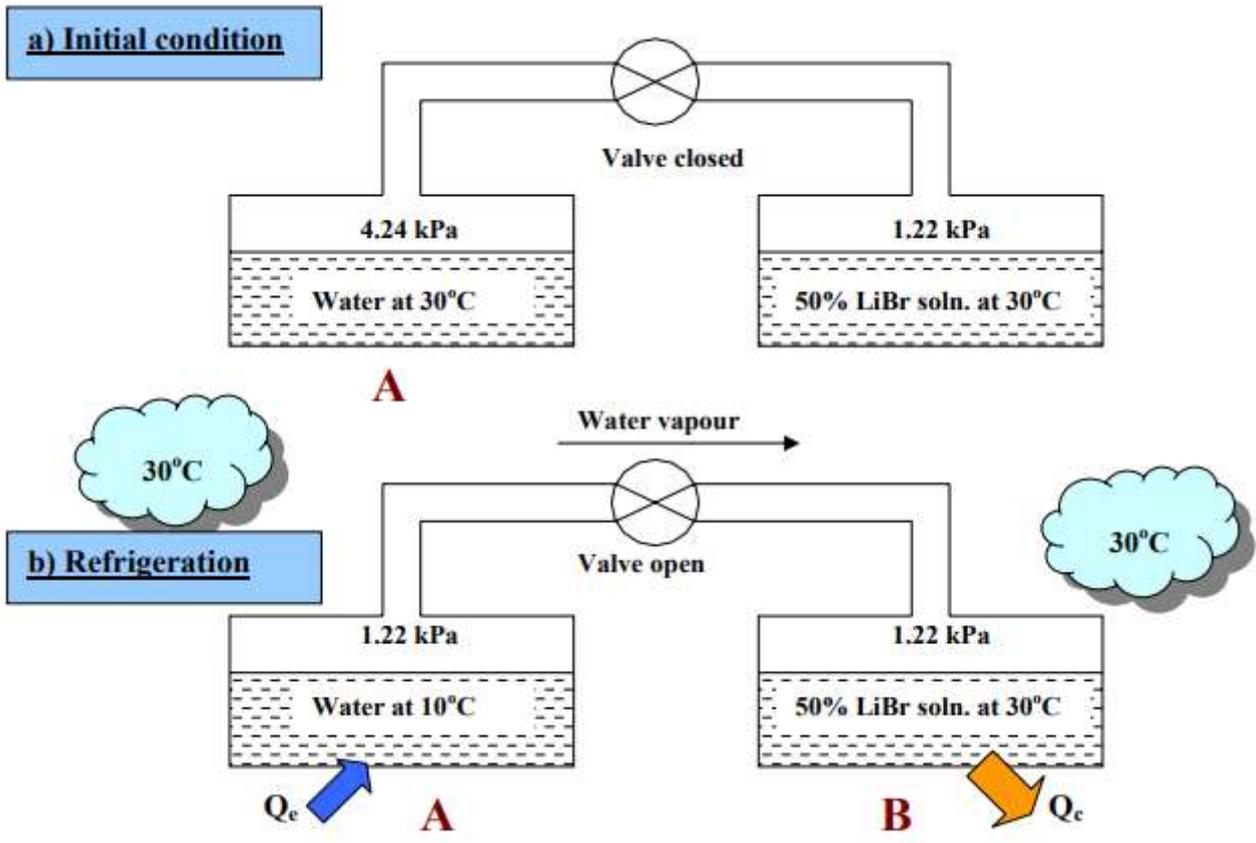
Basic principle

- When a solute such as lithium bromide salt is dissolved in a solvent such as water, the boiling point of the solvent (water) is elevated. On the other hand, if the temperature of the solution (solvent + solute) is held constant, then the effect of dissolving the solute is to reduce the vapour pressure of the solvent below that of the saturation pressure of pure solvent at that temperature.
- If the solute itself has some vapour pressure (i.e., volatile solute) then the total pressure exerted over the solution is the sum total of the partial pressures of solute and solvent.
- In the simplest absorption refrigeration system, refrigeration is obtained by connecting two vessels, with one vessel containing pure solvent and the other containing a solution.

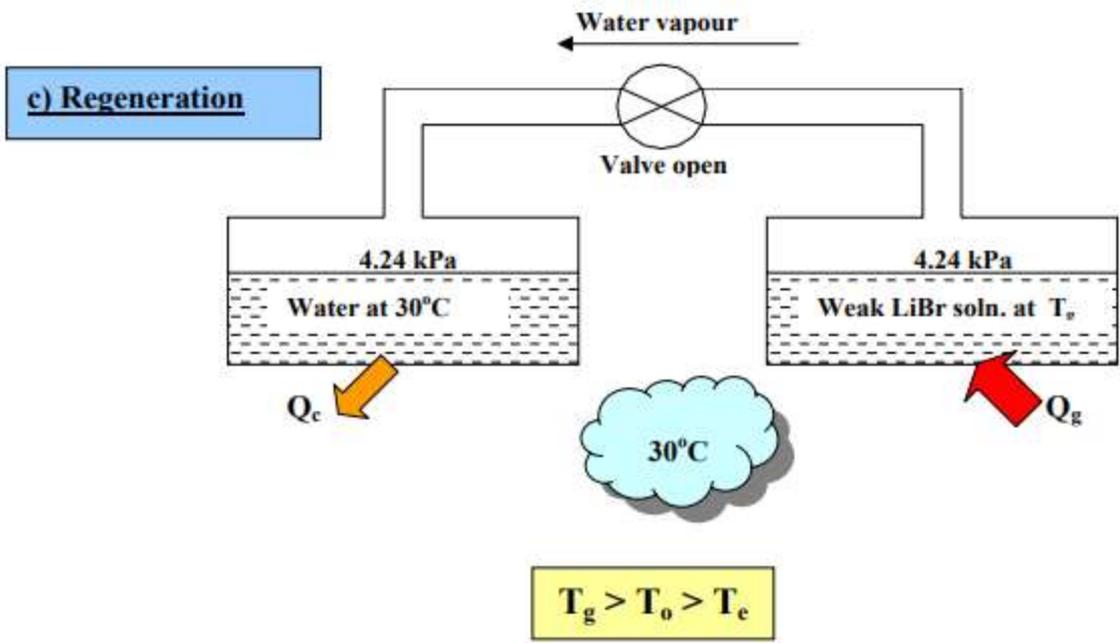
Basic principle

- Since the pressure is almost equal in both the vessels at equilibrium, the temperature of the solution will be higher than that of the pure solvent. This means that if the solution is at ambient temperature, then the pure solvent will be at a temperature lower than the ambient.
- Hence refrigeration effect is produced at the vessel containing pure solvent due to this temperature difference. The solvent evaporates due to heat transfer from the surroundings, flows to the vessel containing solution and is absorbed by the solution. This process is continued as long as the composition and temperature of the solution are maintained and liquid solvent is available in the container.

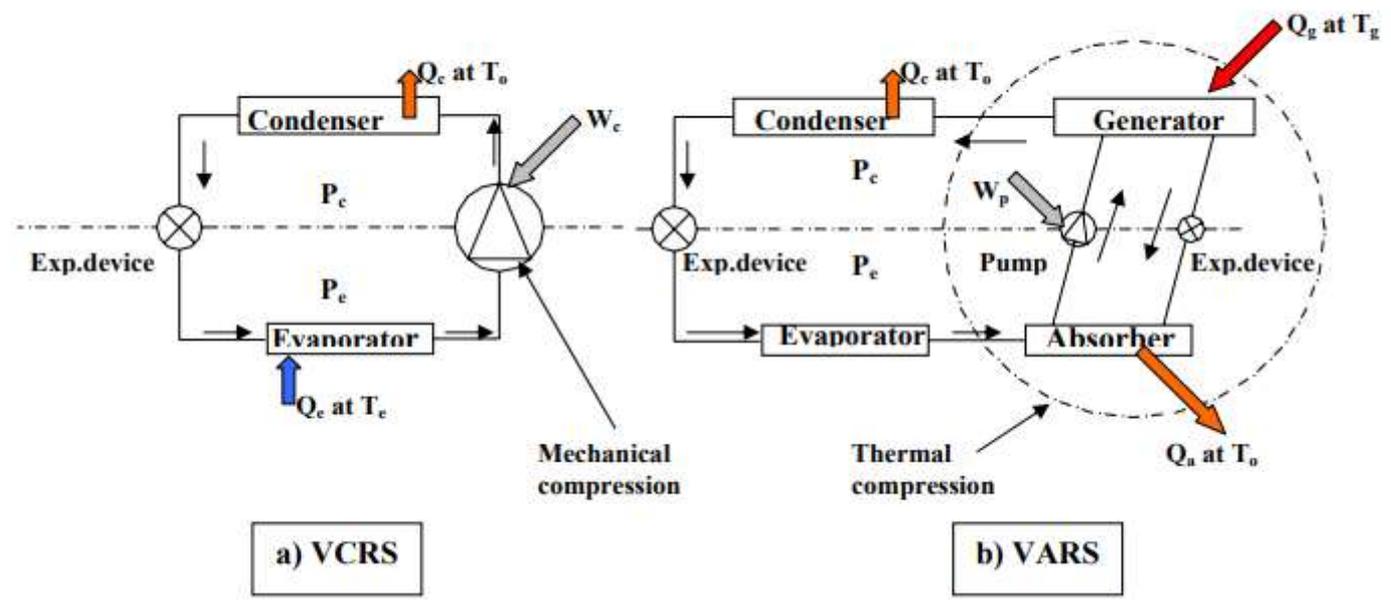
Basic principle



Basic principle



Difference between VCRS AND VARS



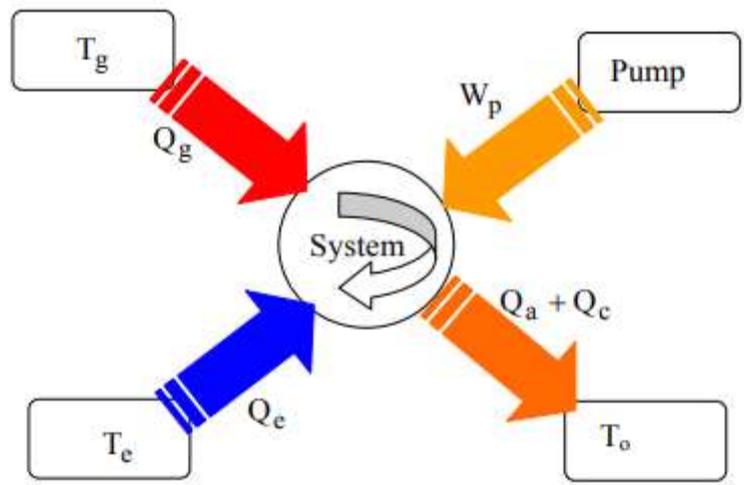
Maximum COP of ideal absorption refrigeration system

- In case of a single stage compression refrigeration system operating between constant evaporator and condenser temperatures, the maximum possible COP is given by Carnot COP:

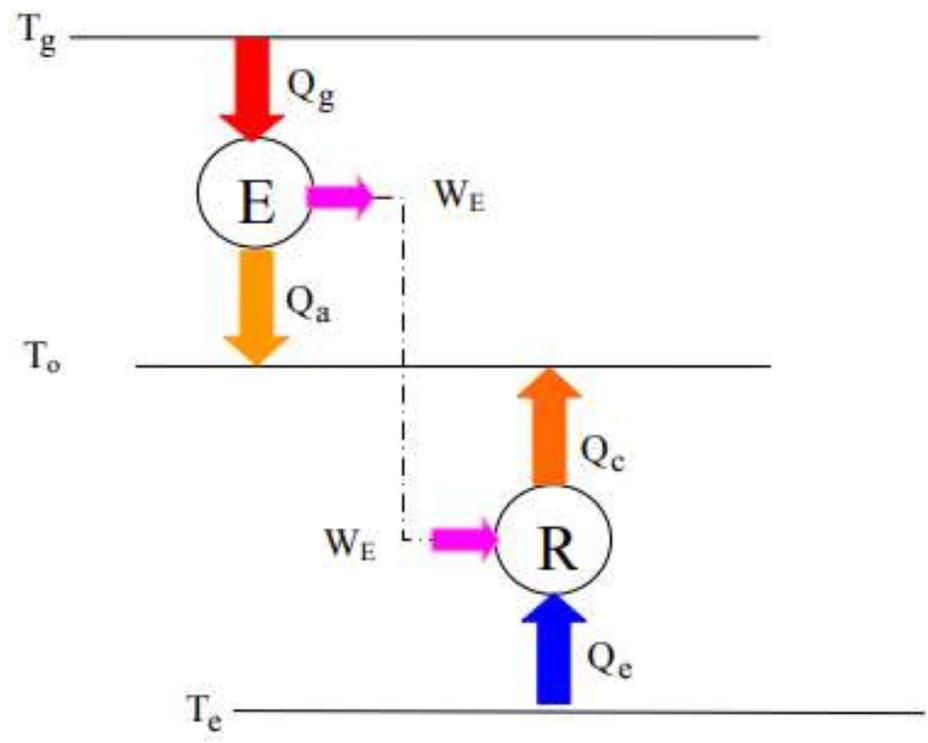
$$\text{COP}_{\text{Carnot}} = \frac{T_e}{T_c - T_e}$$

- If we assume that heat rejection at the absorber and condenser takes place at same external heat sink temperature T_o , then a vapour absorption refrigeration system operates between three temperature levels, T_g , T_o and T_e . The maximum possible COP of a refrigeration system operating between three temperature levels can be obtained by applying first and second laws of thermodynamics to the system.

Various Energy Transfers



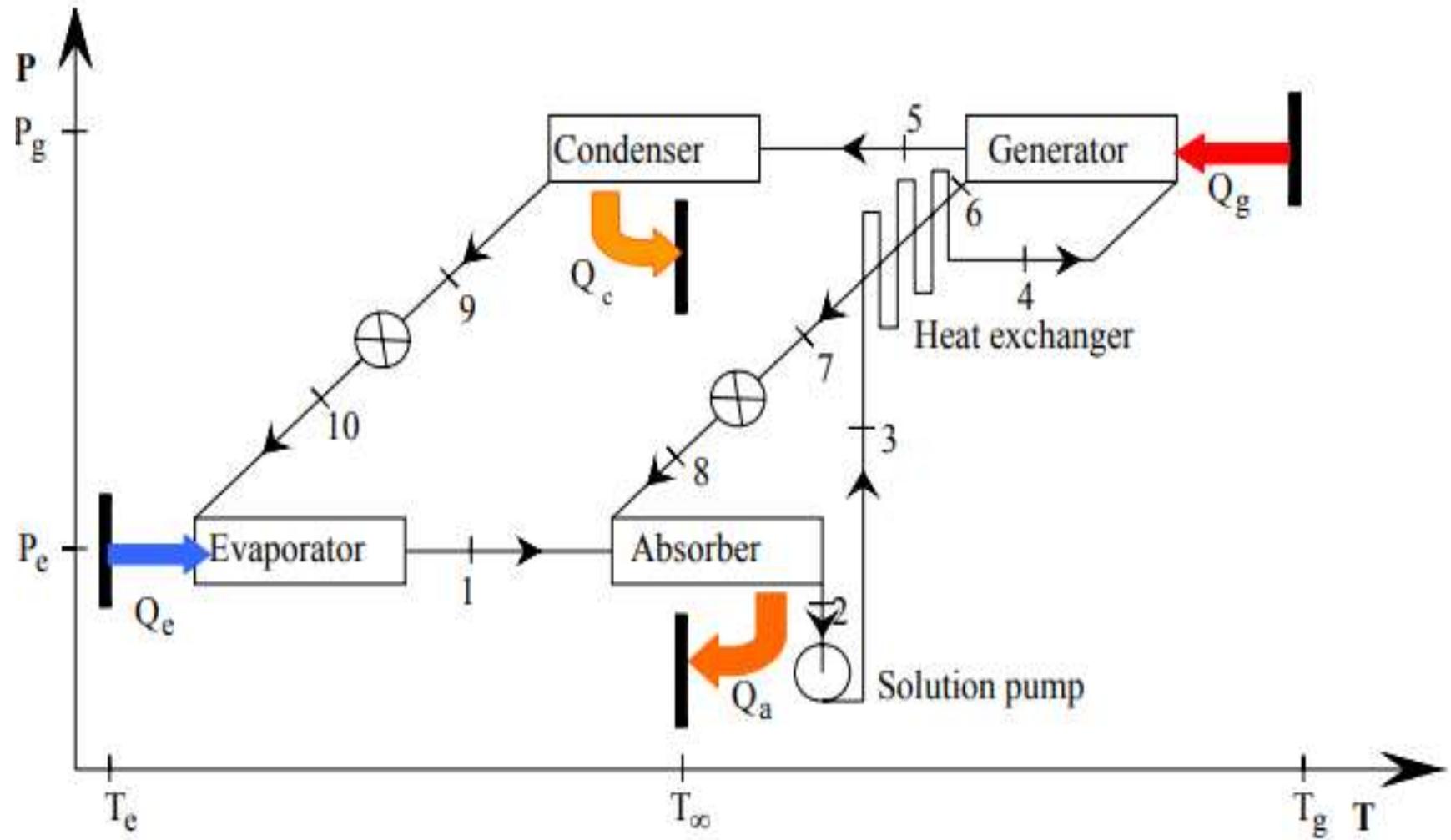
Vapour absorption refrigeration system as a combination of a heat engine and a refrigerator



Properties of refrigerant-absorbent mixtures

- The solution used in absorption refrigeration systems may be considered as a homogeneous binary mixture of refrigerant and absorbent.
- Depending upon the boiling point difference between refrigerant and absorbent and the operating temperatures, one may encounter a pure refrigerant vapour or a mixture of refrigerant and absorbent vapour in generator of the absorption system.
- Unlike pure substances, the thermodynamic state of a binary mixture (in liquid or vapour phase) cannot be fixed by pressure and temperature alone.
- According to Gibbs' phase rule, one more parameter in addition to temperature and pressure is required to completely fix the thermodynamic state.

