Basics of Refrigeration and Air Conditioning

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What is Refrigeration..?

It is the process of cooling of bodies or fluids (liquid+gas) to temperatures lower than those available in the surroundings at a particular time and place.

Cooling

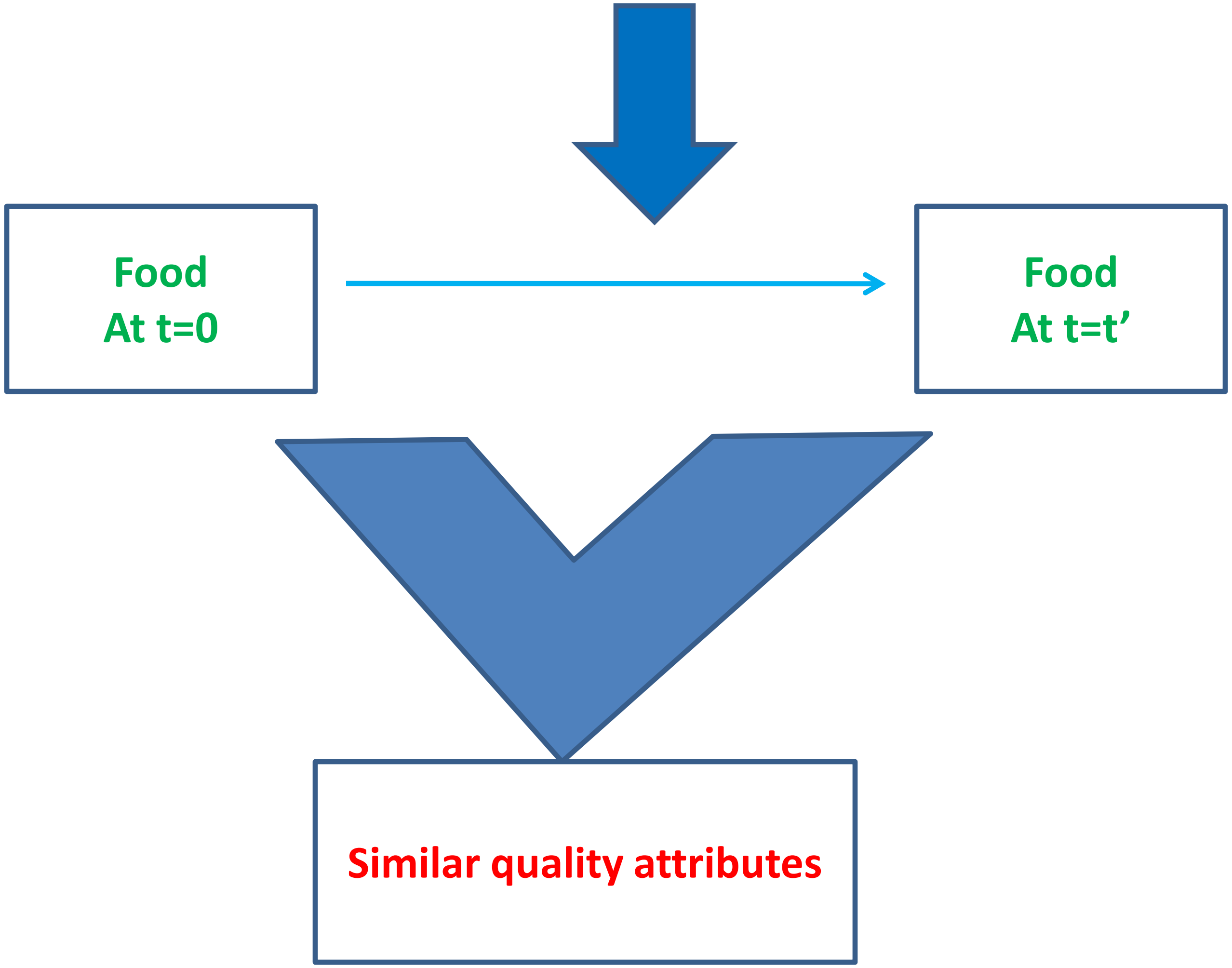
Difference b/w Refrigeration and Cooling

Refrigeration	Cooling
1. Refrigeration is not spontaneous process. 2. The final temperature should always be lower than the surroundings. 3. Example: Cooling of glass of water by adding ice.	1. Cooling can be spontaneous process. 2. The final temperature need not be lower than the surroundings. 3. Example: Cooling of cup of tea/coffee.

Why Refrigeration..?

1. It is required in food processing and preservation.
2. It is required in various chemical and process industries.
3. It is required for comfort and industrial air conditioning etc.

What is preservation..?



Preservation by Refrigeration

Provide low temperature

Refrigeration

FOOD

1. Retards the Metabolic activity (like respiration in case of fruits and vegetables)

2. Freeze the freely available moisture content of food

3. Enzyme activity ceases

4. The microorganisms can't grow/multiply

What is Air conditioning..?

It is the treatment of air to control its temperature, humidity, quality and circulation as per the requirement.

T (˚C)

H_2O

Difference b/w Refrigeration and Air conditioning

Refrigeration	Air conditioning
1. Thermal energy is transferred from one place to a place of higher temperature	1. Thermal energy is taken away from the place to keep the air cooler
2. regulating the temperature of air such as cooling and freezing of products	2. maintaining the temperature of a certain volume of air and also maintaining the purity and humidity
3. The appliance has a condenser, compressor, and evaporator in one unit	3. The compressor and condenser are a separate unit from the evaporator
4. Cold air is kept inside the unit	4. Cold air is pushed away from the unit

History of Refrigeration

History of refrigeration can be divided into two broad classes:

(a) Age of natural refrigeration

It is the time b/w **prehistoric time** to the beginning of **19^{th} century**.

(b) Age of Artificial refrigeration

From 19^{th} century onwards

Pre-history to Beginning of 19th century

Natural Refrigeration methods

Why do we call it as natural refrigeration methods ?

Because, in natural refrigeration , we rely on *Nature* for providing refrigeration

1. By Use of natural ice

(a) Ice transported from colder regions viz., polar regions to the other parts of earth

(b) Ice harvested in winter season and stored for summer

(c) Ice production by nocturnal cooling- This methods used for centuries for ice production particularly by India and middle east countries.

India

Middle East countries

What is nocturnal cooling

1. As the term suggest, **Nocturnal cooling** is a night process, So, it is also known as night sky cooling.
2. It is basically governed by physics of radiative cooling.

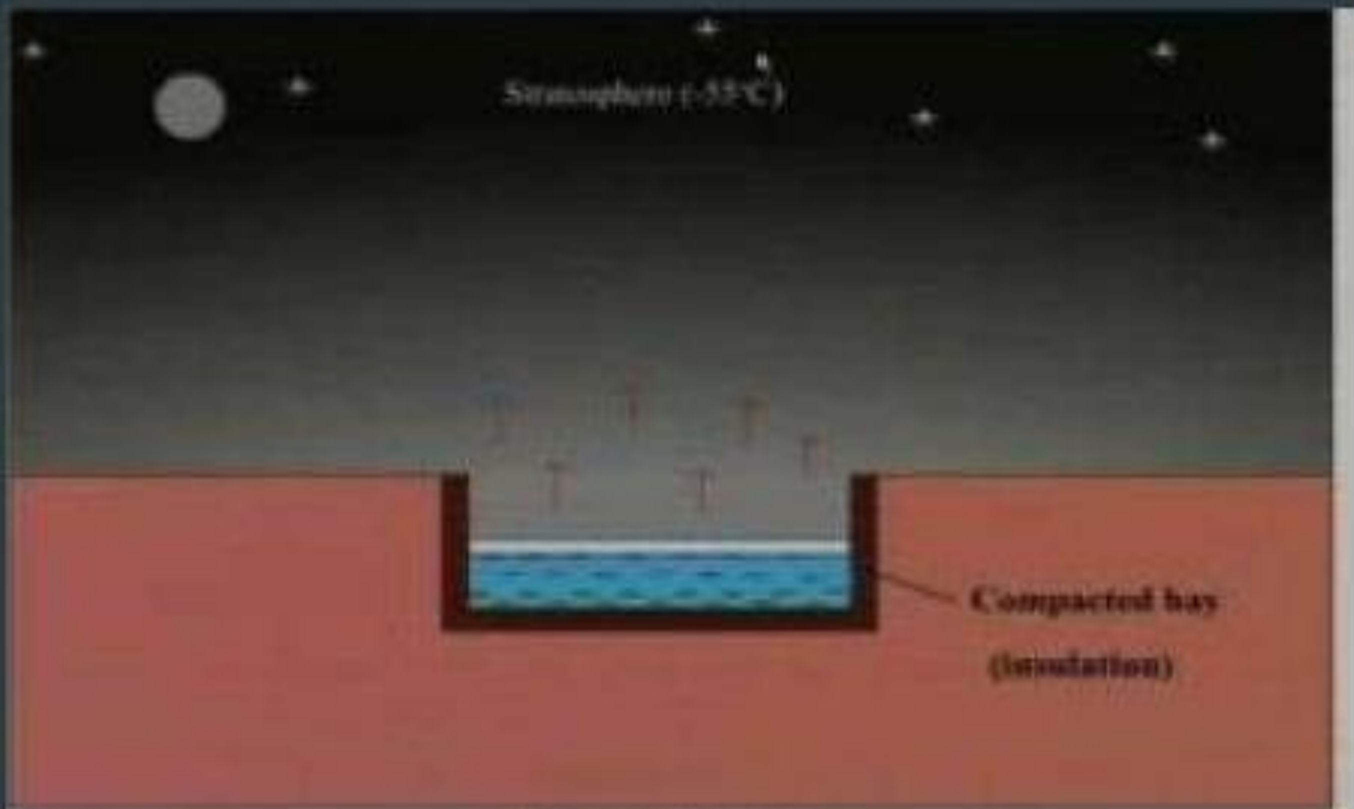
2. It must have a shallow water pool and a heat sink (at negative temperature i.e. from 0 to -˚C.

