PART 1 (Refrigeration: Refrigerating effect, Ton of Refrigeration; Coefficient of performance, methods of refrigeration, construction and working of domestic refrigerator, concept of heat pump.)

PART2 (Air-Conditioning: Its meaning and application, humidity, dry bulb, wet bulb, and dew point temperatures, comfort conditions, construction and working of window air conditioner.)

PART-1

Refrigeration and Refrigeration effect

Refrigeration may be defined as the process of removing heat from a substance under controlled conditions. It also includes the process of reducing and maintaining the temperature of a body below the general temperature of its surroundings.

Refrigeration systems work on the principle of heat transfer, where heat is absorbed from a low-temperature space (e.g., the inside of a refrigerator) and released into a higher-temperature space (e.g., the surrounding room).

The **Refrigerating Effect** is a measure of the heat absorption that occurs within the refrigeration cycle. In S.I. units, it is expressed as KJ/s or KJ/min

UNITS OF REFRIGERATION

The practical unit of refrigeration is expressed in terms of **ton** of refrigeration‟ (briefly written as TR).

A ton of refrigeration (1 TR) is defined as the amount of heat, which is to be extracted from one tonne (1000Kg) of water at 0 degree C in order to convert into ice at 0 degree C in 24 hours (1 day).

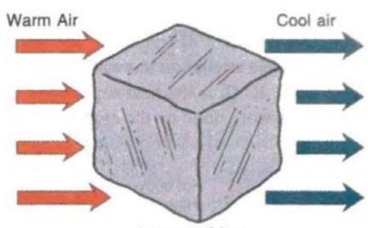
1 TR = 210 kJ/min = 3.5 KW.

Since the latent heat of ice is 335 KJ/Kg, therefore one ton of refrigeration. In actual practice, one tone of refrigeration is taken as equivalent to 210 kJ/min or 3.5KW.

Since the latent heat of ice is 335 kJ/kg, therefore one tonne of refrigeration,

$$1\text{TR} = 1000 \times 335 \text{ kJ in 24 hours}$$

$$= \frac{1000 \times 335}{24 \times 60} = 232.6 \text{ kJ/min}$$



One tonne (1000 kg) of ice requires 335 kJ/kg to melt. When this is accomplished in 24 hours, it is known as a heat transfer rate of 1 tonne of refrigeration (1TR).

In actual practice, one tonne of refrigeration is taken as equivalent to 210 kJ/min or 3.5 kW 3.5 kJ/s).

COEFFICIENT OF PERFORMANCE

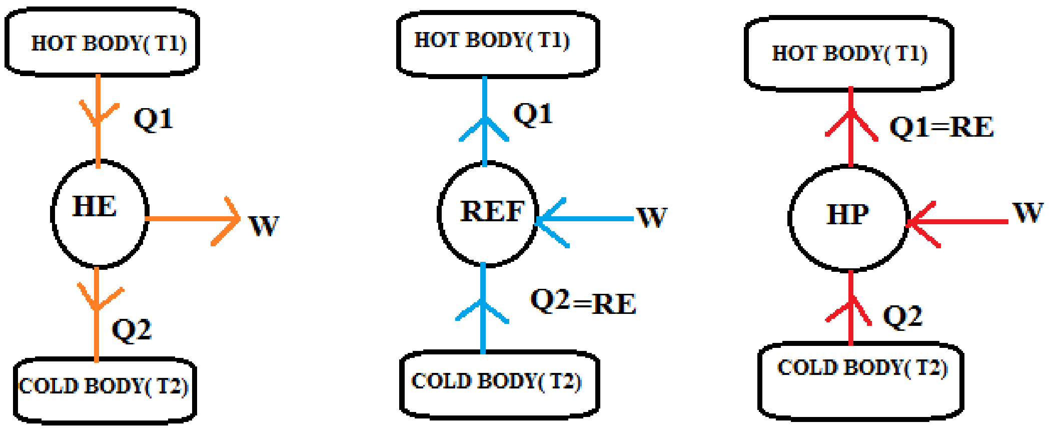
The coefficient of performance (briefly written as C.O.P.) is the ratio of heat extracted in the refrigerator to the work done on the refrigerant. It is also known as theoretical coefficient of performance. Mathematically,

$$\text{Theoretical C.O.P.} = \frac{Q}{W}$$

where Q = Amount of heat extracted in the refrigerator (or the amount of refrigeration produced, or the capacity of a refrigerator), and

W = Amount of work done.

COMPARISON THE COPS OF A REFRIGERATOR AND A HEAT PUMP.