Basic Vapour Absorption Refrigeration System



Basic Vapour Absorption Refrigeration System

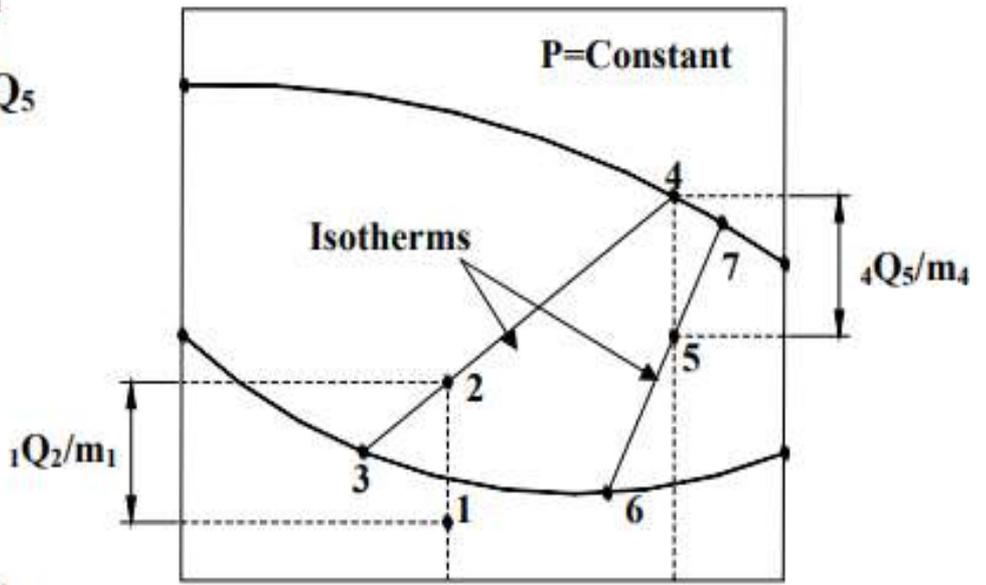
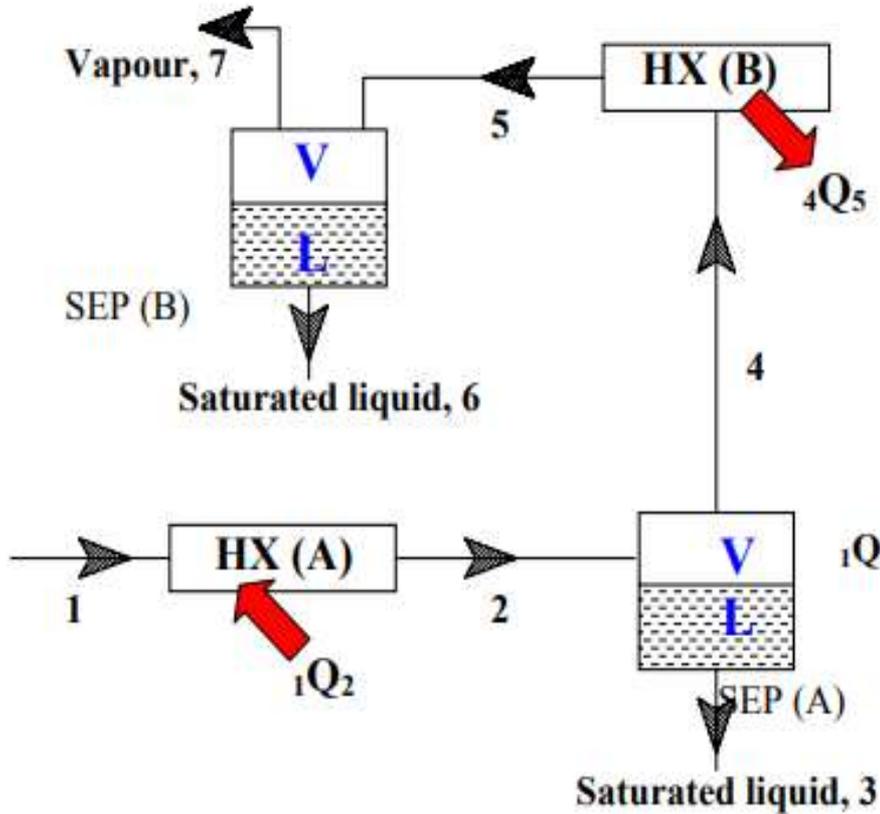
- **The thermodynamic performance of the above system can be evaluated by applying mass and energy balance to each component assuming a steady flow process.**
- **In simple theoretical analyses, internal irreversibilities such as pressure drops between the components are generally neglected.**
- **To find the performance from the mass and energy balance equations one needs to know inputs such as the type of refrigerant-absorbent mixtures used in the system, operating temperatures, composition of solution at the entry and exit of absorber, effectiveness of solution heat exchanger etc.**

Refrigerant-absorbent combinations for VARS

- The refrigerant should exhibit high solubility with solution in the absorber. This is to say that it should exhibit negative deviation from Raoult's law at absorber.
- There should be large difference in the boiling points of refrigerant and absorbent (greater than 200°C), so that only refrigerant is boiled-off in the generator. This ensures that only pure refrigerant circulates through refrigerant circuit (condenser-expansion valve-evaporator) leading to isothermal heat transfer in evaporator and condenser.
- It should exhibit small heat of mixing so that a high COP can be achieved. However, this requirement contradicts the first requirement. Hence, in practice a trade-off is required between solubility and heat of mixing.

- **The refrigerant-absorbent mixture should have high thermal conductivity and low viscosity for high performance.**
- **It should not undergo crystallization or solidification inside the system. vi. The mixture should be safe, chemically stable, non-corrosive, inexpensive and should be available easily**

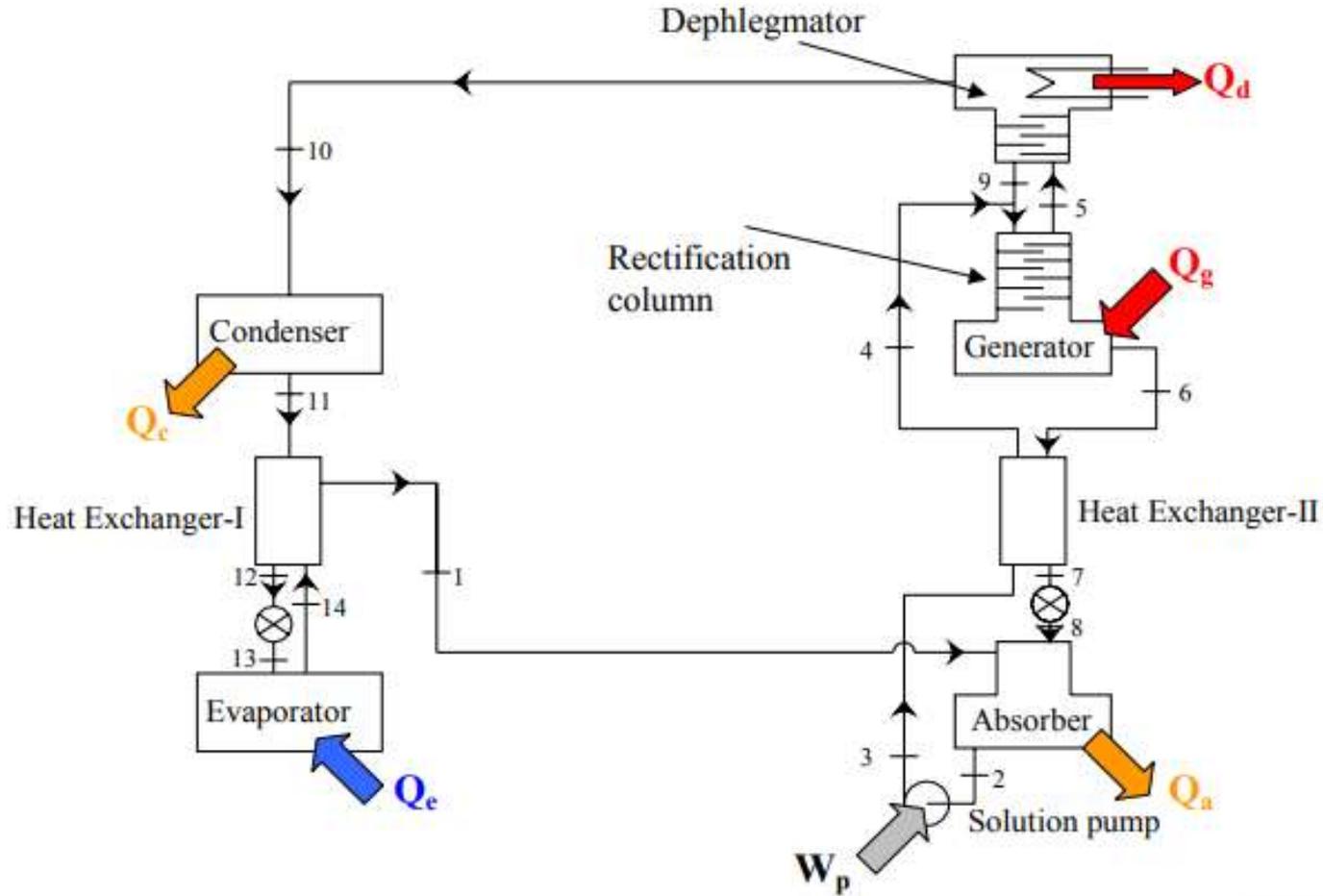
Heating and cooling of NH₃-H₂O solution – concept of rectification



Simple Ammonia-Water VARS

- It may be noted that from the above arrangement consisting of heating, cooling and separation, one finally obtains a vapour at state 7 that is rich in ammonia.
- That is the combination of heat exchangers with separators is equivalent to the process of rectification. Heat exchanger A plays the role of generator, while heat exchanger B plays the role of dephlegmator.
- To improve the process of rectification in actual vapour absorption refrigeration systems, a rectifying column is introduced between the generator and dephlegmator.
- In the rectifying column, the vapour from the separator A comes in contact with the saturated liquid coming from separator B. As a result, there will be heat and mass transfer between the vapour and liquid and finally the vapour comes out at a much higher concentration of ammonia.

Schematic of NH₃-H₂O based vapour absorption refrigeration system



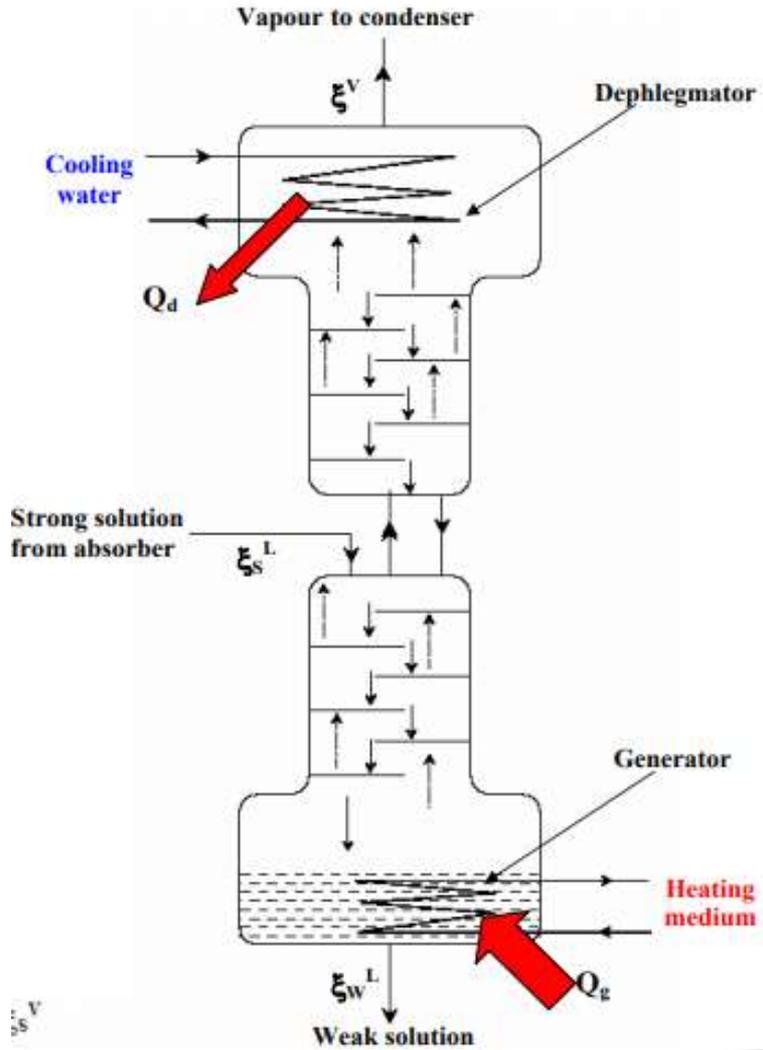
Working principle

- **Compared to water-lithium bromide systems, this system uses three additional components: a rectification column, a dephlegmator and a subcooling heat exchanger (Heat Exchanger-I).**
- **As mentioned before, the function of rectification column and dephlegmator is to reduce the concentration of water vapour at the exit of the generator. Without these the vapour leaving the generator may consist of five to ten percent of water.**
- **However, with rectification column and dephlegmator the concentration of water is reduced to less than one percent. The rectification column could be in the form of a packed bed or a spray column or a perforated plate column in which the vapour and solution exchange heat and mass.**

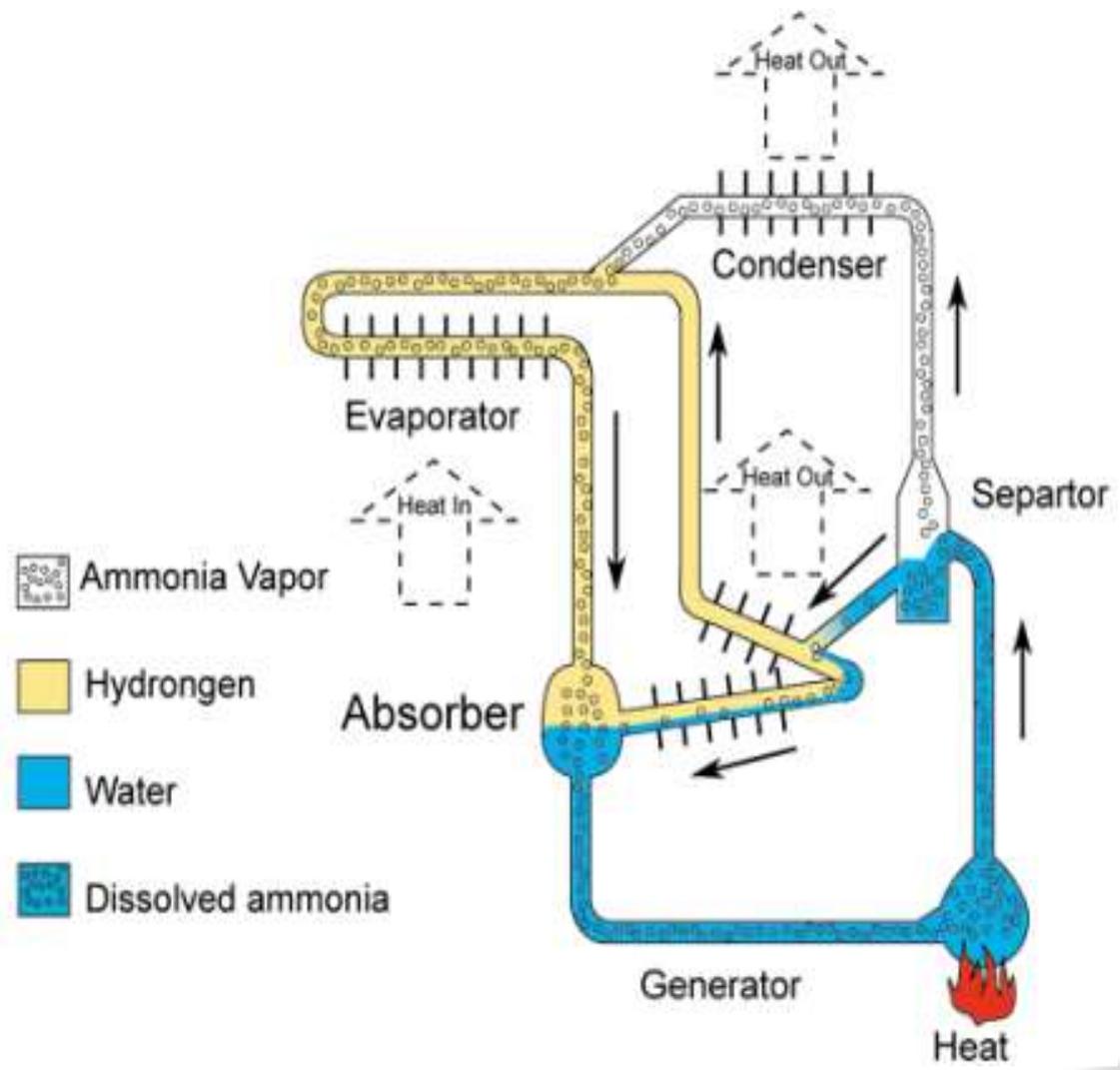
Simple Ammonia-Water VARS

- It is designed to provide a large residence time for the fluids so that high heat and mass transfer rates could be obtained.
- The subcooling heat exchanger, which is normally of counterflow type is used to increase the refrigeration effect and to ensure liquid entry into the refrigerant expansion valve.