3. As India and Middle-East countries lie on Tropic of cancer at which sun can be directly overhead

So, In case of these countries the temperature of earth can not be at 0 ˚C.

Hence, the Stratosphere (around -55 ˚C) will act as heat sink and helps in nocturnal cooling in open sky condition.

Nocturnal Cooling



Nocturnal Cooling

Limitations of nocturnal cooling

1. It is not possible to make ice when the sky is not clear or it is cloudy because the radiations reflected back towards the earth.
2. For ice formation, A **good insulation** is required around the shallow pool of water.
3. We can not make thick slab of ice with this method.
4. The method is restricted to the shallow pool of water exclusively.

2. Refrigeration by use of evaporative cooling

-Evaporation produce cooling effect by removing moisture into atmosphere.

-Evaporation is an endothermic process.

-For example:

(i) This is the main principle behind the cooling of water in earthen vessel.

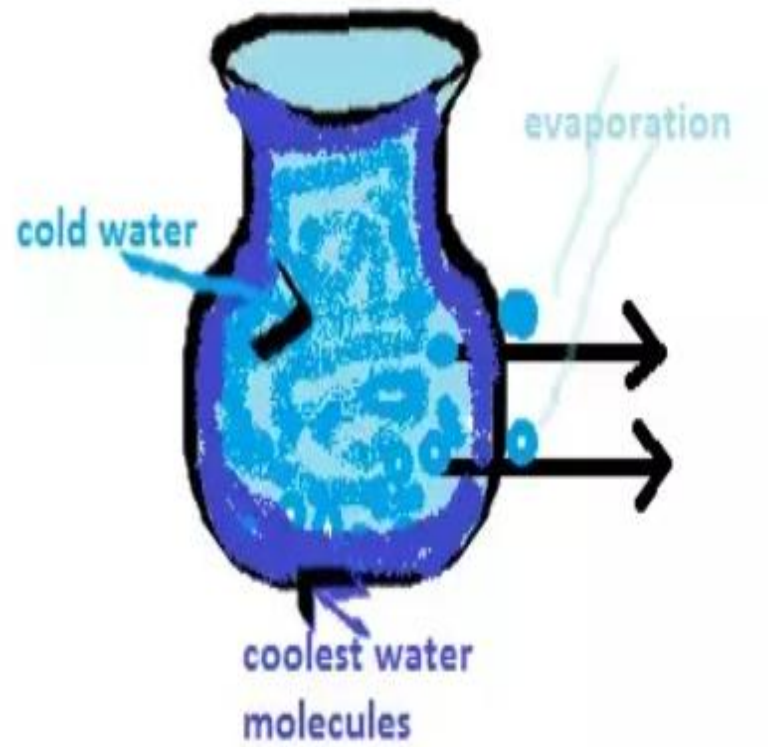
(ii) Cooling of human body after sweating during summer.

Note: Evaporative cooling is very effective in case of dry day. While, It is not much effective during the moist or humid day.

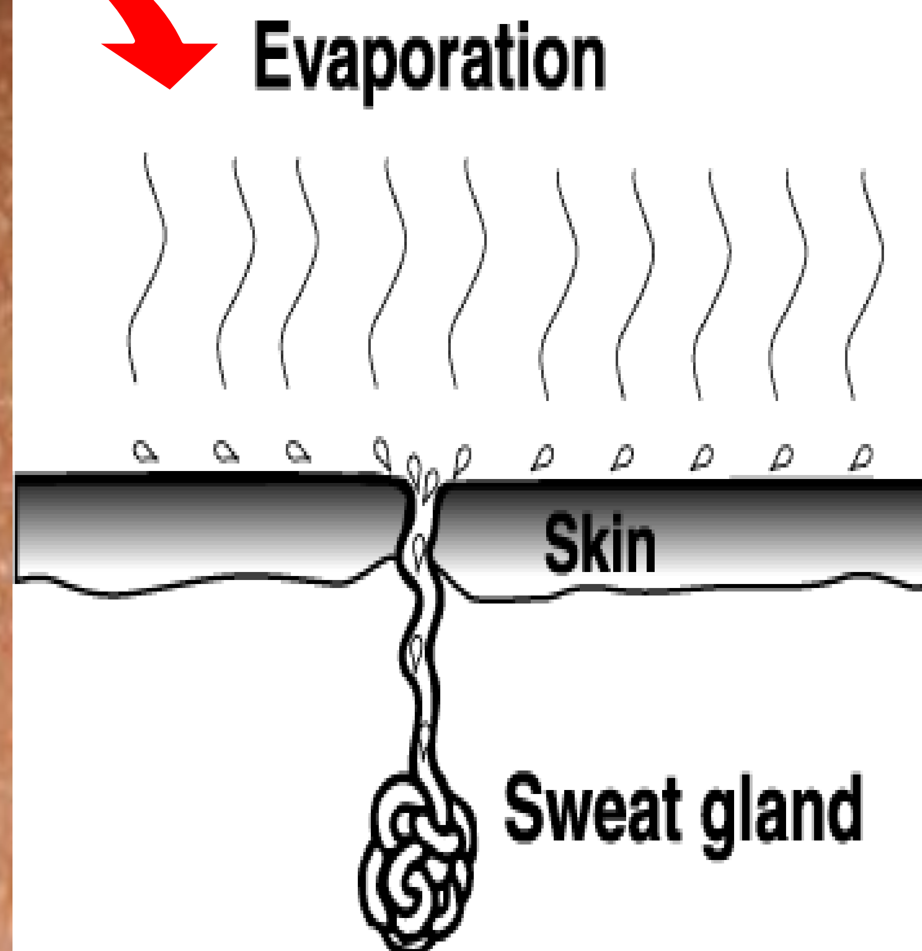
Limitations of Evaporative cooling

-Evaporative cooling is not effective in humid surrounding like coastal areas.

Water cooling in Earthen Vessel



Body cooling after sweating



3. **Cooling by salt solution**

-As dissolution of salt in any solvant is a endothermic process. So, it will take the required energy from solvant and resulting solution. In this way, the temperature of water reduced.

-Limitation

1. **Very low degree of refrigeration could be obtained.**
2. **The recovery of salt is very difficult.**

Limitations of Natural refrigeration methods

1. These methods depends on local conditions.
2. Uncertainty due to dependence of weather.
3. Difficult to produce large amount of refrigeration.
4. Not available to everybody.

Note: To overcome these limitations, people started refrigeration with artificial methods.

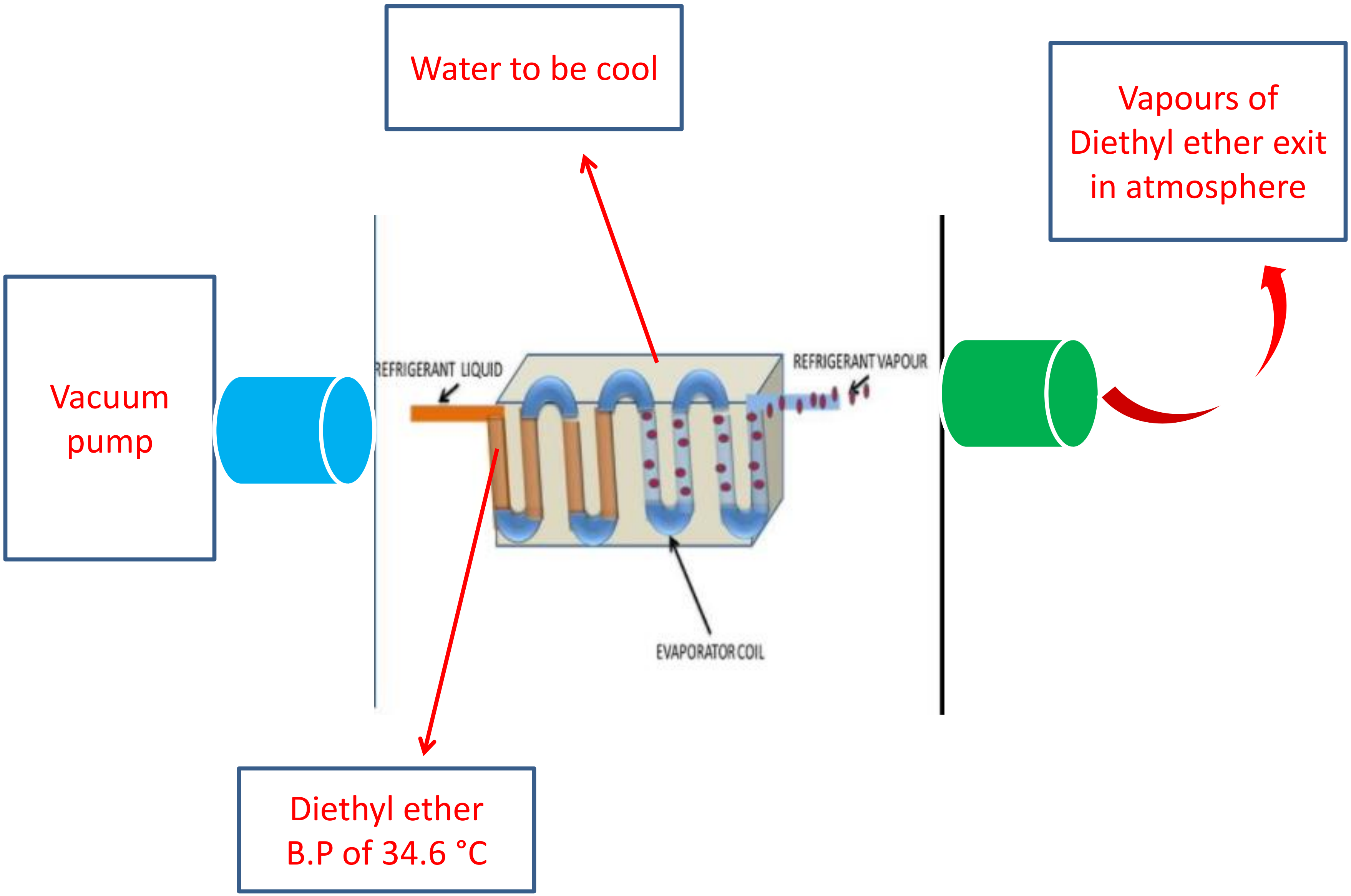
Artificial Refrigeration

The early attempts

1. In 1755, william cullen (Scottish Professor) produces a small quantity of ice

Principle: The absorption of large quantity of heat when a liquid boils at low temperature under the action of vacuum.