Rectification process in the generator

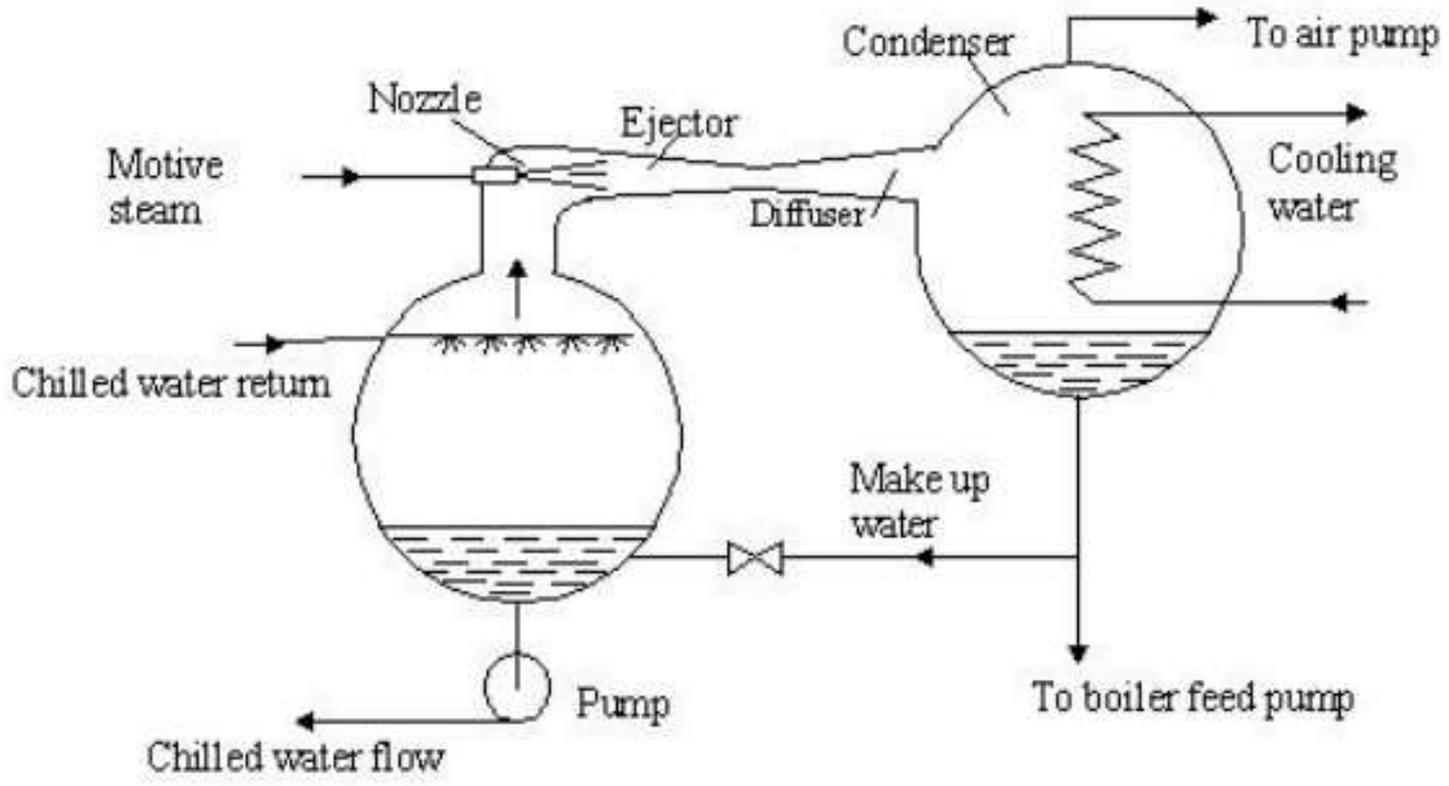


Schematic of a triple fluid vapour absorption refrigeration system



Steam Jet Refrigeration System:

- If water is sprayed into a chamber where a low pressure is maintained, a part of the water will evaporate. The enthalpy of evaporation will cool the remaining water to its saturation temperature at the pressure in the chamber.
- Obviously lower temperature will require lower pressure. Water freezes at 0°C hence temperature lower than 4°C cannot be obtained with water.
- In this system, high velocity steam is used to entrain the evaporating water vapour. High-pressure motive steam passes through either convergent or convergentdivergent nozzle where it acquires either sonic or supersonic velocity and low pressure of the order of 0.009 kPa corresponding to an evaporator temperature of 4°C .





UNIT – III

COMPONENTS OF REFRIGERATION

Compressors

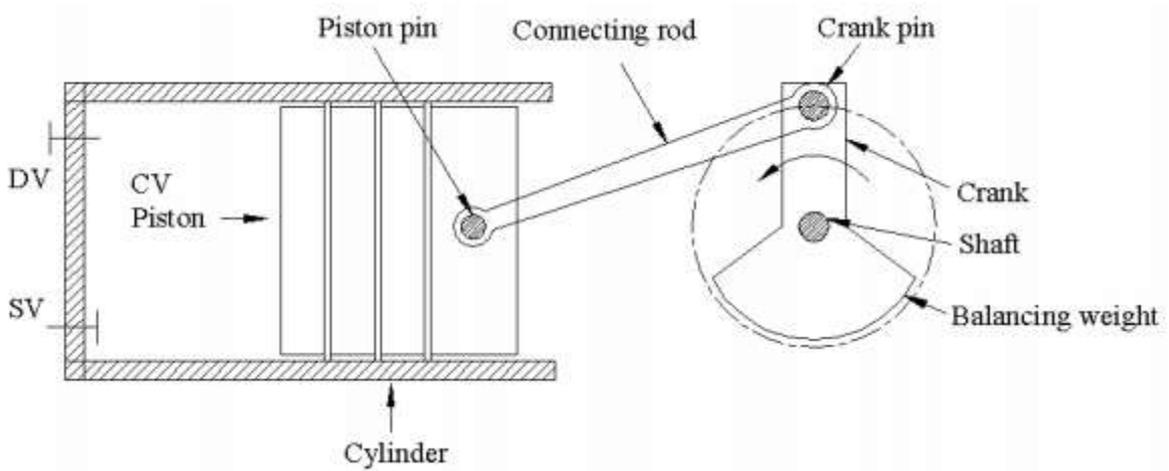
- **A compressor is the most important and often the costliest component (typically 30 to 40 percent of total cost) of any vapour compression refrigeration system (VCRS). The function of a compressor in a VCRS is to continuously draw the refrigerant vapour from the evaporator, so that a low pressure 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

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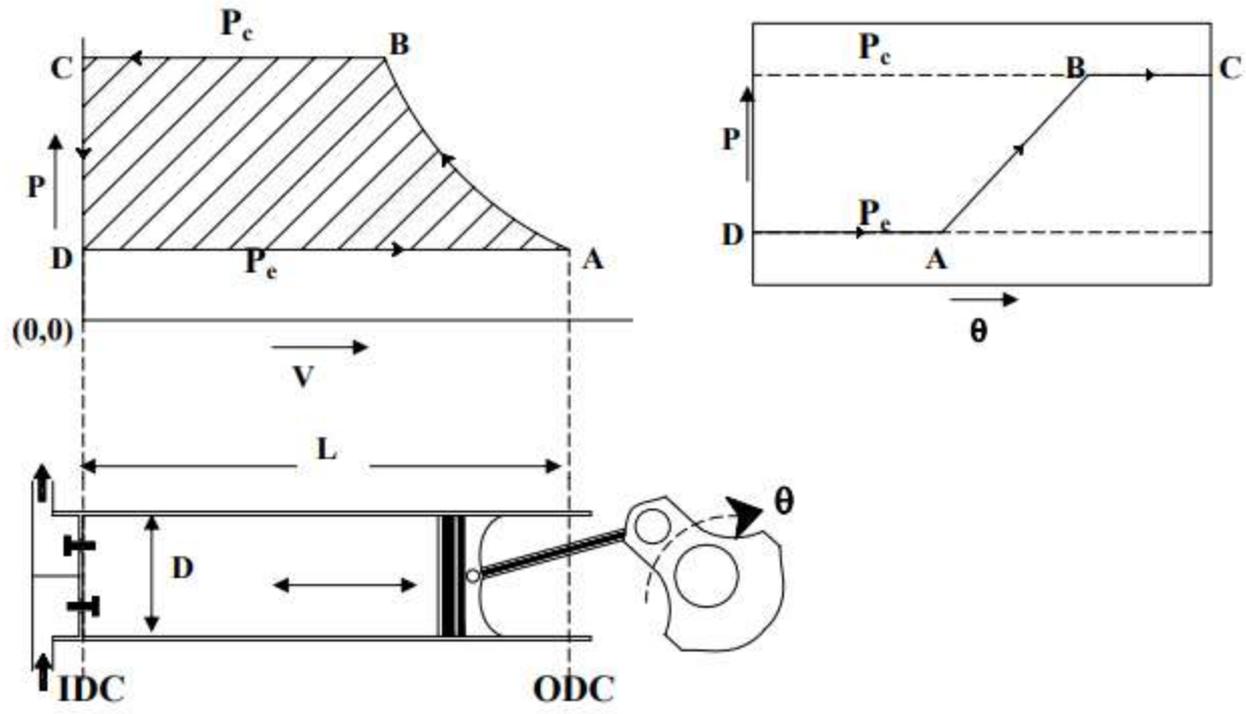
Reciprocating compressors

- 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. 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.**

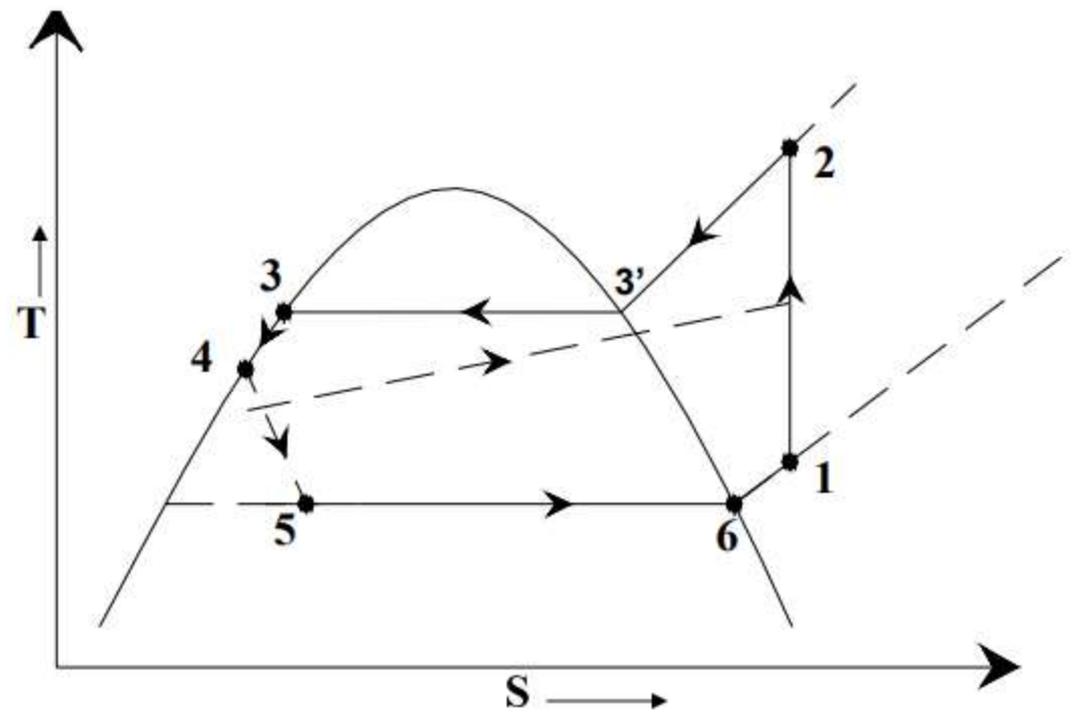
Ideal reciprocating compressor on P-V and P-θ diagrams



Condensers:

- 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.
- 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 T_2 to the saturation temperature corresponding condensing pressure, $T_{3'}$.

Condensers: T-S Diagram



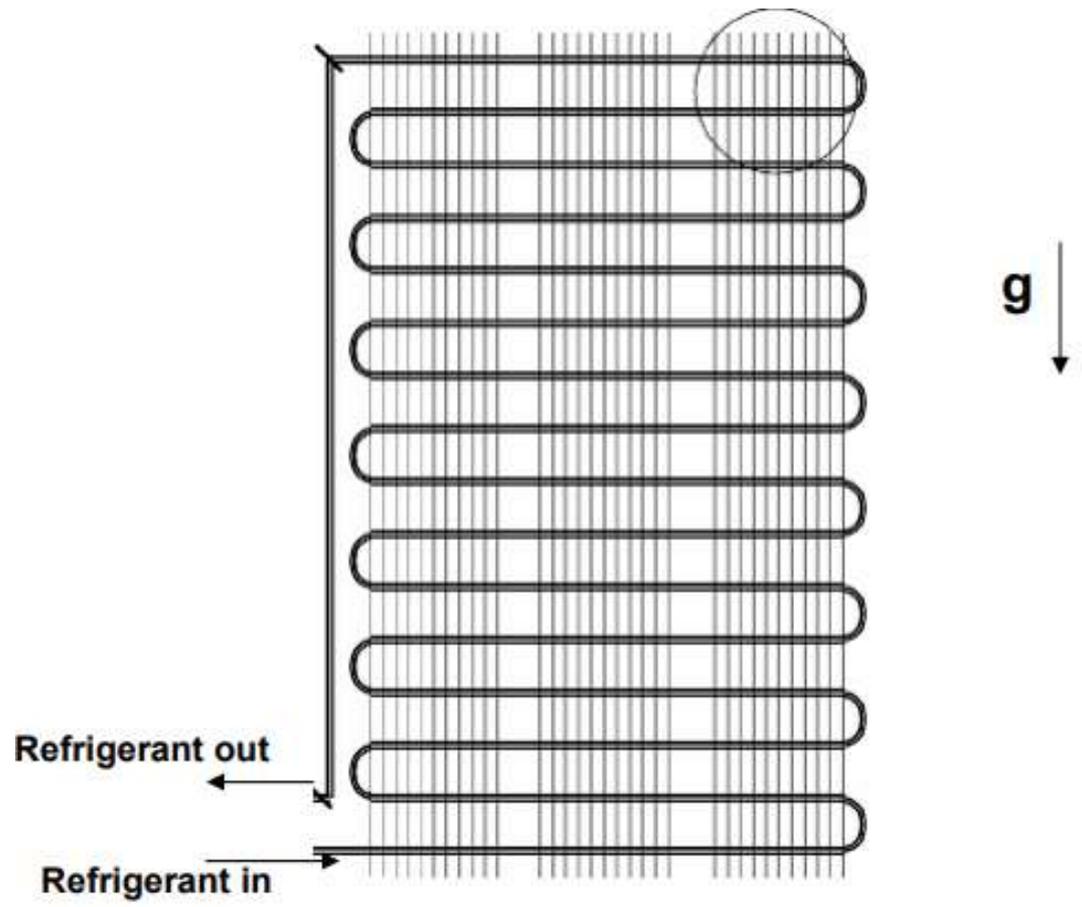
Classification of condensers:

- a) Air cooled condensers
- b) Water cooled condensers, and
- c) Evaporative condensers

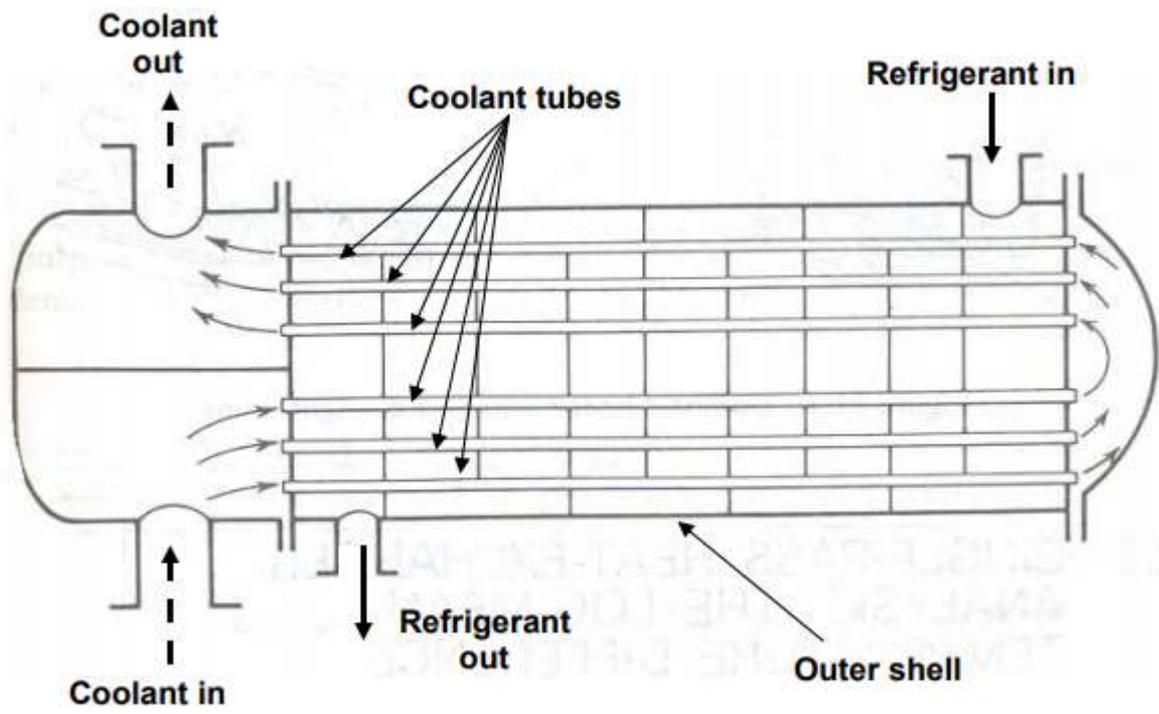
➤ **Air-cooled condensers:**

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.

Condensers:



Shell-and-tube type:



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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

Expansion Devices

- 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

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 ranges from 1.0 m to 6 m.**

Capillary Tube

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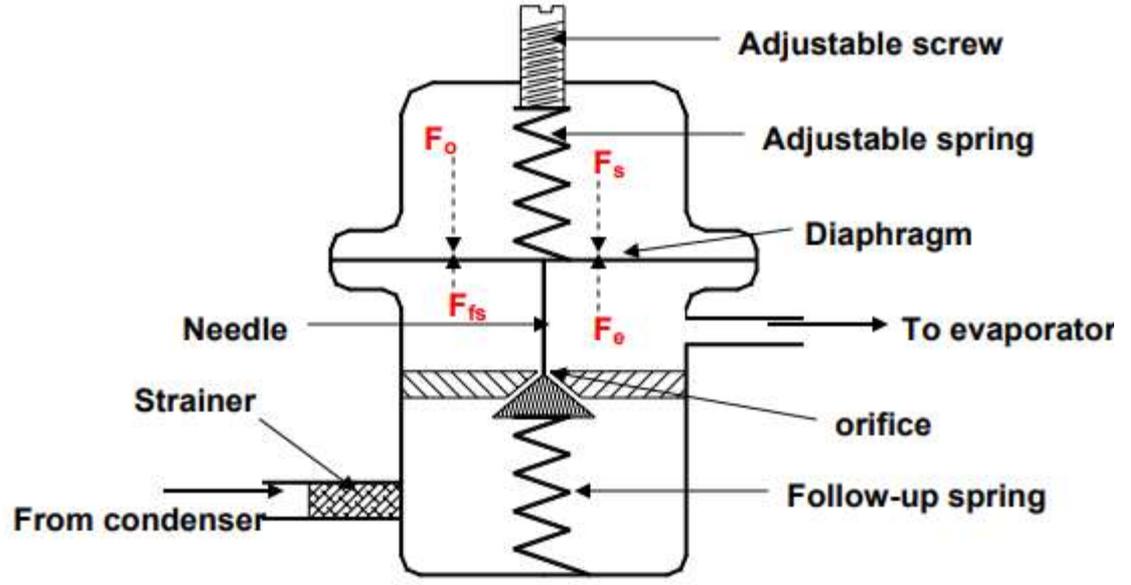
Advantages and disadvantages of capillary tubes

- **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**

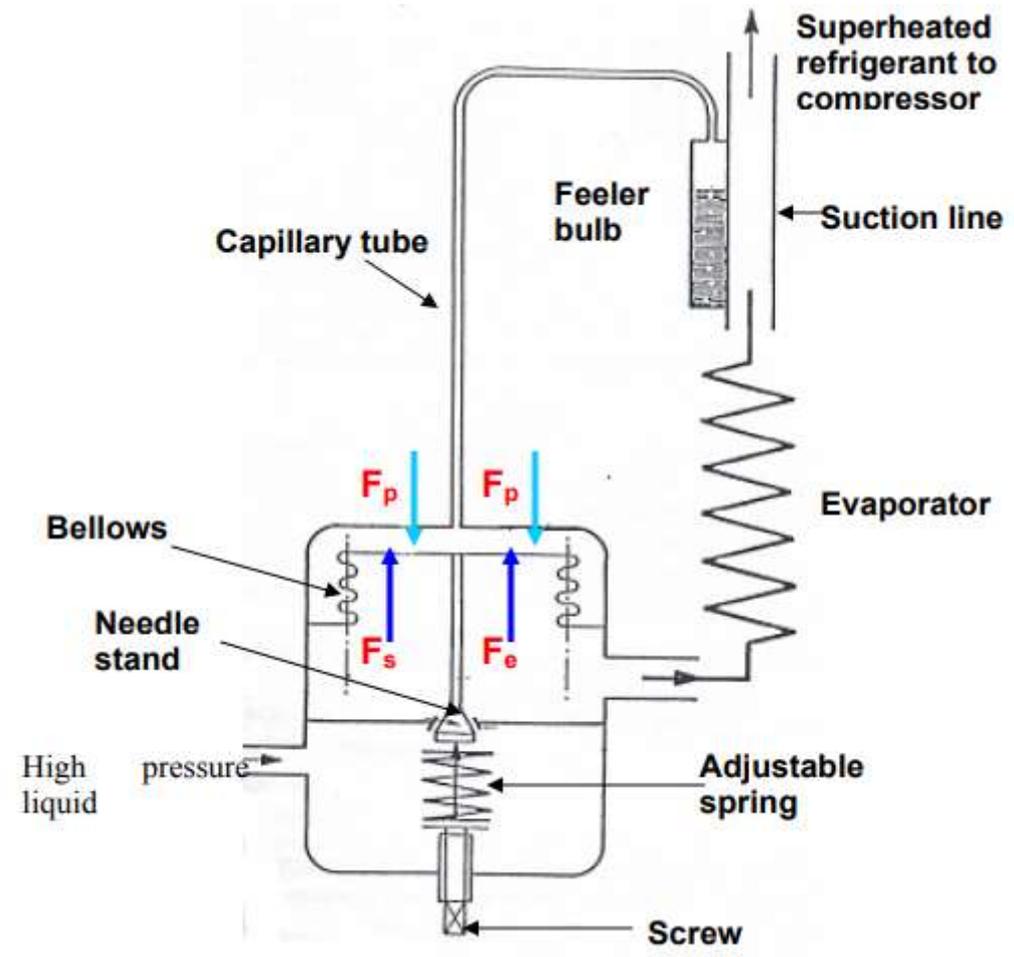
Automatic Expansion Valve (AEV)

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. The valve consists of an adjustment spring that can be adjusted to maintain the required temperature in the evaporator. This exerts force F_s on the top of the diaphragm.



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.**



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.**

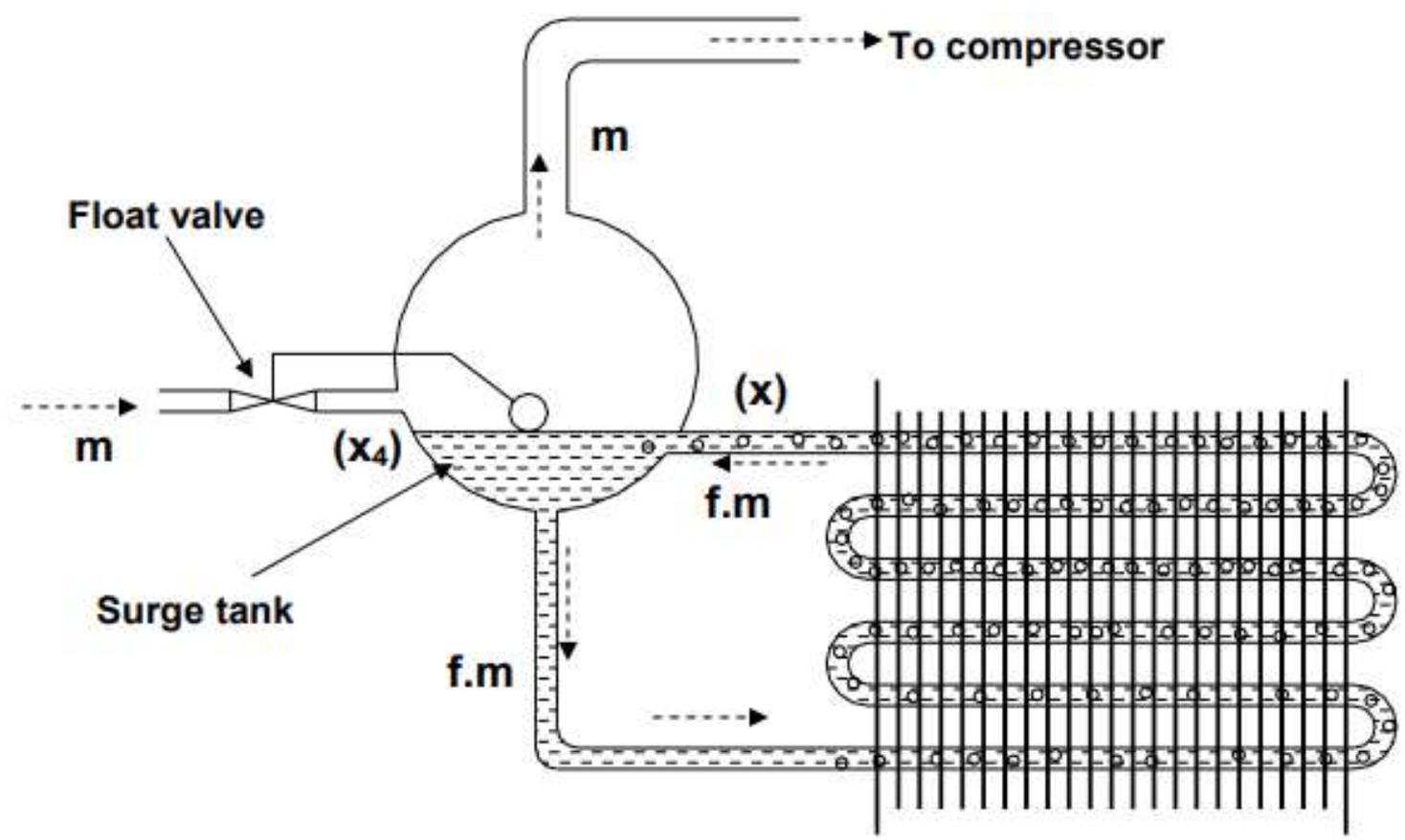
Natural and Forced Convection Type

- 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.

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 $\frac{1}{2} m_e$ where m_e is the mass flow rate through the expansion valve and to the compressor.

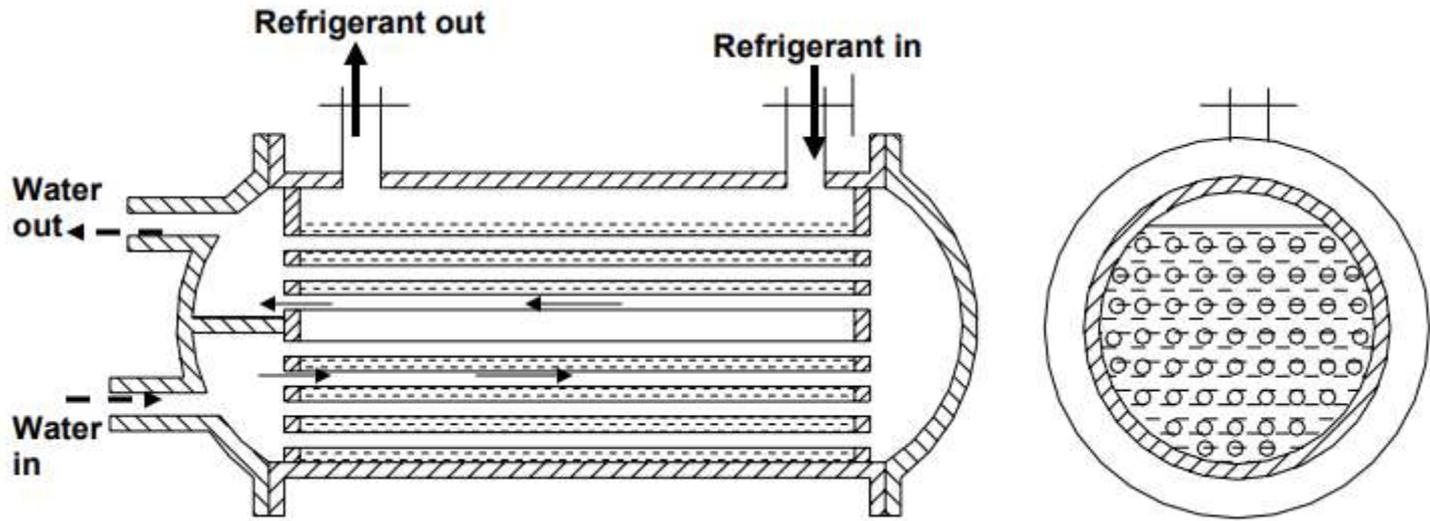
FLOODED Evaporators



Flooded Type Shell-and-Tube Evaporator

- 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.
- 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 FLOODED TYPE EVAPORATOR





UNIT – IV

INTRODUCTION TO AIR CONDITIONING

PSYCHROMETRIC PROPERTIES

- **The properties of moist air are called psychrometric properties and the subject which deals with the behaviour of moist air is known as psychrometry.**
- **Moist air is a mixture of dry air and water vapour. They form a binary mixture. A mixture of two substances requires three properties to completely define its thermodynamic state, unlike a pure substance which requires only two. One of the three properties can be the composition.**
- **Water vapour is present in the atmosphere at a very low partial pressure. At this low pressure and atmospheric temperature, the water vapour behaves as a perfect gas.**

PSYCHROMETRIC PROPERTIES

- Since the water vapour part is continuously variable, all calculations in air- conditioning practice are based on the dry air part.