First Artificial Refrigeration system by William Cullen



Limitations of William Cullen Refrigeration system

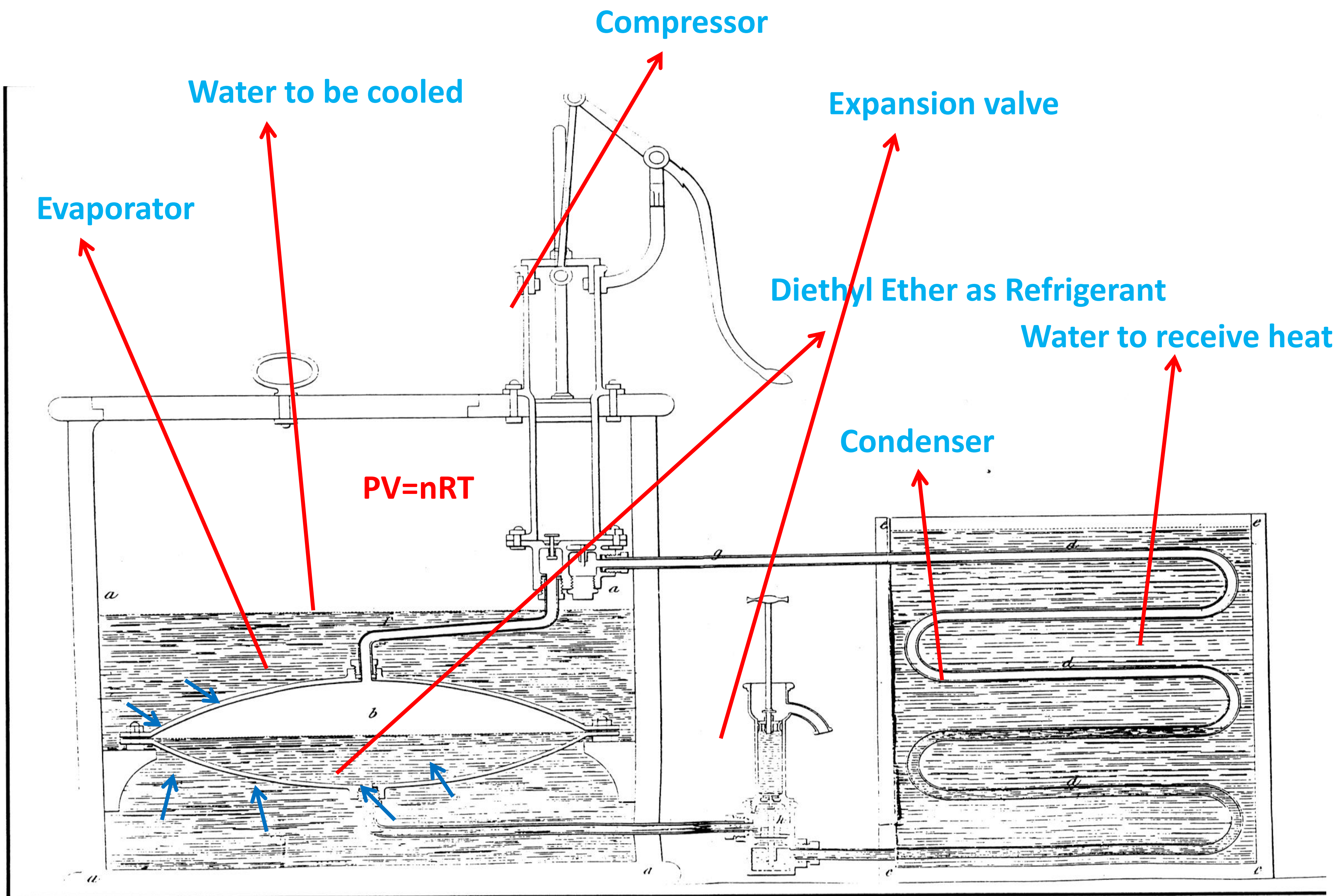
1. This process is not spontaneous because it requires some external mechanical force to maintain vacuum. So, this is the limitation.
2. The Diethyl ether vaporises into atmosphere. So, it need large quantity of Diethyl ether to run the process which is not practical actually.
3. The recycling of refrigerant (Diethyl ether) must be there to make the system more efficient.
4. The amount of refrigeration achieved is very low.

Vapour Compression Refrigeration System

-The concept was first given by Oliver Evans in 1805 who describes closed cycle for producing refrigeration in a continous manner.

- In 1835, Jacob Perkins designed and patented the system as described by Oliver Evans.

Jacob Perkins Refrigeration System/Machine



Working Principle

$$PV=nRT$$

Boyle's Law

$$P \propto \frac{1}{V}$$

Further Developments

- Alexander Twining (American Engineer) used ether, ammonia and CO_2 in vapour compression system- Got Patent in 1850.
- James Harrison- Patent 1856-ether, ammonia and alcohol based VCS-First successful commercial model.
- Charles Tellier (France)-Dimethyl ether based system in 1864. It has lower B.P than Diethyl ether but highly toxic.

Raoul Pictet (1874) SO2 based Model

- Designed SO_2 based system in Geneva.
- This was the most successful refrigerant used almost for 60 yrs in domestic refrigerators.
- SO_2 has lubricating property so no need of extra lubricating material.

Limitation

It forms sulphur-dioxide by reacting with water. Which is highly corrosive. So, it was stoped using in 1930.

- 1877-Carl Von Linde (Germany)- first successful ammonia based system- Landmark in histrory of refrigeration.
- 1885-Fraunz Windhausen-first CO_2 based system- used for 50-60 yr in marine refrigeration.
- Safe refrigerant-non toxic, non inflammable.

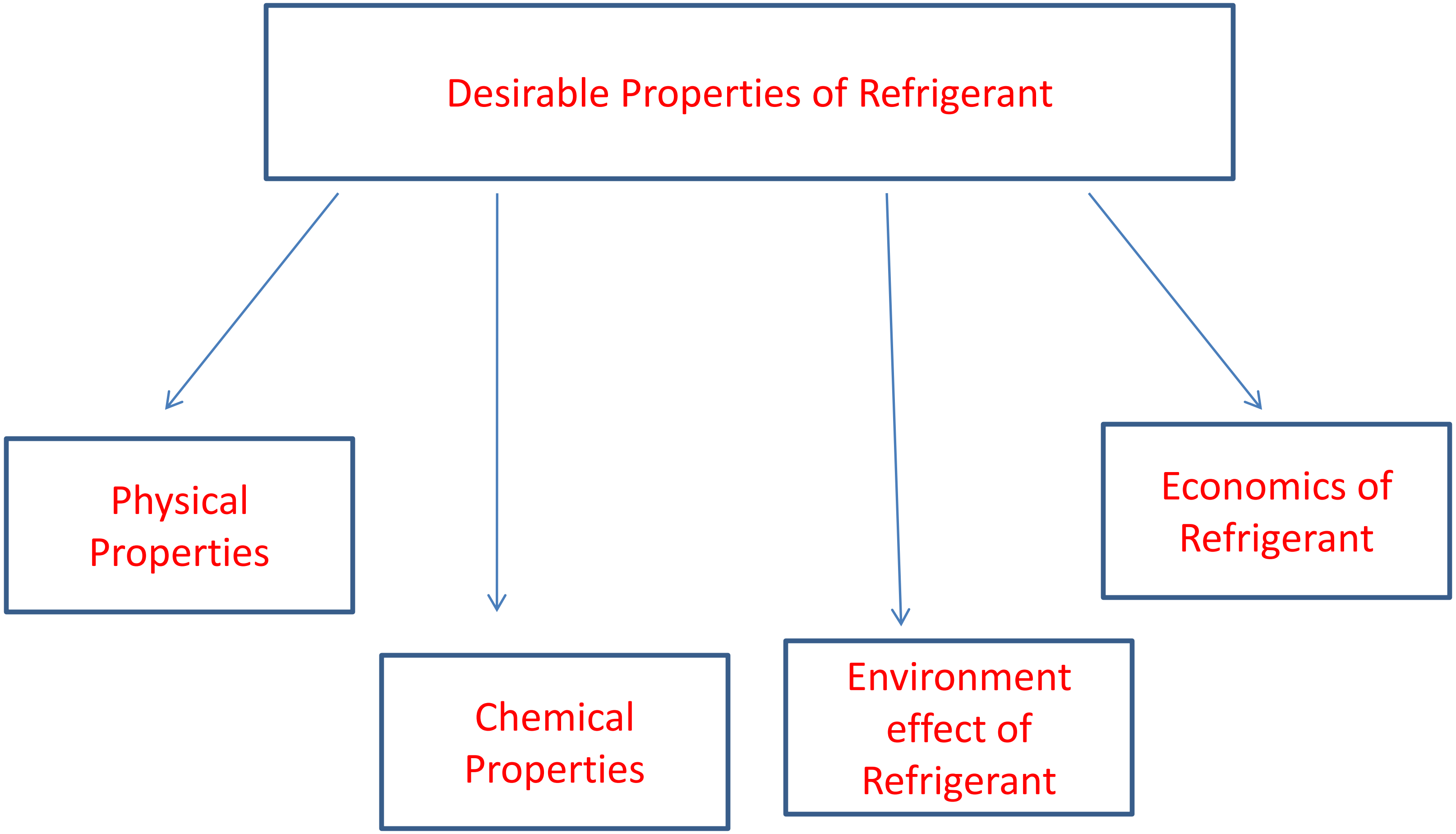
Problem with CO_2

- The condensation of the gas can not take place if the sink temp. is high due to very low critical temp.