- For calculating and defining the psychrometric properties, we may consider a certain volume V of moist air at pressure p and temperature T , containing m_a kg of dry air and m_v kg of water vapour as shown in Figure 6.3. The actual temperature t of moist air is called the dry bulb temperature (DBT). The total pressure p which is equal to the barometric pressure is constant

PSYCHROMETRIC PROPERTIES

Specific Humidity or Humidity Ratio

- Specific or absolute humidity or humidity ratio or moisture content is defined as the ratio of the mass of water vapour to the mass of dry air in a given volume of the mixture. It is denoted by the symbol ω .

Dew Point Temperature

- The normal thermodynamic state 1 as shown in the of moist air is considered as unsaturated air. The water vapour existing at temperature T of the mixture and partial pressure p_v of the vapour in the mixture is normally in a superheated state.

PSYCHROMETRIC PROPERTIES

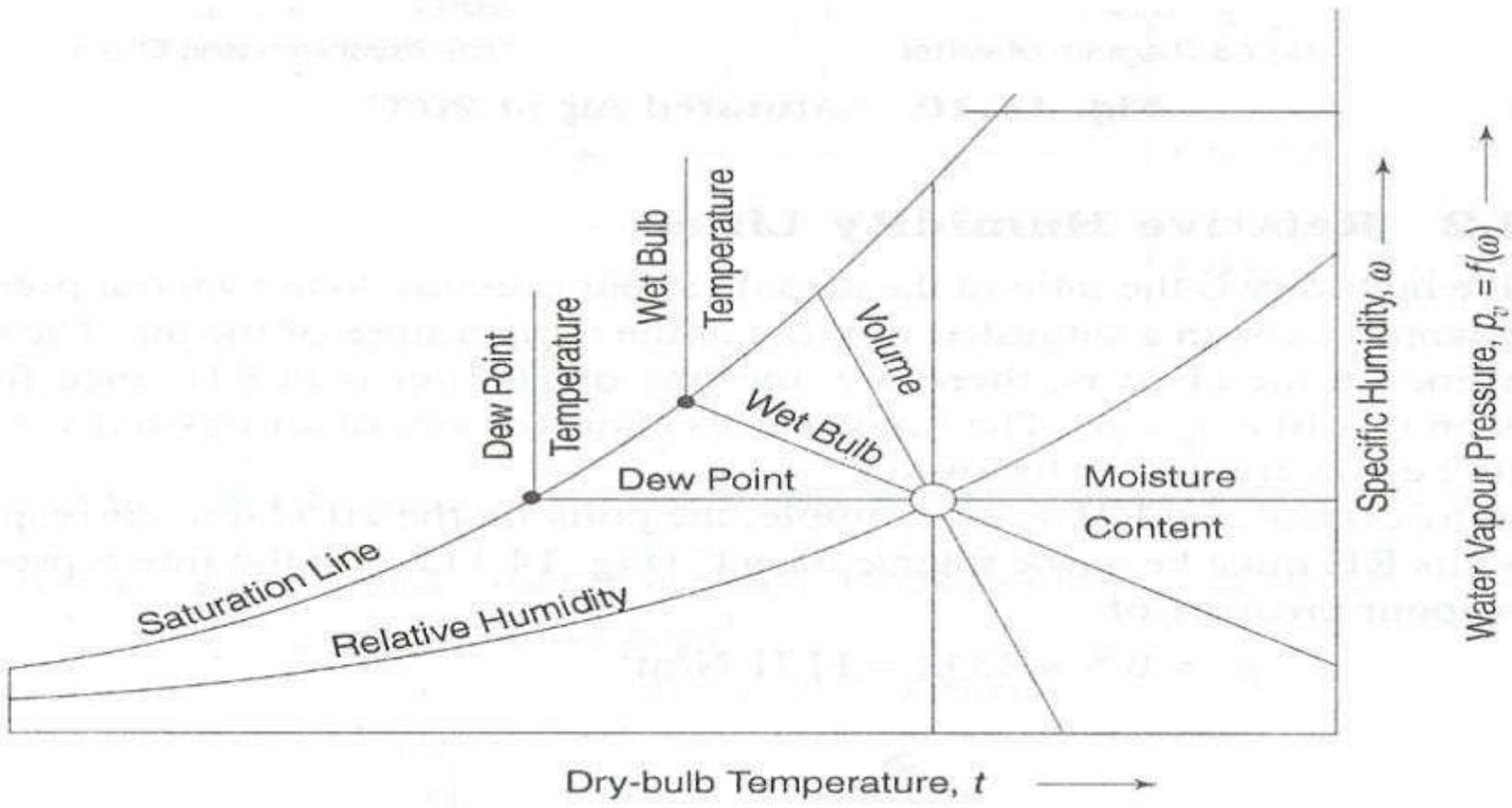
Relative Humidity

- The relative humidity is defined as the ratio of the mole fraction of water vapour in moist air to mole fraction of water vapour in saturated air at the same temperature and pressure.

PSYCHROMETRIC CHART

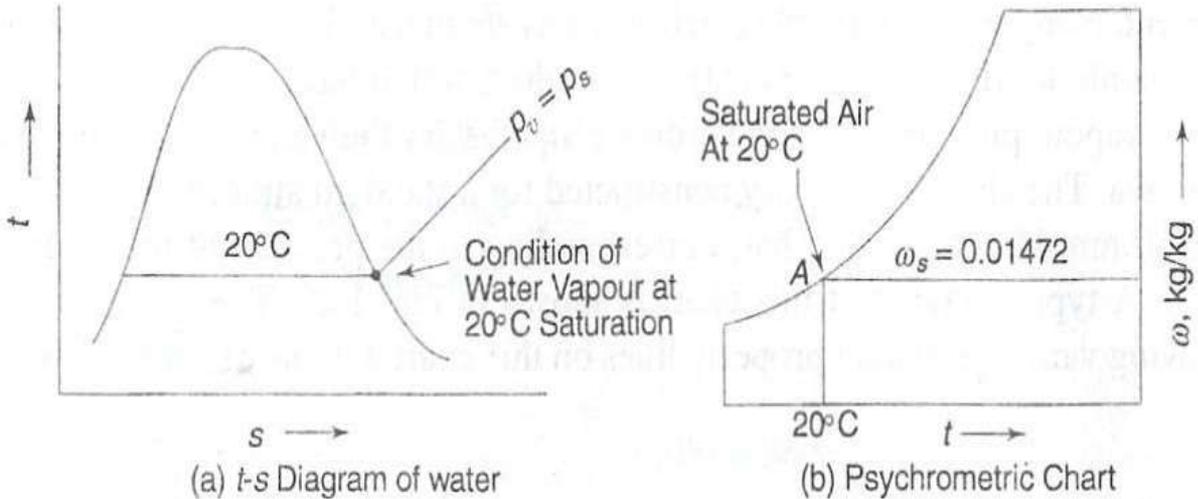
- All data essential for the complete thermodynamic and psychrometric analysis of air- conditioning processes can be summarised in a psychrometric chart. At present, many forms of psychrometric charts are in use. The chart which is most commonly used is the ω -t chart, i.e. a chart which has specific humidity or water vapour pressure along the ordinate and the dry bulb temperature along the abscissa.
- The chart is normally constructed for a standard atmospheric pressure of 760 mm Hg or 1.01325 bar, corresponding to the pressure at the mean sea level. A typical layout of this chart is shown in Figure

PSYCHROMETRIC CHART



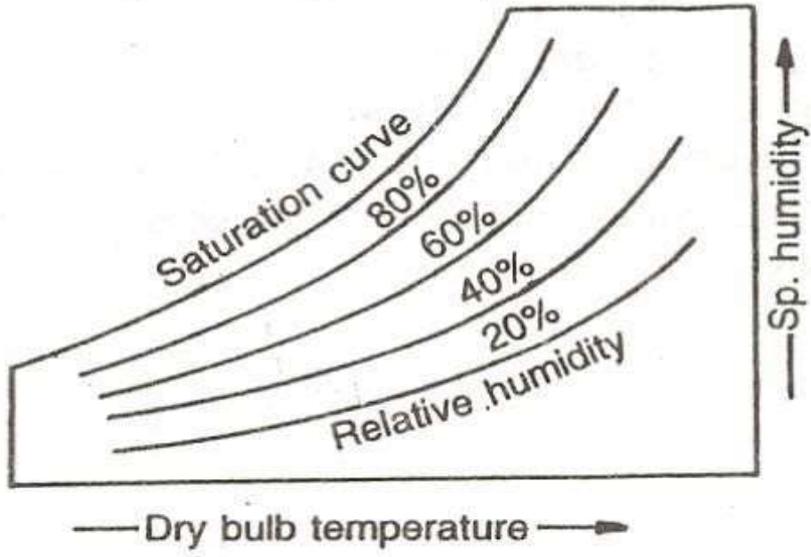
Saturation Line

- The saturation line represents the states of saturated air at different temperatures. As an example of fixing such a state on the chart, consider an atmosphere A at 20°C and saturation as shown in Figure 6.9. From the steam tables at 20°C, water vapour pressure.



Relative Humidity Lines

- The relative humidity is defined as the ratio of the mole fraction of water vapour in moist air to mole fraction of water vapour in saturated air at the same temperature and pressure.

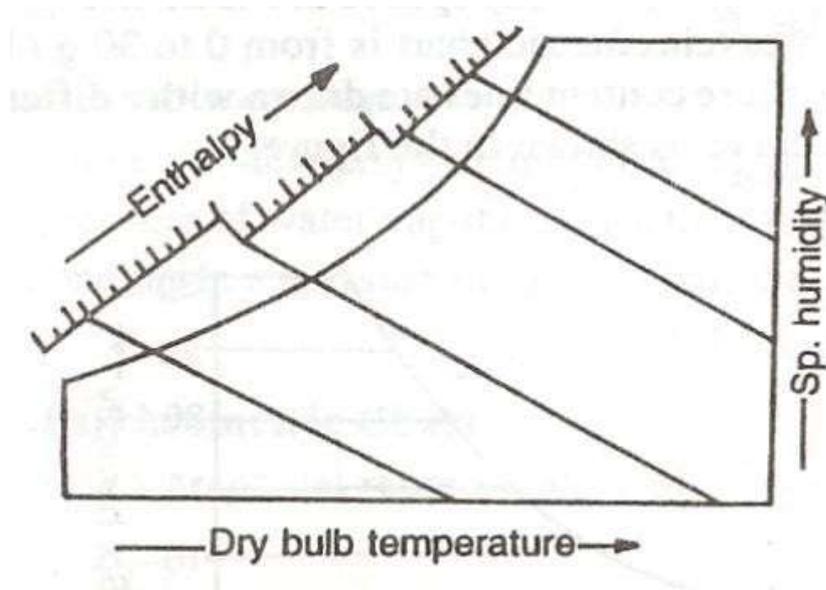


Constant Specific Volume Lines

- **The constant specific volumes lines are obliquely inclined straight lines and uniformly spaced as shown in Figure These lines are drawn up to the saturation curve.**
- **To establish points on line of constant specific volume, 0.90 m³/kg for example, From the perfect-gas equation, the specific volume v is substitute 0.90 for v , the barometric pressure for p_t , and at arbitrary values of T solve for p_s . the pairs of p_s and t values then describe the line of constant v .**

Constant Enthalpy Lines

- The enthalpy (or total heat) lines are inclined straight lines and uniformly spaced as shown in Figure. These lines are parallel to the wet bulb temperature lines, and are drawn up to the saturation curve. Some of these lines coincide with the wet bulb temperature lines also.



CLASSIFICATION OF AIR CONDITIONING SYSTEMS

- **Individual room air conditioning systems or simply individual systems**
- **Evaporative cooling air conditioning systems**
- **Desiccant-based air conditioning systems or simply desiccant systems**
- **Thermal storage air conditioning systems or simply thermal storage systems**
- **Clean room air conditioning systems or simply clean room systems**
- **Space conditioning air conditioning systems or simply space systems**
- **Unitary packaged air conditioning systems or simply packaged systems**
- **Central hydronic air conditioning systems or simply central systems.**

INDIVIDUAL AIR CONDITIONING SYSTEMS

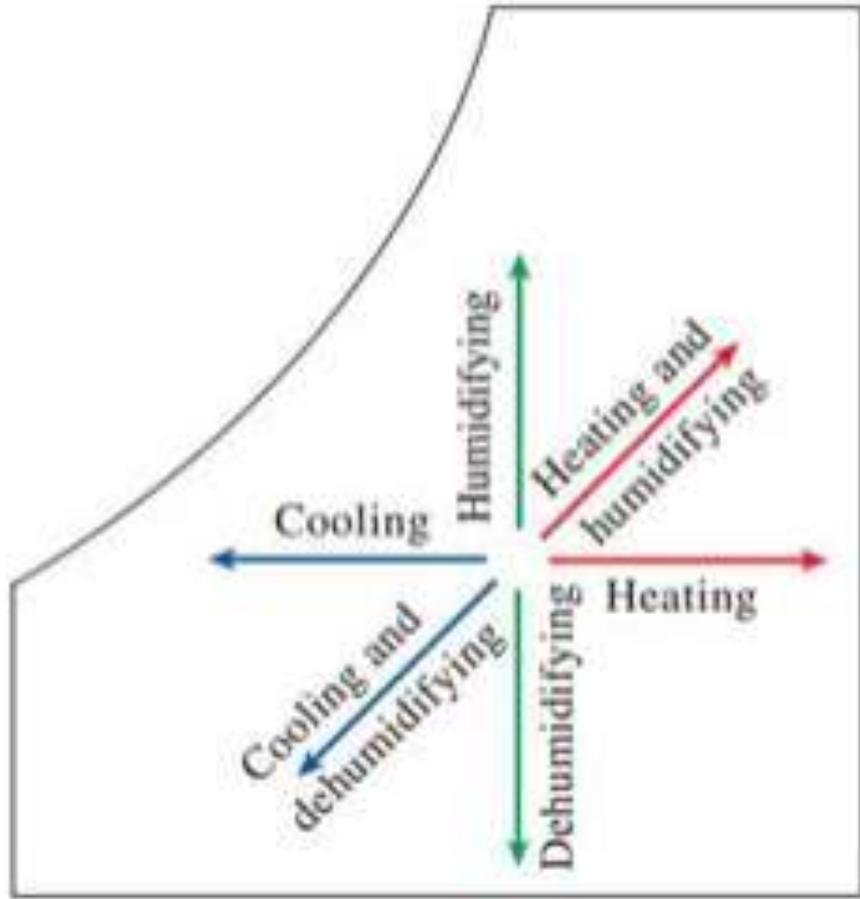
- **An individual room air conditioning system or simply an individual system uses a self-contained, factory-made packaged air conditioner to serve an individual room.**

- **It is ready to use after electric cable and necessary water drainage are connected. Individual systems always use a DX coil to cool the air directly. Individual systems can be subdivided into the two following air conditioning systems:**
 - **Room air conditioning (RAC) systems**
 - **Packaged terminal air conditioning (PTAC) systems**

Psychrometric Processes

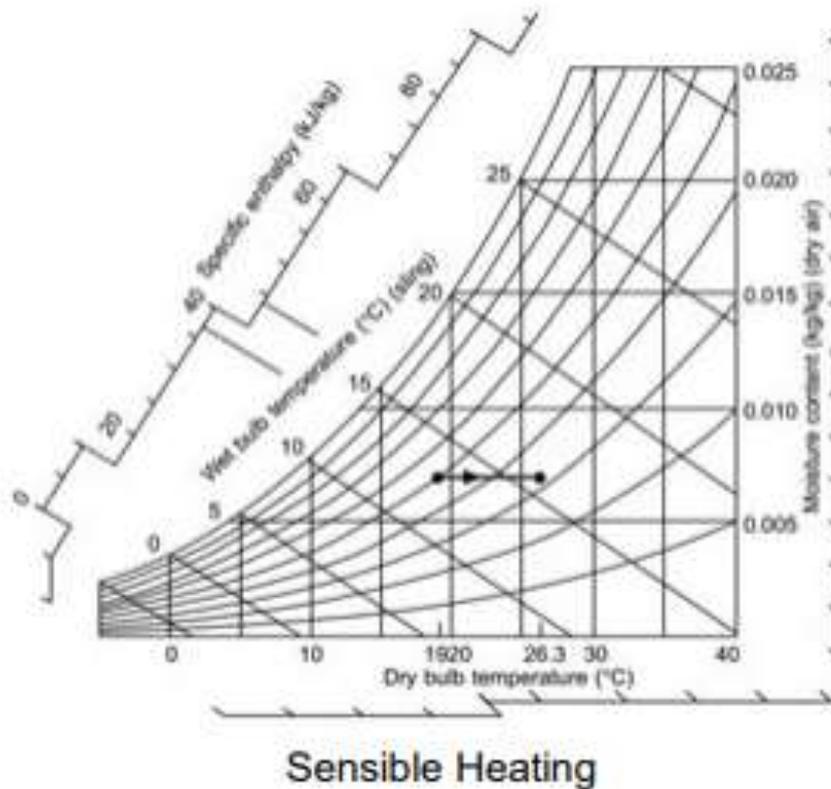
- **Air conditioning processes are most commonly used to achieve a more comfortable interior environment. This is done by controlling the temperature and humidity of the interior space and ensuring adequate amount of fresh air in the space.**
- ◎ **Temperature Control: Sensible Heating, Sensible Cooling**
- ◎ **Humidity Control: Adiabatic saturation, steam injection, air washer, cooling and dehumidifying coil**
- ◎ **Fresh air: Adiabatic Mixing of airstreams**