- 1920-Copeland and Edwards build isobutane based domestic refrigerators.
- It was stopped due to its highly inflammable property.

Desirable properties of Refrigerant

- Refrigerants are widely used in Refrigeration cycle where cooling effect below the atmospheric temperatures are needed. Whenever we choose them for particular use Properties of Refrigerants also plays a vital role in economic and environmental friendly application. Here are some of the desirable properties of refrigerant explained in detail.


Desirable Properties of Refrigerant
Physical Properties
Chemical Properties
Environment effect of Refrigerant
Economics of Refrigerant

Physical properties of Refrigerant

1. Low freezing point: Refrigerants should have low freezing point than the normal operating conditions. It should not freeze during application. Water for example cannot be used below 0 C.
2. Low condensing pressure: The lower the condenser pressure the power required for compression will be lower. Higher condenser pressure will result in high operating costs. Refrigerants with low boiling points will have high condenser pressure and high vapor density. The condenser tubes have to be designed for higher pressures which also give raise to capital cost of the equipment.

3. High Evaporator Pressure:

i. This is the most important property of refrigerant. In a negative pressure evaporator Atmospheric air or Moisture will Leak into the system. The moisture inside the system will starts freezing at low temperature zones and clogs and chokes the system.

ii. Atmospheric air ingression into the system will occupy the heat transfer area and results in poor heat transfer rates. Presence of air will reduce the partial pressure of refrigerant and the condensation temperature will rise. It increasers the condenser pressures and thereby the power consumption for the compressor will also rise.

iii. Atmospheric air ingression inside the system may sometime results in explosions if the flammability values of the refrigerants are in wide range.

iv. Due to the above disadvantages, Positive evaporator pressure is preferred. Leak outside the system results in refrigerant loss and it can be identified easily and refrigerant loss can be topped up. Moderately high evaporator pressure boosts the compressor suction pressure thus reduces the power costs.

4. High Critical Pressure: Critical pressure of the refrigerant should be higher than the condenser pressures. Otherwise the zone of condensation decreases and the heat rejection occurs.
5. High Vapor Density: Refrigerants with High vapor density/ Low specific volume will require a smaller compressors and velocity can be kept small and so the condenser tubes used will also be in smaller diameter.
6. High Dielectric strength: In hermetically sealed compressors refrigerant vapor contacts with motor windings and may cause short circuits. Therefore dielectric strength should be high to avoid short circuits.
7. High Latent Heat of Vaporization: Higher latent heat of vaporization of the refrigerant will result in lower mass flow rates according to the Heat transfer equation. If the mass flow is very small it is difficult to control the flow rates. Therefore ammonia cannot be used for small refrigeration systems.
8. High Heat Transfer Coefficient: Higher heat transfer coefficient requires smaller area and lower pressure drop. This makes the equipments compact and reduced the operating cost.

Chemical properties of Refrigerant

1. Toxicity: Toxicity is the important properties of refrigerants. The refrigerants should be non poisonous to humans and food stuff. The toxicity depends upon the concentration and exposure limits.
2. Oil Solubility: The lubricating oils must be soluble in Refrigerants. If the oil is not miscible in the refrigerant used and it is heavier it will settle down in the evaporator and reduces the heat transfer. Therefore oil separators are to be employed. If the oil density is less than the refrigerant used and it if it is immiscible, the oil will float on the surface of the refrigerant. Therefore overflow drain is to be provided to remove oil. If the refrigerant velocity is not sufficient, then it cannot carry all oil back into the compressor. It may accumulate in evaporator. This phenomenon is called Oil logging.
3. Low Water Solubility: Most of the refrigerants form acids or bases in the presence of water. This will cause corrosion and deteriorates valves, Seals and Metallic parts. Insulation of windings in hermatic compressors will also get damaged. The free water apart from the dissolved water in refrigerant freezes below 0 Deg C and chokes the narrow orifice of expansion valve. This may also cause bursting of the tubes.
4. Reactivity: The refrigerants should not react with the materials used in refrigeration cycle like evaporators, condenser tubes, compressors, control valves etc. Ammonia reacts with Copper and Cuprous alloys and forms copper complexes. CH_3Cl reacts with Aluminium. Most of the refrigerants form acids with water. CCl_2F_2, CH_4Cl can form HCL with water which dissolves the copper from condenser tubes and deposits them on compressor pistons and deteriorates the life of the machinery.

Environmental effect of refrigerant

1. Leakage Detection:

i. **Ammonia and SO_2** can be detected by their characteristic smell. Strong smelling chemicals like acrolein may be added to refrigerant for easy leak detection.

ii. **Freon leak** can be detected by a halide torch. It consists of an alcohol lamp that emits a blue flame. If Freon is present blue flame turns into green. This test is based on Beilstein Test for Chlorine.

iii. **SO_2 can be detected** with NH_3 H_2O Solution. It makes white fumes of ammonium sulfide.

iv. Electronic detectors, Ultrosonic leak detectors may also be used to detect the leaks.

2. Flammability: The refrigerant should not make combustion mixture in Air. Freon, Carbon Dioxide, SO_2 are non flammable. Methane, butane and other hydrocarbons are flammable. Ammonia will form explosive mixture when the concentration in air is between 16 to 25 %.

3. ODP: The ozone depletion potential (ODP) of a refrigerant is the relative amount of depletion to the ozone layer it can cause. ODP of R11 is fixed as the maximum value of 1.0. R-22 for example, has an ODP of 0.055.

4. GWP: Global Warming Potential (GWP) is a relative measure of how much heat a refrigerant traps in the atmosphere. GWP of Carbon Dioxide is 1.0. For Methane GWP is 72, it means that if the same mass of CH_4 and CO_2 were introduced into the atmosphere, that methane will trap 72 times more heat than the carbon dioxide. It is normally mentioned as 20 years or 100 years period.

5. STEL: Short Term Exposure Limit is the maximum concentration to which one can be exposed up to maximum of 15 minutes.

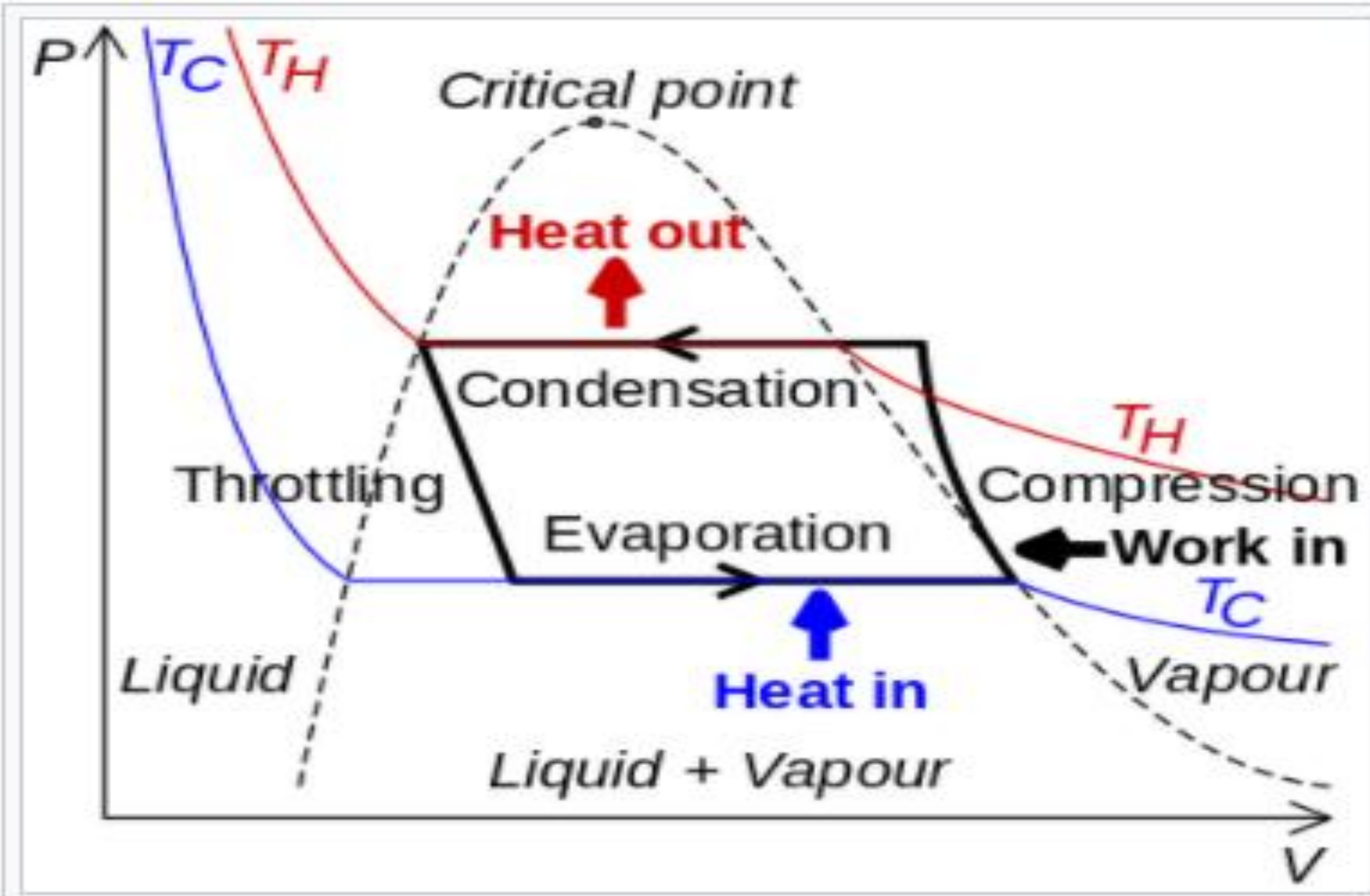
6. TWA: Time weighted Average is the concentration to which repeated eight hour exposures for five days in a week which is considered to be safe.

Economics of Refrigerant

1. Cost of refrigerants: The quantity of refrigerant used in any industry is very small. Therefore cost of the refrigerants is normally high when compared to other chemicals. Similarly if it is very low industry professional will not take necessary action to control the leaks.
2. Availability: Refrigerants should be readily available near the usage point. It must be sourced and procured within a short span of time to enable the user in case of leaks, maintenance schedules etc.

Vapour compression refrigeration system

- Vapor compression refrigeration system is the most popular and universally used system for the production of low temperature.
- In this system a working fluid known as refrigerant (such as Freon-12, Freon-22, NH_3, SO_2, CO_2, etc.) is used.
- The refrigerant is circulated throughout the closed system, alternately condensing and evaporating. During its evaporation, the refrigerant absorbs its latent heat from the system to be cooled.



P
T_C
T_H
Critical point
Heat out
Condensation
T_H
Throttling
Compression
Evaporation
Work in
T_C
Liquid
Heat in
Vapour
Liquid + Vapour
V

Components of VCRS

1. Compressor
2. Condenser
3. Receiver
4. Expansion valve
5. Evaporator

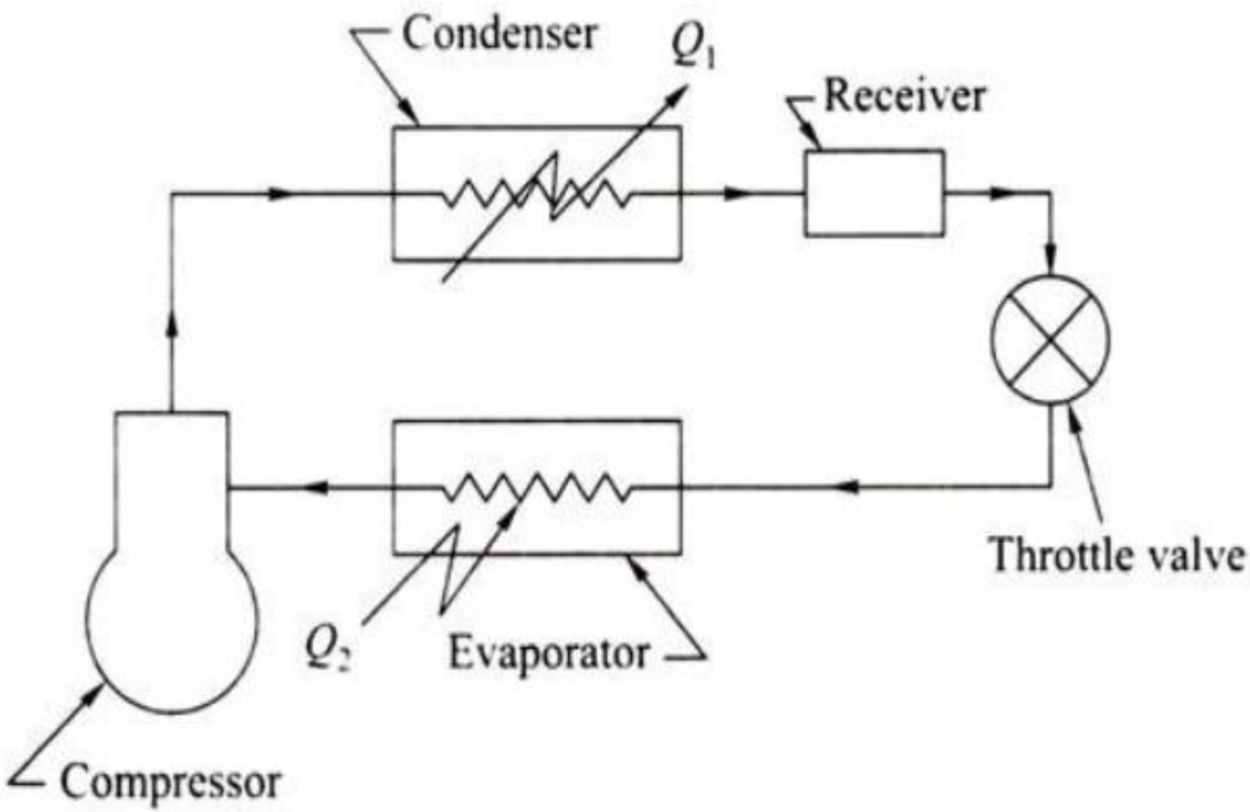


Fig. 6.2 Simple vapor compression refrigeration system

1. Compressor

- A mechanical device which is necessary to keep the refrigerant circulating to undertake the refrigeration cycle is known as compressor.
- Vapor formed in evaporator at low temperature and pressure is sucked by the compressor and compresses it at higher temperature and pressure and supplies to the condenser where heat is rejected to the surrounding through water or air, according to the type of condenser (either water-cooled or air-cooled).
- Generally, compressor is driven by an electrical motor. The electrical energy supplied is the power input to refrigeration system.

Main function of compressor

(a) It removes the refrigerant vapor from evaporator, so that the desired pressure and temperature can be maintained.

(b) It increases the pressure and temperature of refrigerant vapor by the process of compression.

Types of compressor

a. Reciprocating compressor

(i) Open-type compressor

(ii) Hermetic sealed compressor

b. Rotary type compressor

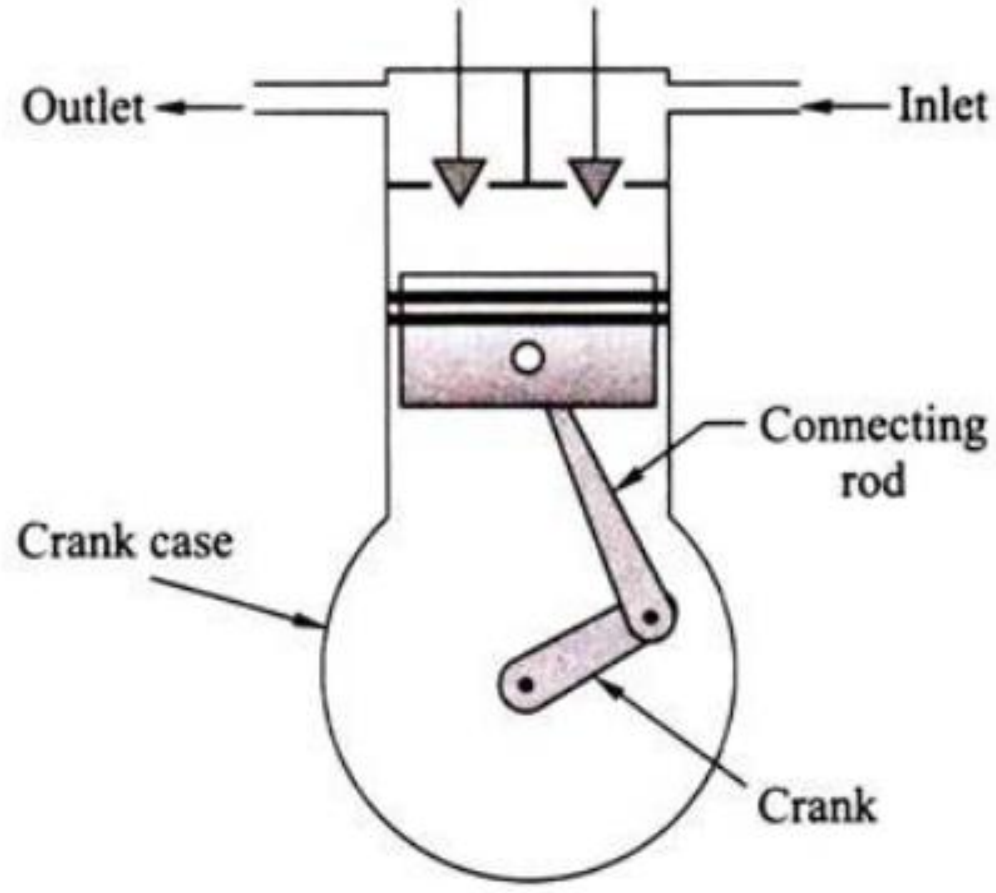
c. Centrifugal compressor

a. Reciprocating or Scotch Yoke compressor

- The compressor in which vapor refrigerant is compressed by the reciprocating (back and forth) motion of the piston in a cylinder is known as reciprocating compressor.
- It is suitable with the refrigerant which requires a comparatively small displacement at comparatively high pressure (such as R-12, R-22, NH_3, etc.).
- Reciprocating compressors are available in sizes as small as 0.5- 150 kW viz., small size refrigerating units such as domestic refrigerator, window air conditioners,

- Large size compressors upto 150 kW for large-capacity installations such as cold storage, NH_3 plant, and central air conditioning system.