Psychrometric Processes



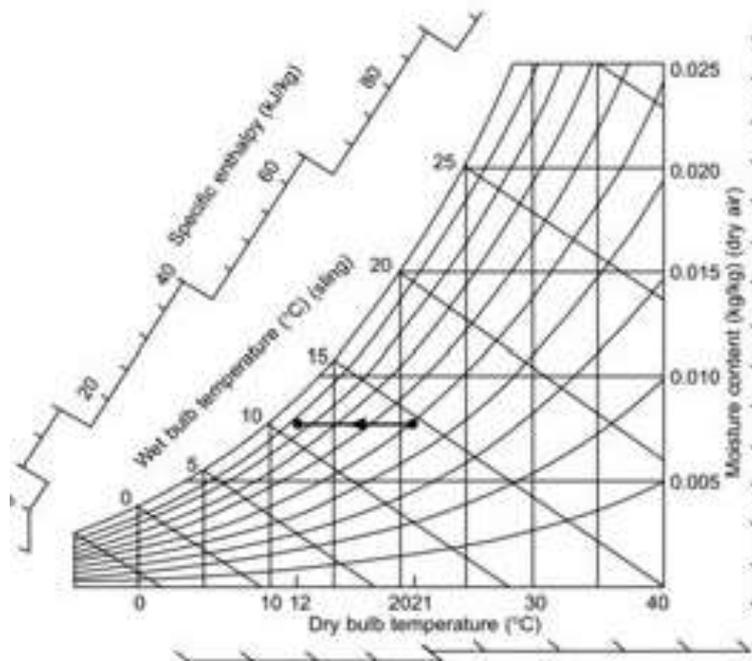
Sensible Heating of Air

- DBT increases, moisture content remains constant
- ⊙ Note that RH of air decreases, which may cause dry skin, respiratory difficulties, and an increase in static electricity



Sensible Cooling of Air

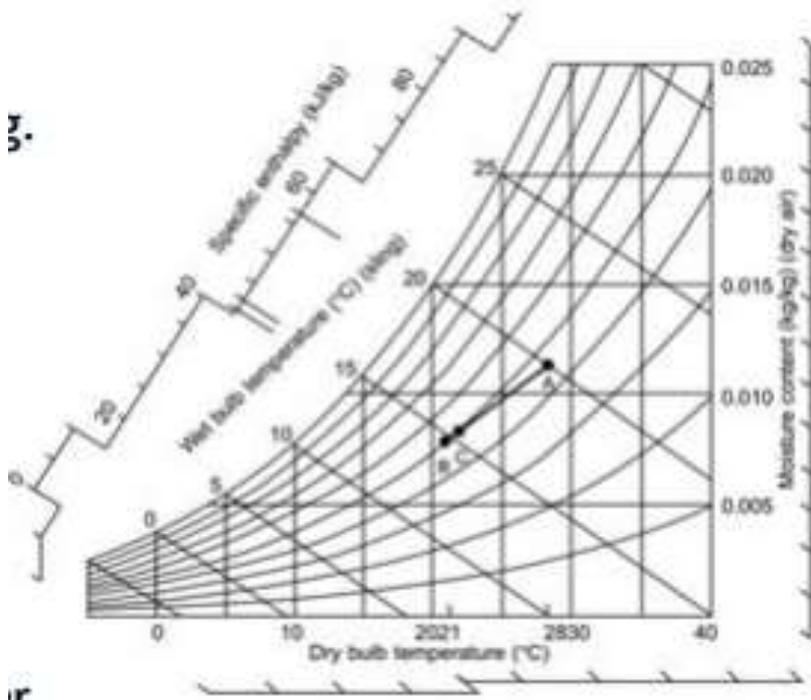
- DBT decreases, moisture content remains constant
- ⊙ Note that RH of air increases
- ⊙ Cooling can be achieved by passing the air over some coils through which a refrigerant or chilled water flows.



Sensible Cooling

Adiabatic mixing of airstreams

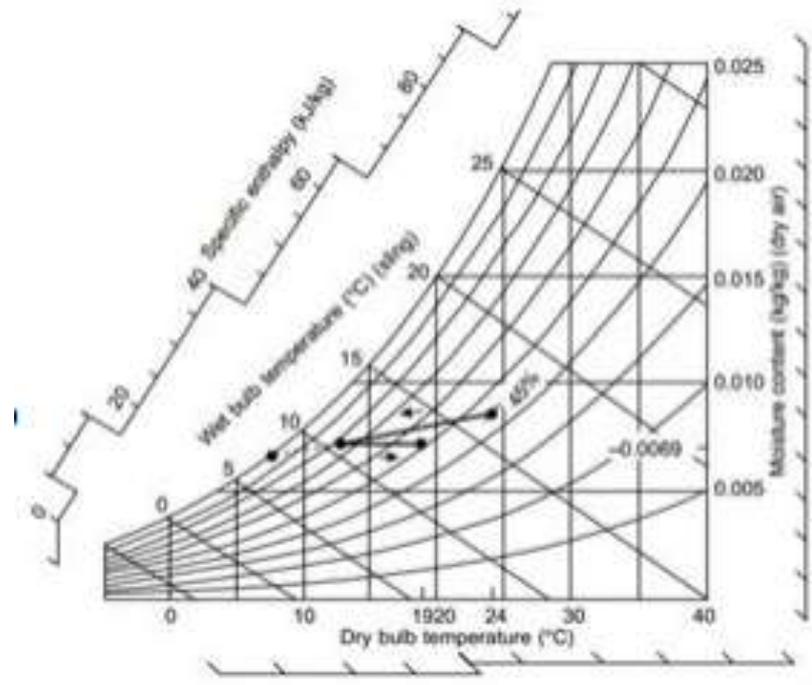
- Many air-conditioning applications require the mixing of two airstreams. E.g. Air conditioning in hospitals, large buildings etc. require that the conditioned air be mixed with a certain fraction of fresh outside air



Adiabatic mixing of airstreams

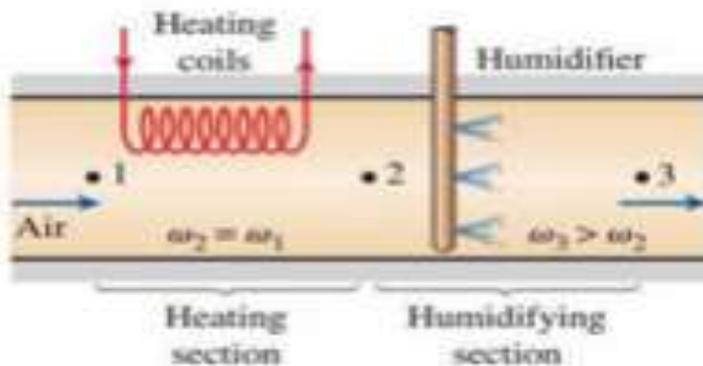
Cooling with Dehumidification followed by Reheating

- If air is to be cooled and dehumidified, it may be found that the process line joining the inlet and outlet conditions does not meet the saturation line, e.g. in cooling air from 24°C dry bulb, 45% saturation, to 19°C dry bulb, 50% saturation, the process line shows this to be impossible in one step.



Heating with Humidification

- Sensible heating decreases RH. This can be eliminated by humidifying the heated air. This is accomplished by passing the air first through a heating section (process 1-2) and then through a humidifying section (process 2-3)
- The properties of air at state 3 depend on how the humidification is accomplished – steam injection/adiabatic spraying. So, the heating (excess or lower) should be done accordingly in the heating section.



Advantages

- **There are no supply, return, or exhaust ducts.**
- **Individual air conditioning systems are the most compact, flexible, and lower in initial cost than**
- **others, except portable air conditioning units.**
- **Building space is saved for mechanical rooms and duct shafts.**
- **It is easier to match the requirements of an individual control zone.**
- **They are quick to install.**

Disadvantages

- **Temperature control is usually on /off, resulting in space temperature swing.**
- **Air filters are limited to coarse or low-efficiency filters.**
- **Local outdoor ventilation air intake is often affected by wind speed and wind direction.**
- **Noise level is not suitable for critical applications.**
- **More regular maintenance of coils and filters is required than for packaged and central systems.**



UNIT – V

AIR CONDITIONING SYSTEMS

BASICS OF HEAT PUMP AND HEAT RECOVERY

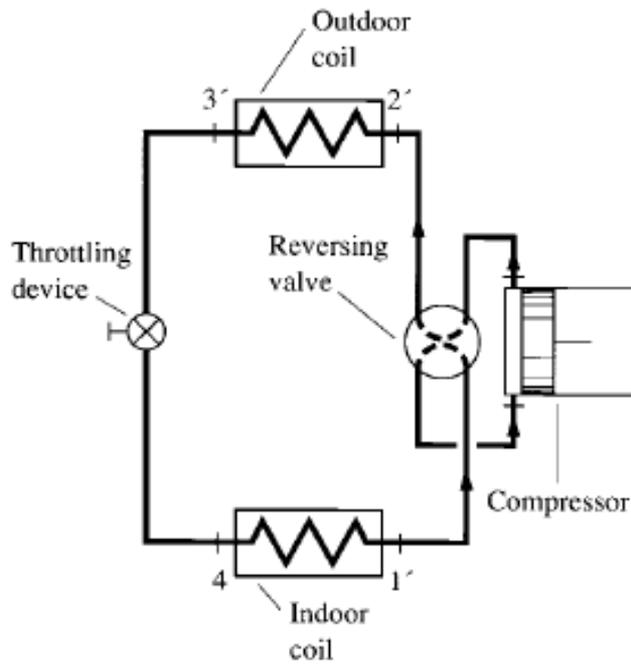
- **A heat pump extracts heat from a heat source and rejects heat to air or water at a higher temperature.**
- **During summer, the heat extraction, or refrigeration effect, is the useful effect for cooling, whereas in winter the rejected heat alone, or rejected heat plus the supplementary heating from a heater, forms the useful effect for heating.**
- **A heat pump is a packaged air conditioner or a packaged unit with a reversing valve or other changeover setup. A heat pump has all the main components of an air conditioner or packaged unit: fan, filters, compressor, evaporator, condenser, short capillary tube, and controls.**

BASICS OF HEAT PUMP AND HEAT RECOVERY

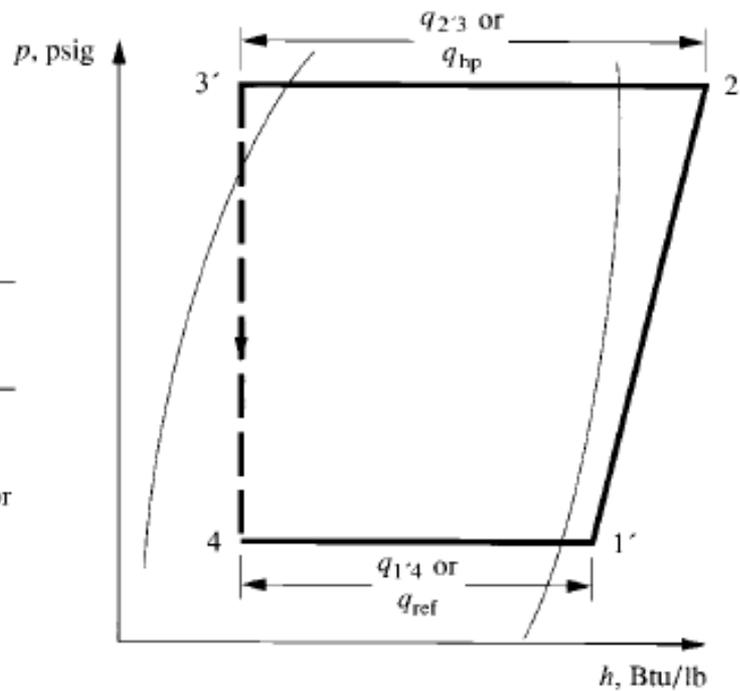
- The apparatus for changing from cooling to heating or vice versa is often a reversing valve, in which the refrigerant flow to the condenser is changed to the evaporator. Alternatively, air passage through the evaporator may be changed over to passage through the condenser.
- A supplementary heater is often provided when the heat pump capacity does not meet the required output during low outdoor temperatures.
- A heat pump system consists of heat pumps and piping work; system components include heat exchangers, heat source, heat sink, and controls to provide effective and energy-efficient heating and cooling operations.

Heat Pump Cycle

$$\text{COP}_{\text{ref}} = \frac{h_{1'} - h_4}{W} = \frac{q_{1'4}}{W_{\text{in}}}$$



(a)



(b)

- Here polytropic compression is a real and irreversible process. Both the sub-cooling of the liquid refrigerant in the condenser and the superheating of the vapor refrigerant after the evaporator increase the useful heating effect q_{23} . Excessive superheating, which must be avoided, leads to a too-high hot-gas discharge temperature and to a lower refrigeration capacity in the evaporator.

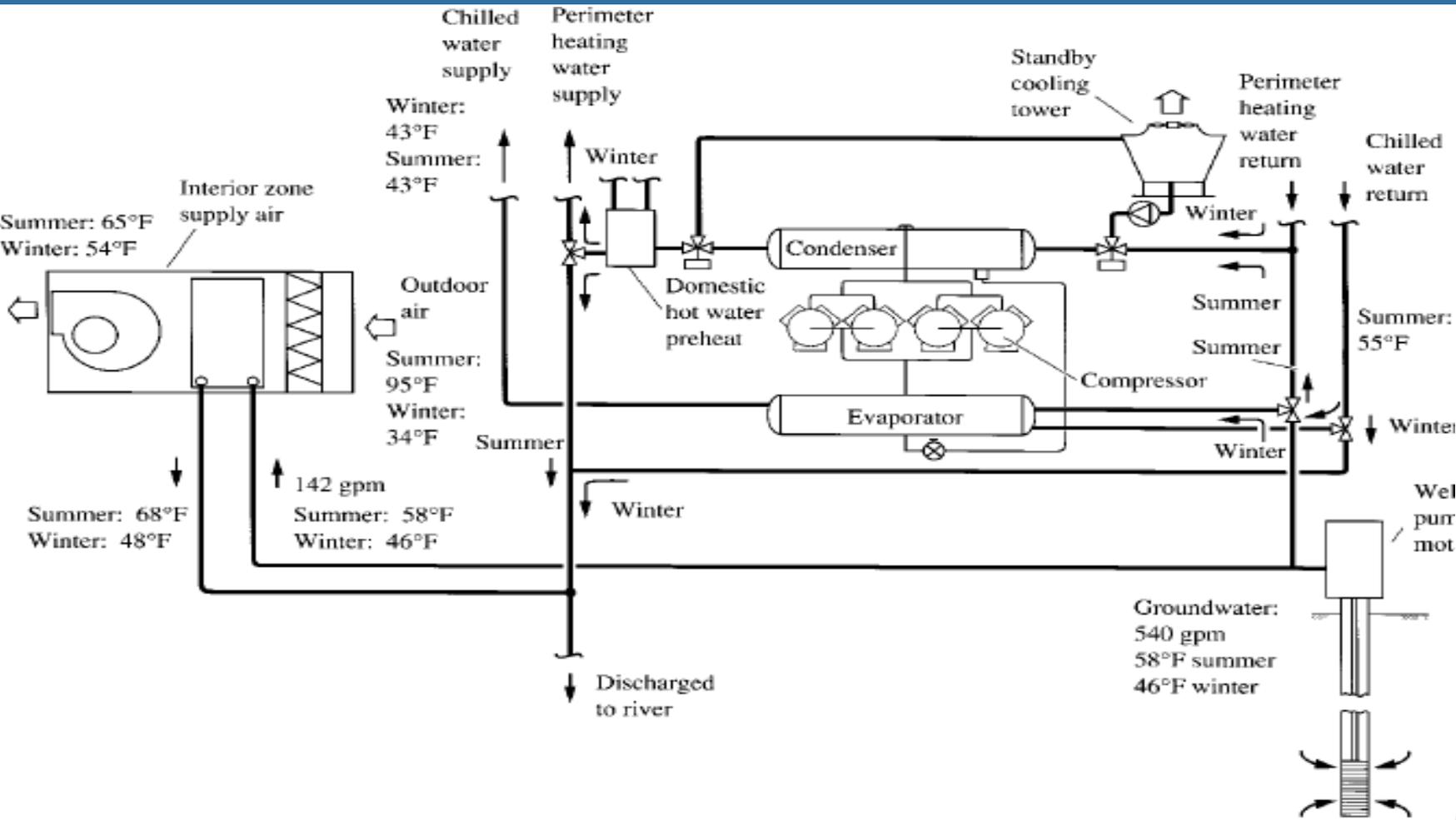
Classification of Heat Pumps

- According to the types of heat sources from which heat is absorbed by the refrigerant, currently used heat pump systems can be mainly classified into two categories: air-source and water-source heat pump systems. Water-source heat pumps can again be subdivided into water-source, groundwater, ground-coupled, and surface water heat pump systems.
- Heat pump systems are often energy-efficient cooling/heating systems. Many new technologies currently being developed, such as engine-driven heat pumps, may significantly increase the system performance factor of the heat pump system. Ground-coupled heat pumps with direct-expansion ground coils provide another opportunity to increase the COP of the heat pump system.

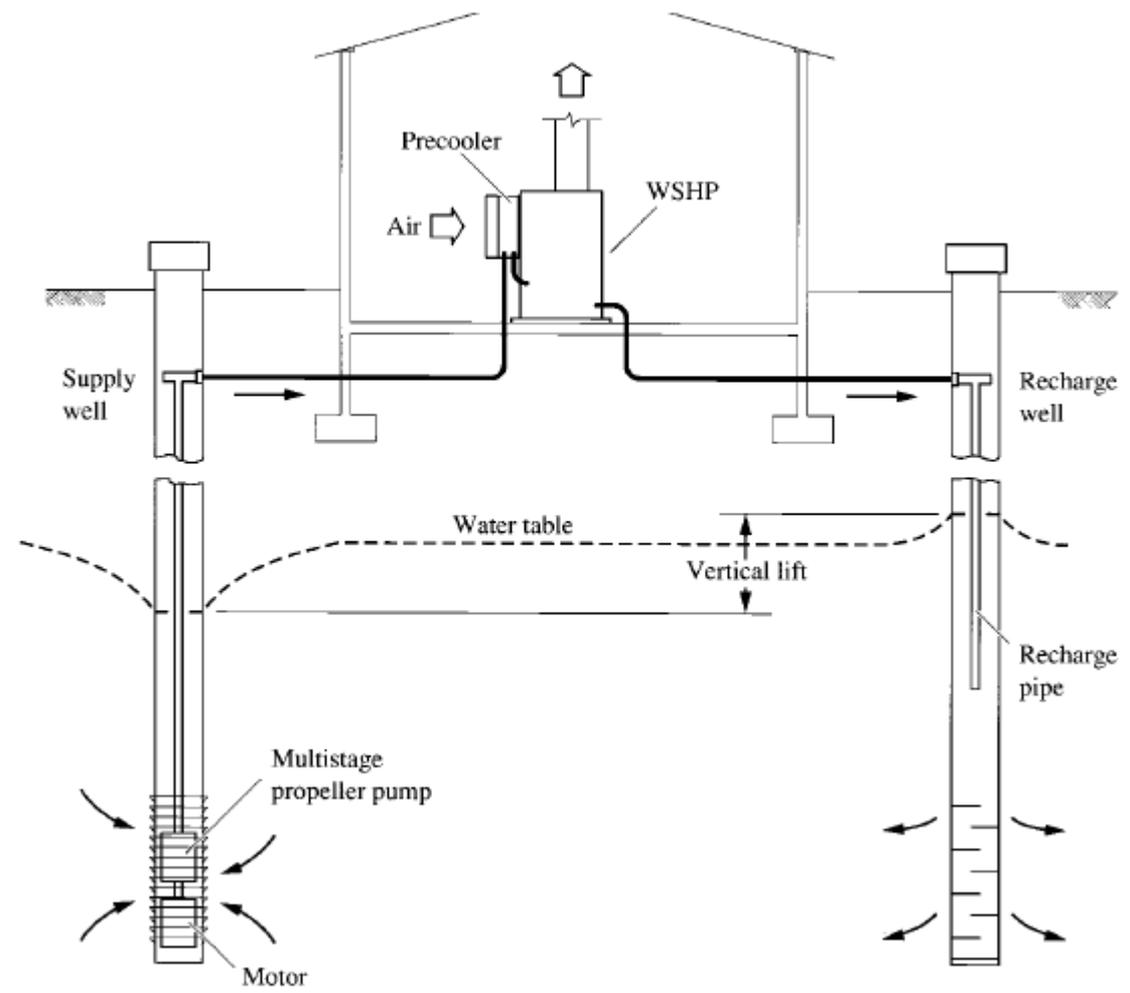
GROUNDWATER HEAT PUMP SYSTEMS

- **Groundwater heat pump (GWHP) systems use well water as a heat source during heating and as a heat sink during cooling. When the groundwater is more than 30 ft (9 m) deep, its year-round temperature is fairly constant. Groundwater heat pump systems are usually open-loop systems.**
- **They are mainly used in low-rise residences in northern climates such as New York or North Dakota. Sometimes they are used for low-rise commercial buildings where groundwater is readily available and local codes permit such usage.**

A typical groundwater heat pump system for a hospital.



A typical residential groundwater heat pump system.

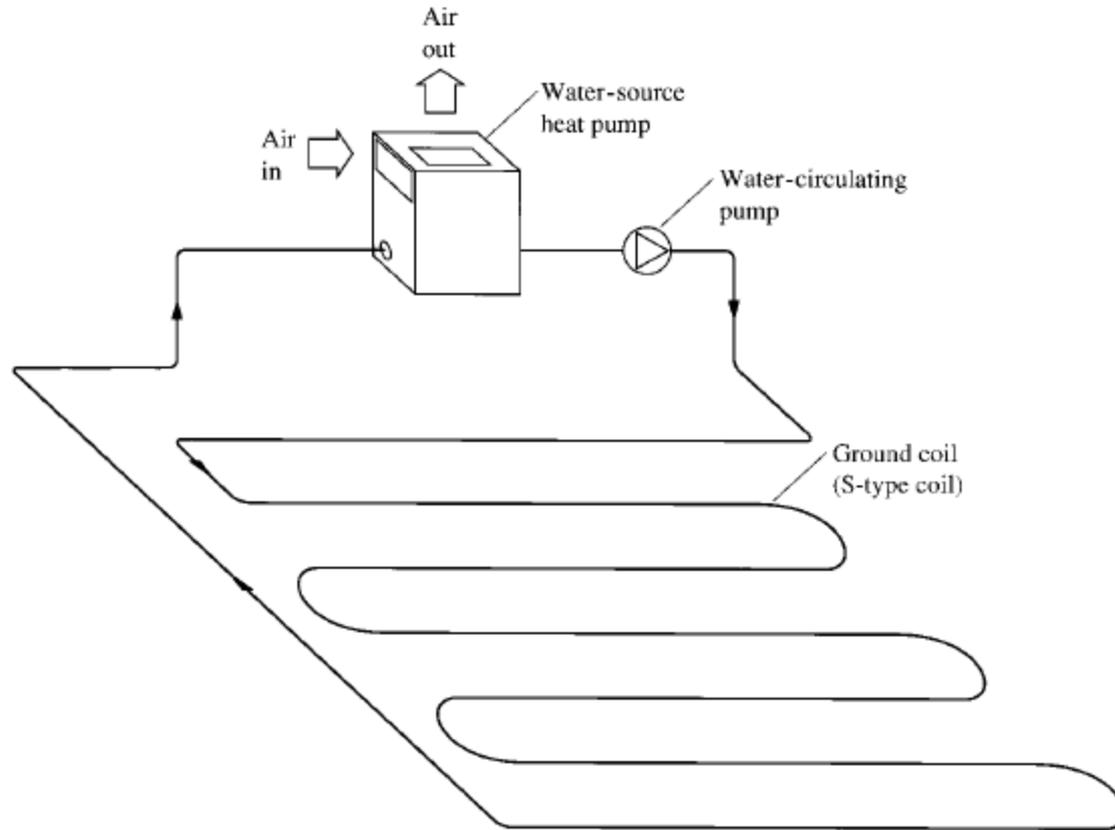


GROUND-COUPLED AND SURFACE WATER HEAT PUMP SYSTEMS



- **Ground-coupled heat pump systems can be categorized as ground coil heat pump systems and direct-expansion ground-coupled heat pump systems. Of the ground coil heat pump systems, both horizontal and vertical coils are used. Many types of direct-expansion ground-coupled heat pump systems are still being developed. In fact, horizontal ground coil heat pump systems are the most widely used ground-coupled heat pump systems.**

GROUND-COUPLED AND SURFACE WATER HEAT PUMP SYSTEMS



AIR-TO-AIR HEAT RECOVERY

- In HVAC&R systems, it is always beneficial if the cooling effect of the exhaust air can be used to cool and dehumidify the incoming outdoor air during summer, and if the heating effect can be used to heat the cold outdoor air during winter. Air-to-air heat recovery is used to recover the cooling and heating energy from the exhaust air for the sake of saving energy.
- In an air-to-air heat recovery system, the exhaust air is the airstream used to provide cooling capacity or heating energy. The other airstream used to extract heat energy from or release heat energy to the exhaust airstream is the outdoor airstream, which has a greater temperature and enthalpy difference between these airstreams than the supply airstream

FAN FUNDAMENTALS

- A fan is the prime mover of an air system or ventilation system. It moves the air and provides continuous airflow so that the conditioned air, space air, exhaust air, or outdoor air can be transported from one location to another through air ducts or other air passages.

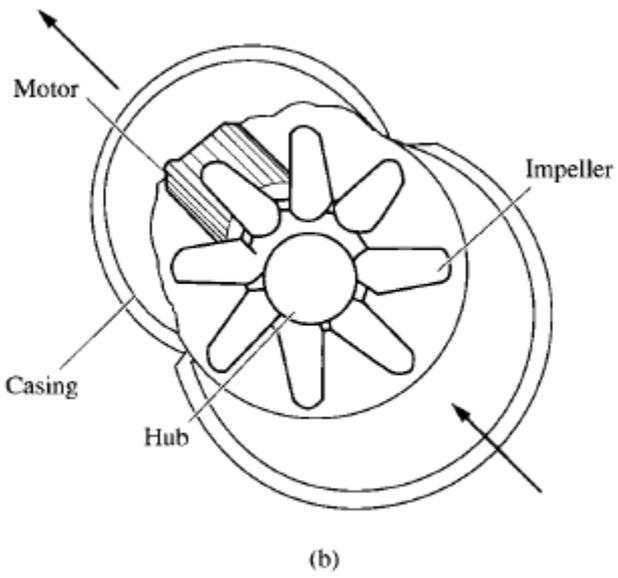
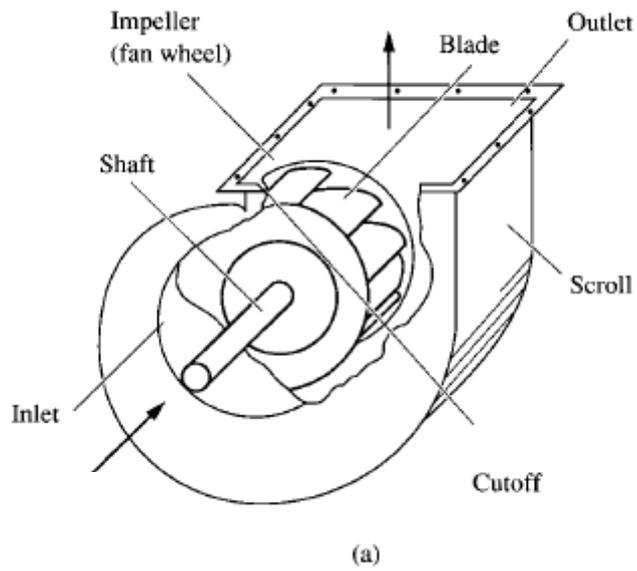
$$R_{\text{com}} = \frac{P_{\text{dis}}}{P_{\text{sac}}}$$

- A blower is usually an enclosed multiblade rotor that compresses air to a higher discharge pressure. There is no clear distinction between a fan and a blower. Traditionally, blowers do not discharge air at low pressure as some fans do.
- A fan is driven by a motor directly (direct drive) or via belt and pulleys (belt drive). Some large industrial fans in power plants are driven by steam or gas turbines.

FAN FUNDAMENTALS

- **Two types of fans are widely used in air conditioning and ventilation systems: centrifugal fans and axial fans. Fans can be mounted individually as ventilating equipment to provide outdoor air or air movement inside a building. They can also transport air containing dust particles or material from one place to another via air duct systems. In air conditioning systems, fans are often installed in air-handling units, packaged units, or other air conditioning equipment.**
- **In both centrifugal fans and axial fans, the increase of air static pressure is created by the conversion of velocity pressure to static pressure. In centrifugal fans, air is radially discharged from the impeller, also known as the fan wheel air turns 90° from its inlet to its outlet.**

FAN TYPES



Types of fans: (a) centrifugal; (b) axial

FAN SELECTION

- **Pressure-volume flow operating characteristics:** Selecting a fan to provide the required volume flow rate and total pressure loss for an air system or a ventilating system is of prime importance. Direction of rotation and discharge position for centrifugal fans. An undersized fan results in an uncontrolled indoor environment. An oversized fan wastes energy and money.
- **Fan capacity modulation:** A variable-air-volume system operates at a reduced volume flow rate during part-load operation. Effective and economical fan capacity modulation is an important factor that affects the operation of an air system.

FAN SELECTION

- **Fan efficiency:** Fan efficiency is closely related to the energy consumption of an air system. Fans should be selected so that they can operate at high efficiency during as much of their operation time as possible.
- **Sound power level:** Most commercial and public buildings and many industrial applications need a quiet indoor environment. Fans are the major source of noise in an air system. Usually, the higher the fan total efficiency, the lower the sound power level of the selected fan. A fan with a low sound power level and sound power level at high frequencies is preferable. High-frequency sound is more easily attenuated than low-frequency sound.

FAN FUNDAMENTALS

- **Airflow direction:** In many applications, a straight-through or in-line flow occupies less space and simplifies layout.
- **Initial cost:** The initial cost of the fan modulation device, sound attenuator(s), and space occupied by a particular type of fan, in addition to the cost of the fan itself, should be considered.

Air Filtration and Industrial Air Cleaning

- **Air cleaning is the process of removing airborne particles present in the air. It can be classified into two categories: air filtration and industrial air cleaning. Air filtration involves the removal of airborne particles present in outdoor air as well as recirculated air from a given space.**
- **Most airborne particles removed by air filtration are smaller than 1 μ m, and the concentration of these particulates in the conditioned airstream is often less than 2 mg /m³. The purpose of air filtration is to benefit the health and comfort of the occupants in the conditioned space as well as maintain the cleanliness required in manufacturing processes. Air filtration is one of the essential factors that affects the indoor air quality of the conditioned space.**

Air Filtration and Industrial Air Cleaning

- **Industrial air cleaning mainly involves the removal of dust and gaseous contaminants from the industrial manufacturing processes, and it provides pollution control to the exhaust gas and flue gas.**
- **Air contaminants that are discharged to the outdoor environment are governed by the U.S. Environmental Protection Agency (EPA), and those that are exhausted to the indoor working space are regulated by the Occupational Safety and Health Administration (OSHA).**

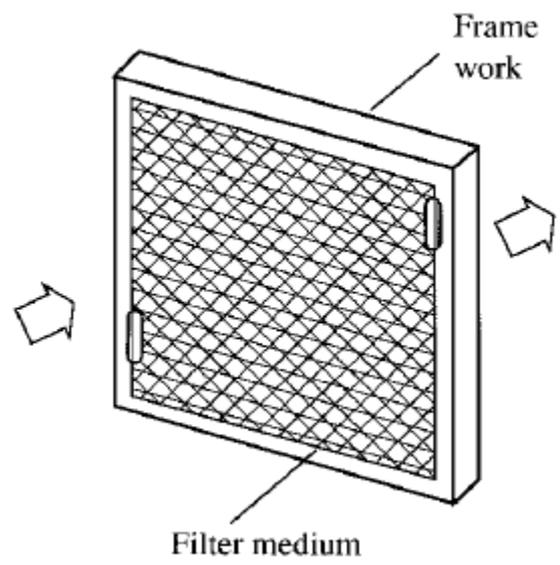
AIR FILTERS

The removal or collection of dust particles in air filtration is performed by various combinations of the following mechanisms.