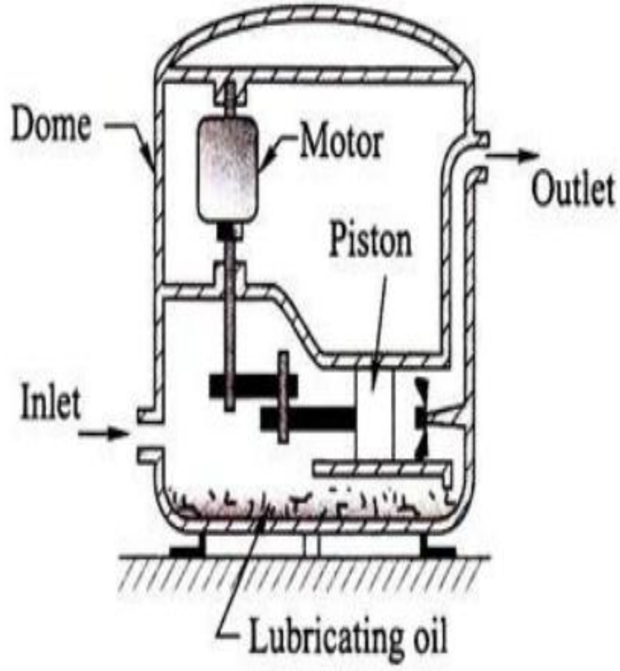
Open type Reciprocating compressor



- The open-type compressor is flexible in the sense that by varying the speed of the compressor, different capacities can be maintained.
- It can be operated by any type of prime mover/system such as electrical motors, petrol/diesel engine, etc.
- The motor and compressor both are separate units and are coupled with a common shaft for power transmission.
- The motor can be easily replaced in case of a motor burn out.

Working of Reciprocating compressor

Hermatic Sealed type Reciprocating compressor

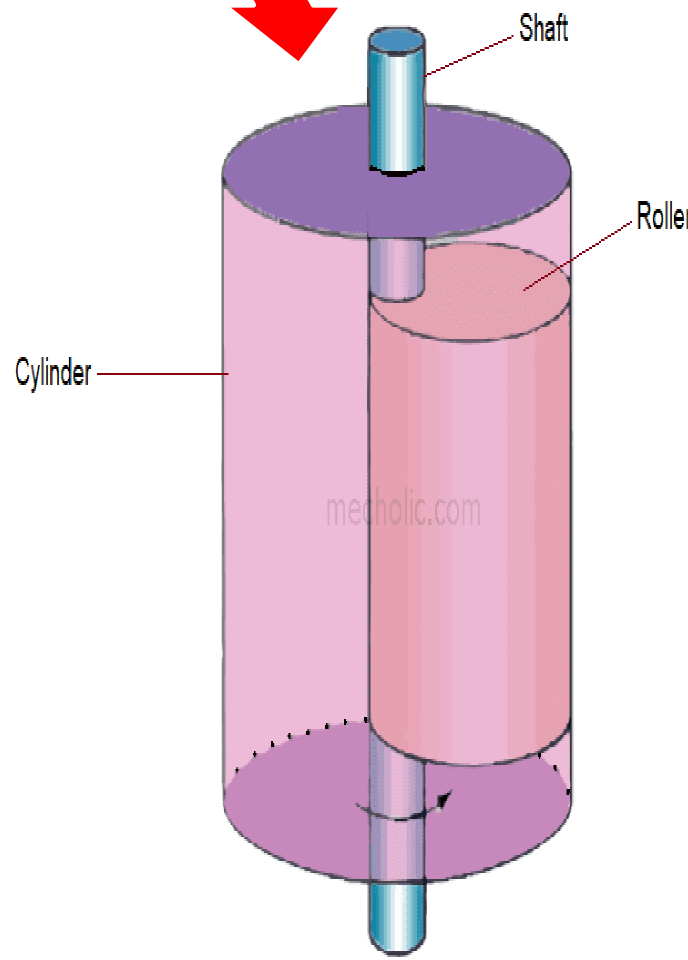


- The compressor and electric motor both are coupled and sealed in a metallic dome.
- In this type of compressor there is no need of shaft seal. The compressor and motor have a common shaft and are assembled in a single body.
- All joints are completely welded, such that there is no leakage of refrigerants.
- In this case, the noise and vibrations are completely eliminated. This is used for low- capacity unit, such as domestic fridges, window air conditioner, etc.

Rotary Compressor

- The **rotary compressors** are suitable for pumping refrigerant vapors having moderate or low condensing pressure.
- This type of compressor is suitable for R21 (**Dichlorofluoromethane**) and R114 (**1,2-Dichlorotetrafluoroethane**).
- It is designed for continous delivery unlike reciprocating compressor.
- It is designed for low starting torque.


LG
WARNING


Shaft
Roller
Cylinder
mecholic.com

Working of Rotary Compressor

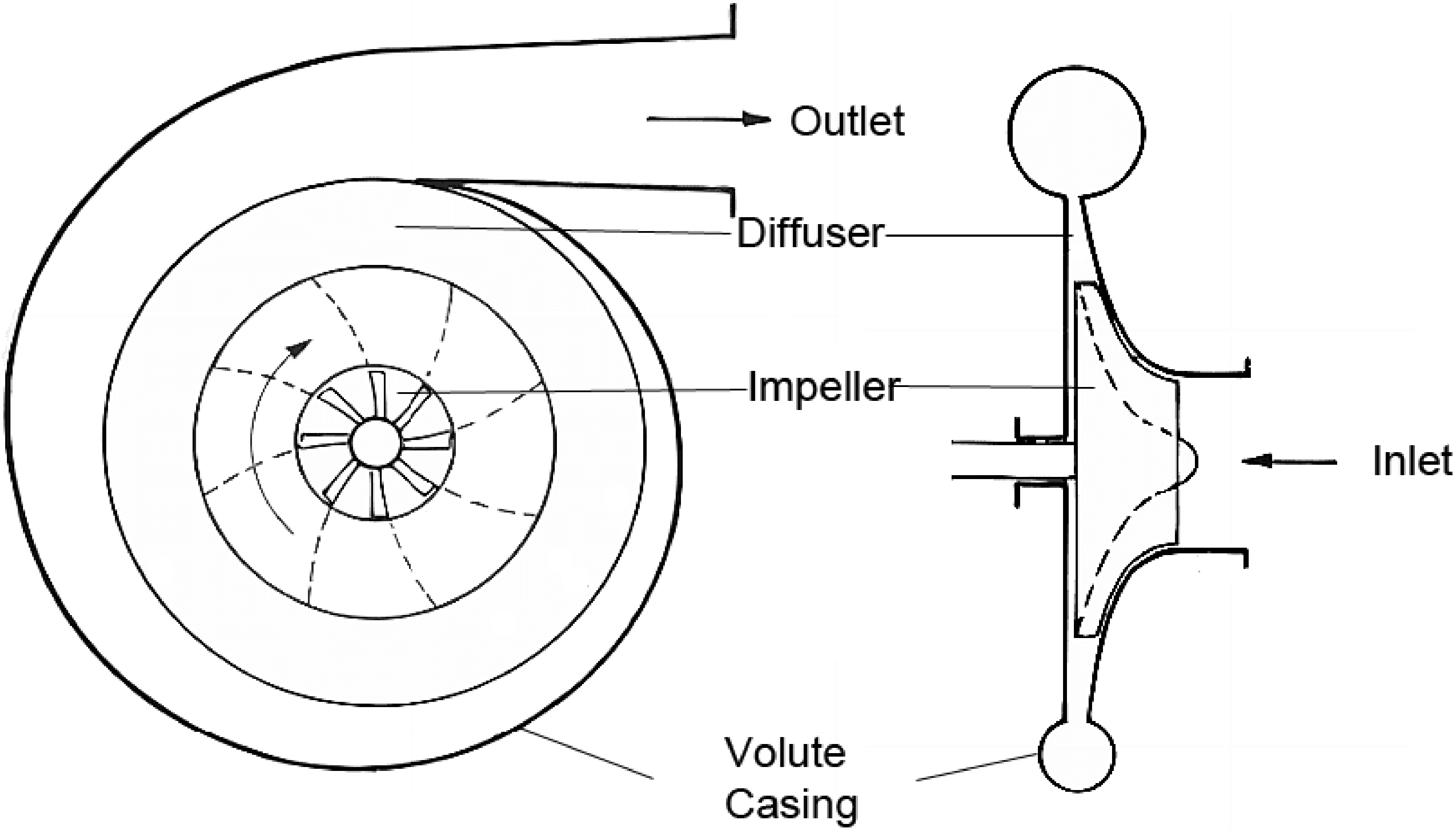
Difference b/w Reciprocating and Rotary Compressor

1. Performance: Rotary compressor supply continous while reciprocating compressor supply with slight gap. **Rotary compressor is best for large scale air conditioning**.
2. Efficiency: Since no. of cyllinders can be attached in side the compressor. So extremly high pressure can be achieved.
3. Power: Rotary compressor operate with less power than Reciprocating compressor.
4. Noise and Vibration: Less noise in Rotary compressor than Reciprocating compressor.
5. Cost wise: Reciprocating is cheaper than rotary compressor.
6. Maintenance: easy in reciprocating type than rotary type.