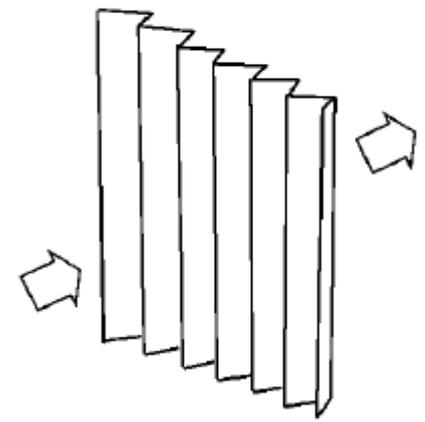
- **Inertial impaction: A sudden change in direction causes a collision between the dust particles, and fibrous media.**
- **Straining: If the filter spaces are smaller than the size of the dust particles, the particles are trapped.**
- **Diffusion: For very fine dust particles, brownian movement causes the particles to settle.**
- **Interception: Dust particles may follow the airstream, contact the fibrous media, and remain there.**
- **Electrostatic effects: Particles and the filter medium are charged to collect the dust in the airstream.**

FILTER TYPES

PANEL FILTER:

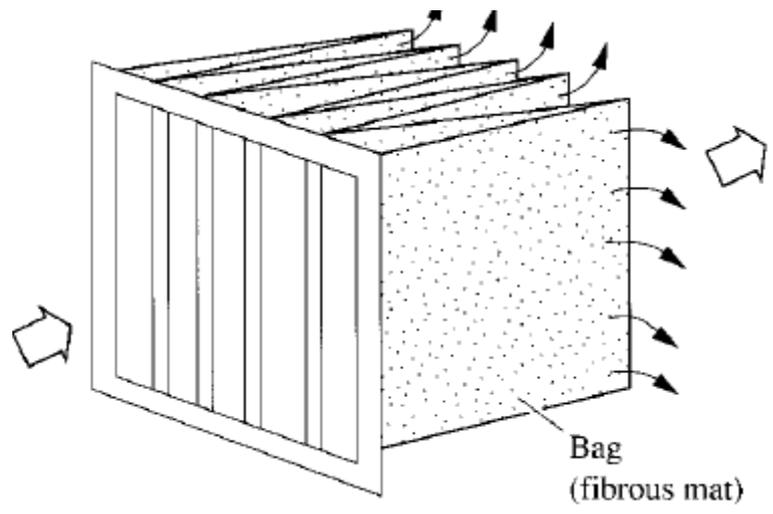


PLEATED FILTER

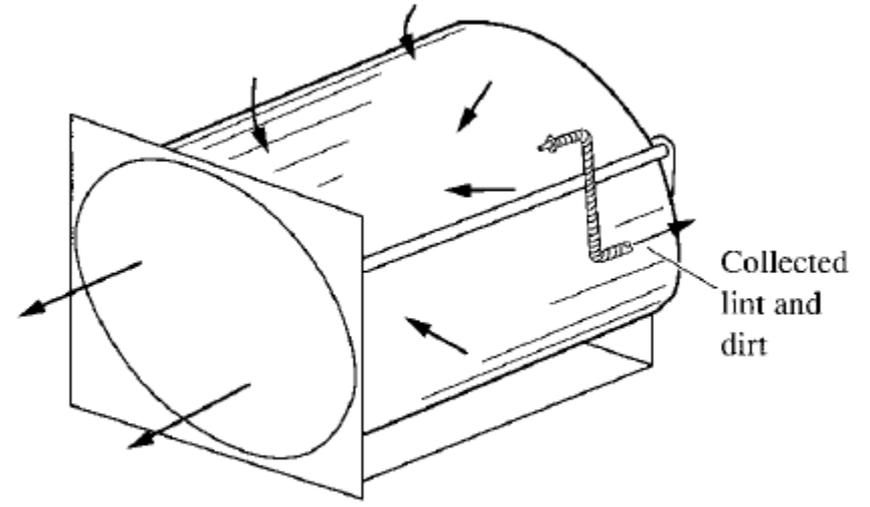


FILTER TYPES

EXTENDED SURFACE FILTER

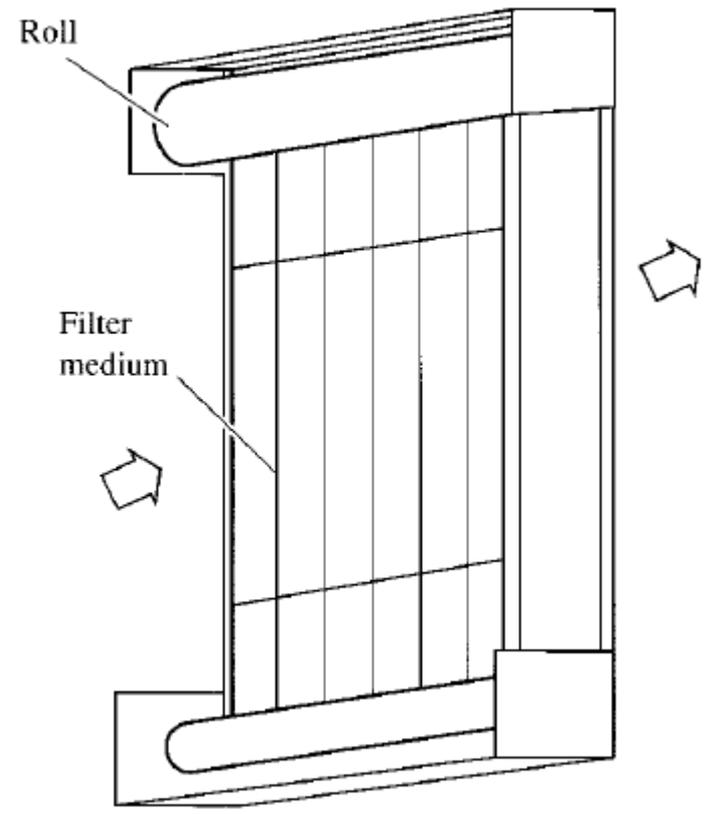


ROTARY FILTER



FILTER TYPES

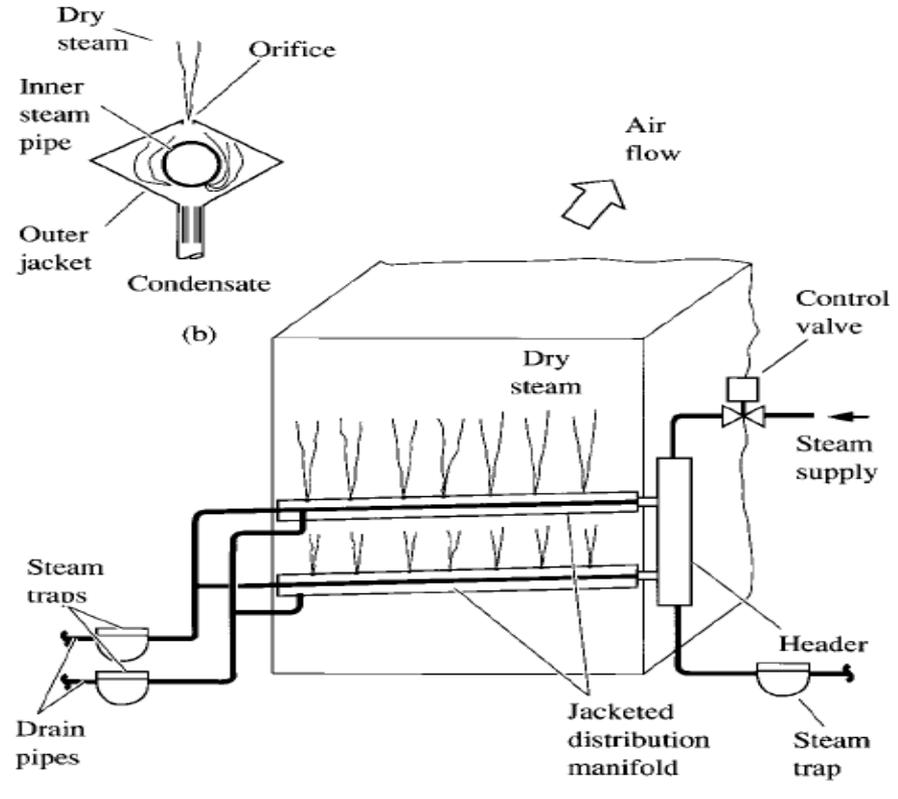
AUTOMATIC RENEWABLE ROLLING FILTER



STEAM AND HEATING ELEMENT HUMIDIFIERS

Steam Grid Humidifiers

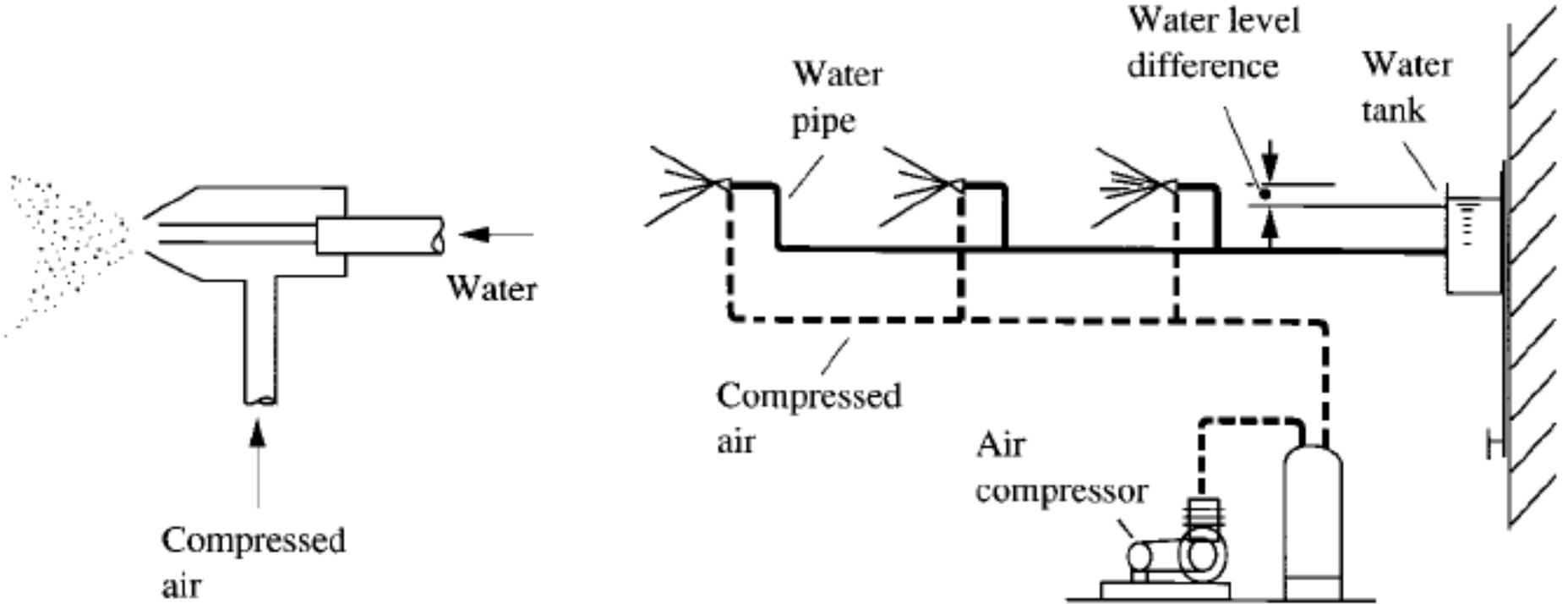
- A steam grid humidifier installed inside ductwork is shown in Fig. A steam grid humidifier may have a single distribution manifold or multiple manifolds.



Wetted Element Humidifiers

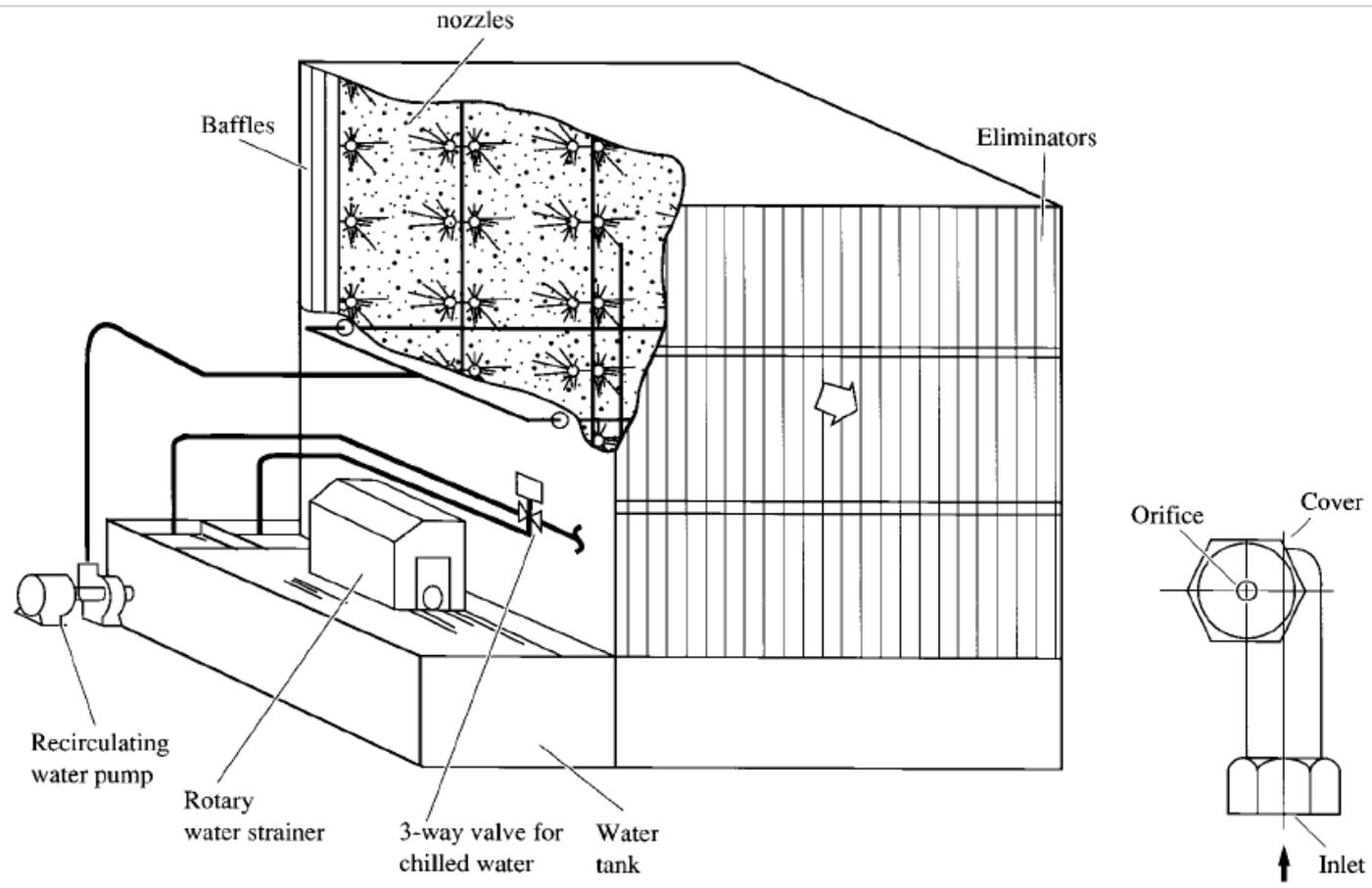
- **Wetted element humidifiers include a wetted element, such as an evaporative pad, plastic, or impregnated cellulose, that is dipped with water from the top. Such humidifiers have been installed in air-handling units and packaged units to humidify the air.**
- **Characteristics of wetted element humidifiers are similar to those of wetted element evaporative coolers. Modulation of the water supply to the water dipping device varies the humidifying capacity and maintains the desirable space relative humidity.**

Pneumatic Atomizing Humidifier



AIR WASHERS

- The air washer was the first air conditioning equipment developed by Carrier in 1904, and it is still used today to humidify, cool, and clean the air in many factories.



Functions of an Air Washer

- **Currently, air washers are used to perform one or more of the following functions:**
 - **Cooling and humidification**
 - **Cooling and dehumidification**
 - **Washing and cleaning**

- **Whether it is a cooling and humidification or cooling and dehumidification process is determined by the temperature of the spraying water.**

- **If recirculating water is used as the spraying water, the temperature of water then approaches the wet-bulb temperature of the air entering the air washer, and the air is humidified and evaporatively cooled.**



Thank you