3. Centrifugal Compressor

- A centrifugal compressor increases the pressure of the refrigerant vapor by centrifugal force.
- This type of compressor is generally suitable for handling refrigerant vapor that requires large displacement and operates at low condensing pressure such as R-11, R-113, etc.
- The impeller of the centrifugal compressor has specially designed blades running radially from the center to the outer periphery of the impeller.
- The impeller of the compressor is coupled with the shaft of motor.
- When this rotates, the refrigerant vapor is pushed out from the center of the impeller to its outer periphery by centrifugal force.

Diagram of Centrifugal Compressor



Centrifugal compressor schematic diagram

Real-time figure of Impeller

Condenser

- A condenser is a heat exchanger in which the two fluids at different temperatures exchange heats.
- The condenser consists of copper or steel coil in which high-pressure and high-temperature refrigerant vapor is condensed.
- The refrigerant vapor rejects heat at high temperature and pressure to another fluid, either water (in case of water-cooled) or atmospheric air (in case of air-cooled) condenser.
- The refrigerant vapor gives off its latent heat to either water or atmospheric air.
- Consequently, the vapor refrigerant condenses and gets recirculated in the refrigeration cycle.
- The heat which is rejected in the condenser might have been picked up while evaporating the refrigerant in evaporator.
- The refrigerant vapor discharged from the compressor is sometimes in the state of superheated vapor, and hence, the condenser de-superheats the high-temperature and high-pressure refrigerant vapor first and then condenses it and also sub-cools the liquid to enhance the performance of the cycle.

Types of condenser

1. **Air-Cooled** Condenser

2. Water-Cooled Condenser

3. Evaporative Condenser

1. **Air-Cooled Condenser**

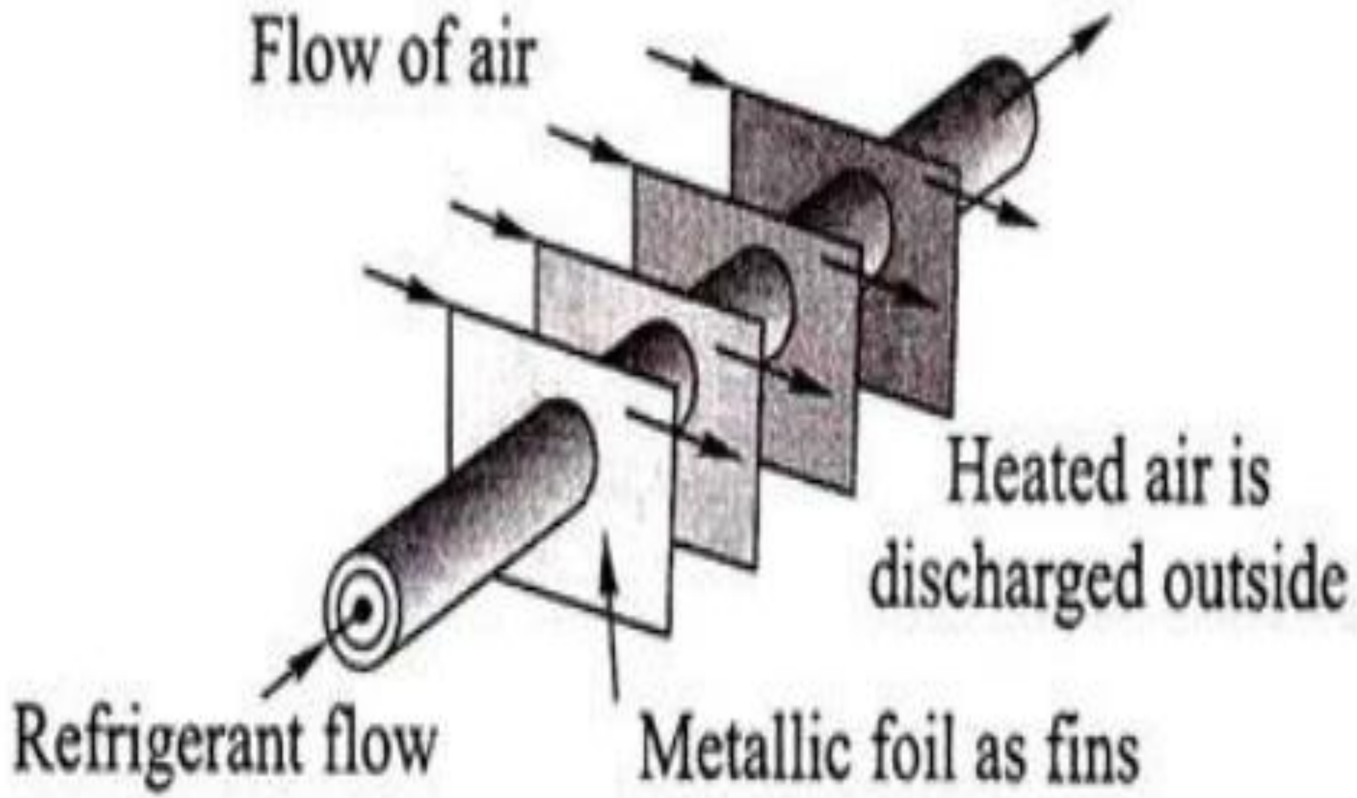
- An air-cooled condenser is cooled by the ambient air.
- The temperature of which is more than the water temperature.
- Hence, the condensing temperature will be higher in an air-cooled condenser than that in a water-cooled condenser.

There are two types air-cooled condenser

a. **Natural Air Circulation Condenser/Natural Convection**

b. **Forced Air Circulation Condenser**

Air-Cooled Condenser



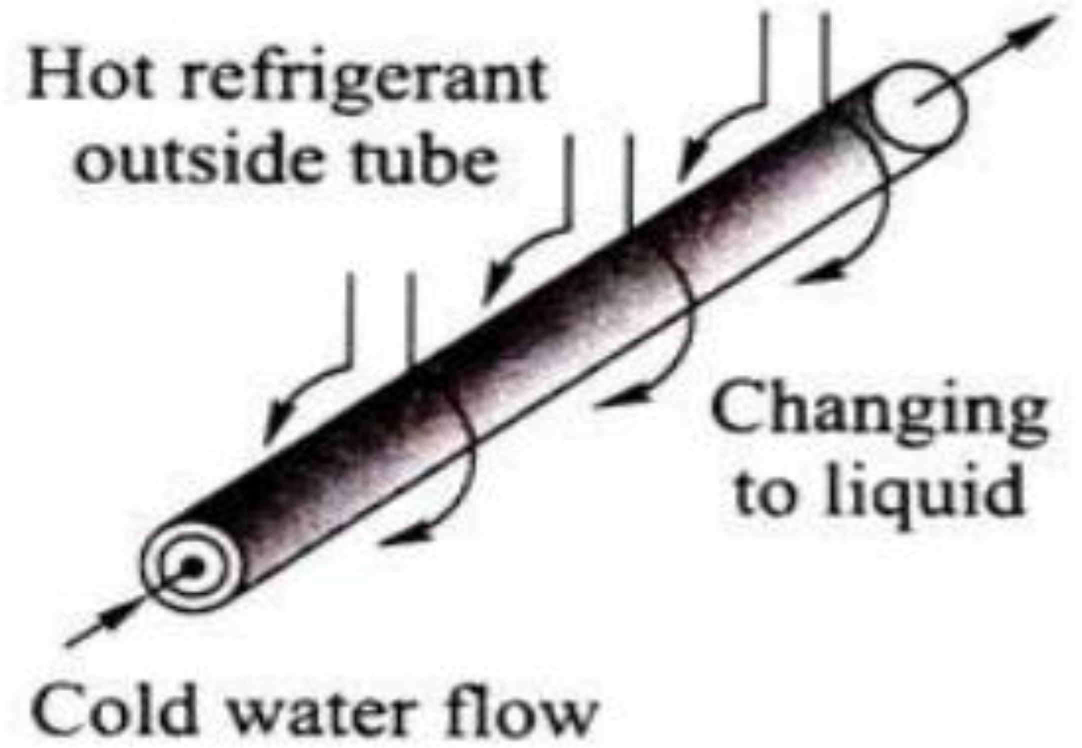
2. Water-Cooled Condenser

- A water-cooled condenser **uses water** as a cooling medium to transfer heat at a higher rate.
- The vapor refrigerant transfers heat to the **cold circulating water**

There are three types of water-cooled condensers

a. **Tube in tube water-cooled condenser**
b. **Shell and tube water-cooled condenser**
c. **Shell and coil water-cooled condenser**

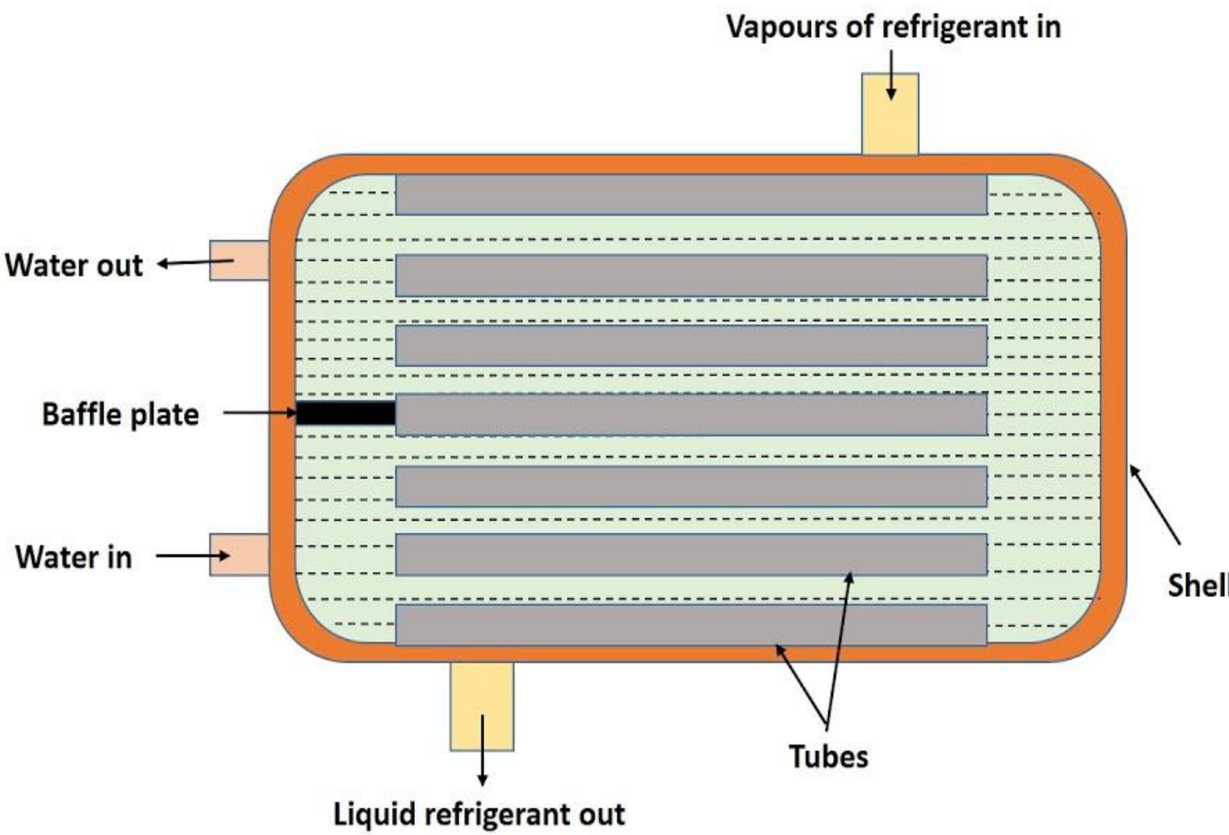
a. Tube in tube water-cooled condenser



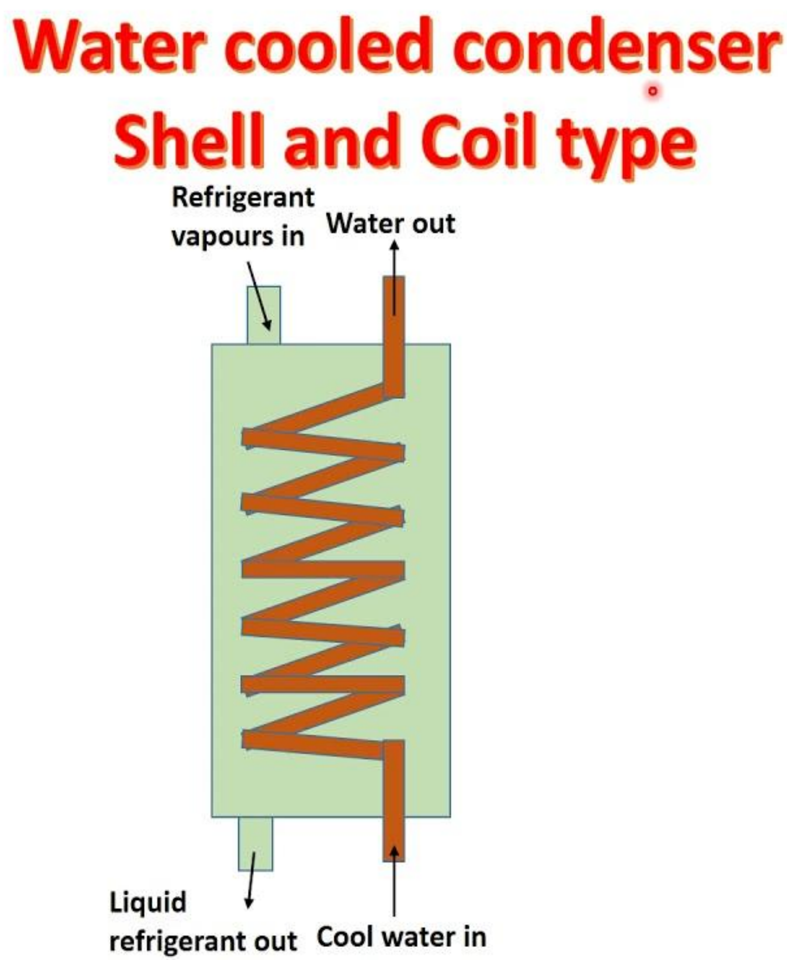
b. Shell and tube water-cooled condenser

Water cooled condenser
Shell and Tube type

AK All Education



C. Shell and coil water-cooled condenser



Receiver

- The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through expansion device.

Expansion Device

- The pressure of the liquid refrigerant from the condenser has to be reduced so that the liquid refrigerant can vaporize at the desired low pressure of evaporator.
- An expansion valve which is also known as throttle valve is a device to reduce the pressure and temperature of the liquid refrigerant before it is supplied to the evaporator where refrigerant gets evaporated.
- The valve actually creates a pressure difference between condenser pressure and evaporator pressure.
- The liquid refrigerant from the condenser is passed through the valve where it reduces the pressure and temperature equivalent to evaporator pressure.
- Sometimes, this valve is also known as refrigerant control valve. The function of the valve is to allow high- pressure and high-temperature liquid refrigerant to pass through evaporator.

Main function of Expansion device

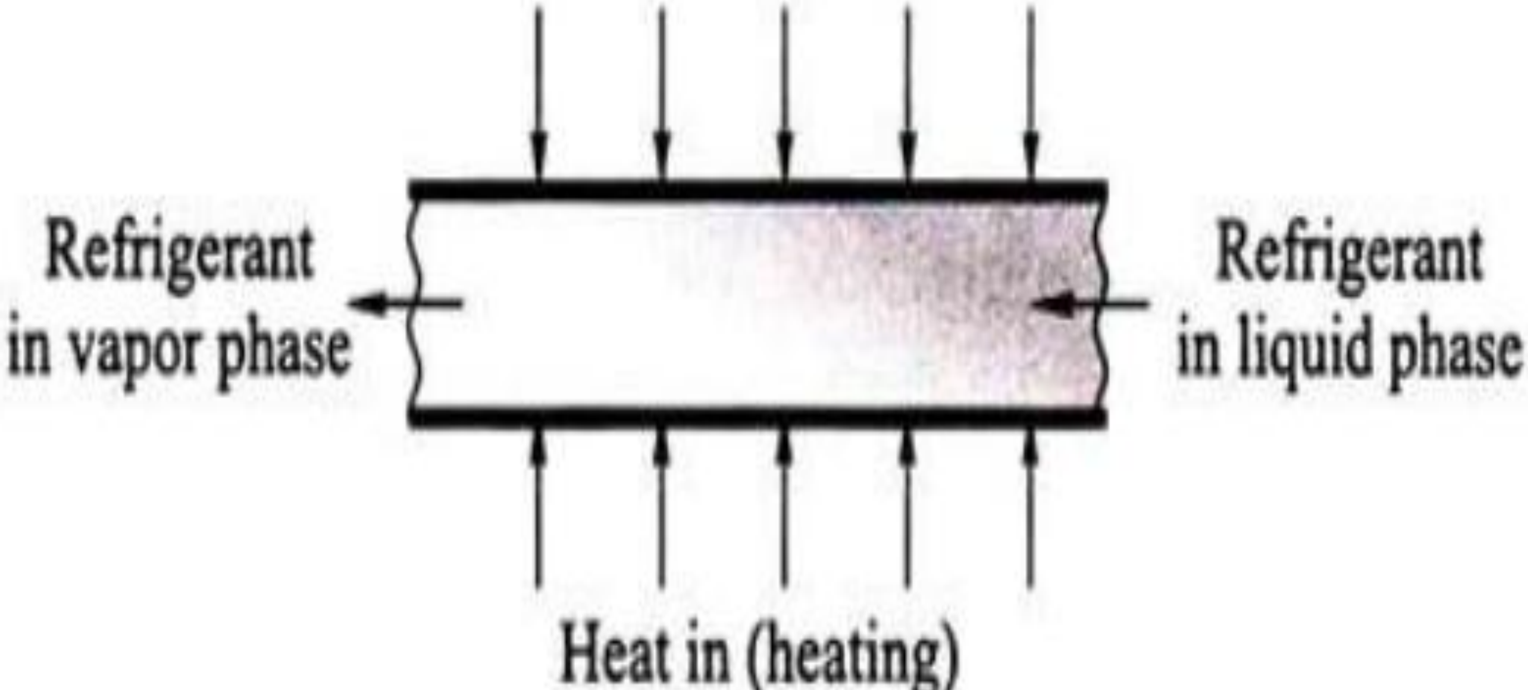
(a) It must reduce the pressure of the liquid refrigerant.

(b) It must regulate the flow of refrigerant to the evaporator.

Evaporator

- Evaporator is a heat exchanger in which a liquid refrigerant is evaporated at low pressure and low temperature.
- The process of heat removal from the system to be cooled is applied in evaporator.
- An evaporator consists of copper or steel tube in which liquid refrigerant evaporates at low pressure and temperature.
- The liquid refrigerant is evaporated inside evaporator coil in order to remove heat from air, water, and brine.
- In the evaporator, the liquid refrigerant absorbs its latent heat of vaporization from the fluid (air, water, or brine) which is to be cooled

Heat exchange in Evaporator



(a) Evaporator coil