HEAT ENGINE REFRIGERATOR HEAT PUMP

Efficiency of heat engine,

$$= \frac{\text{Work Output}}{\text{Heat Input}} = \frac{W}{Q1} = \frac{Q1-Q2}{Q1} = \frac{T1-T2}{T1}$$

Valid for reversible Cycle

COP of REF ,

$$= \frac{RE}{\text{Work Input}} = \frac{Q2}{W} = \frac{Q2}{Q1-Q2}$$

COP of HP ,

$$= \frac{RE}{\text{Work Input}} = \frac{Q1}{W} = \frac{Q1}{Q1-Q2}$$

$$(COP)_{HP} = (COP)_{REF} + 1$$

The COP of Heat Pumps and refrigerator is always greater than 1 and is therefore is a ratio of performance, not a ratio of efficiency, because a machine with an efficiency greater than 1 would imply that the machine is creating something out of nothing, which is impossible.
That's why we express the performance in terms of COP instead of efficiency

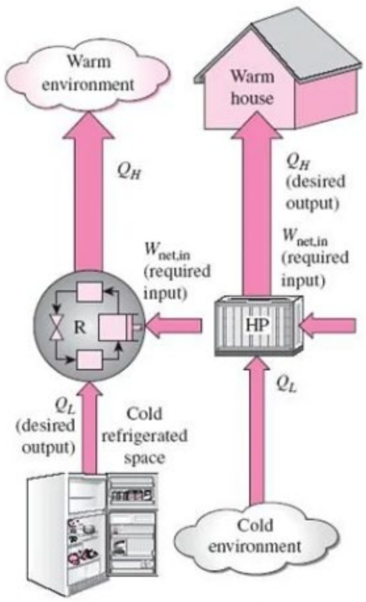
Coefficient of Performance

The performance of refrigerators and heat pumps is expressed in terms of the coefficient of performance (COP), defined as,

$$COP_R = \frac{Desired\ Output}{Required\ Input} = \frac{Cooling\ Effect}{Work\ Input} = \frac{Q_L}{W_{net,in}}$$

$$COP_{HP} = \frac{Desired\ Output}{Required\ Input} = \frac{Heating\ Effect}{Work\ Input} = \frac{Q_H}{W_{net,in}}$$

Both COP_R and COP_{HP} can be greater than 1.
For fixed values of Q_L and Q_H
$COP_{HP} = COP_R + 1$



(a) Refrigerator (b) Heat pump

Problem:

What is the coefficient of performance of a refrigerator that operates with Carnot efficiency between temperatures of -3 °C and 27 °C?

Solution:

1. Reasoning:
   For a refrigerator $COP_{max} = T_{low}/(T_{high} - T_{low})$.
2. Details of the calculation:
   The best possible coefficient of performance is
   $COP_{max} = T_{low}/(T_{high} - T_{low}) = 270/(300 - 270) = 9$.

A refrigerator has a coefficient of performance equal to 5. If the refrigerator absorbs 120 J of thermal energy from a cold reservoir in each cycle, find
(a) the work done in each cycle and
(b) the thermal energy expelled to the hot reservoir.

Solution:

- For a refrigerator the coefficient of performance is COP = $Q_{low}/(-W)$.
- Details of the calculation:
  (a) COP = $Q_{low}/(-W)$. $(-W) = Q_{low}/COP$ = 120/5 J = 24 J.
  The work is done on the system. Ordered (electrical) energy is converted into thermal energy.
  (b) we know $Q_{high} = W + Q_{low}$

$$Q_{high} = 24\ J + 120\ J = 144\ J.$$

The higher temperature of the refrigerant in a refrigeration system operating on the reversed Carnot cycle is 35°C and the lower temperature is -15°C. Determine coefficient of performance.

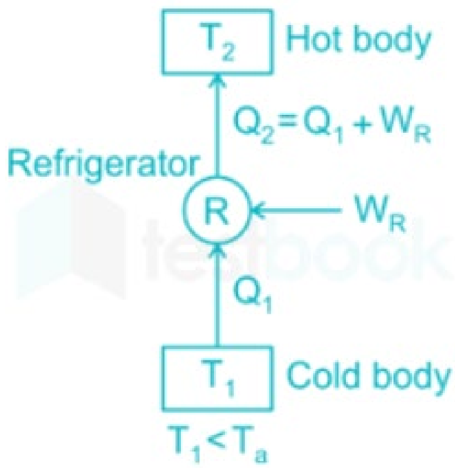
ANS:5.16

Refrigerating Effect R.E. = Q_1, Work input = $Q_2 - Q_1$

$$Coefficient\ of\ Performance\ (COP) = \frac{Refrigerating\ Effect}{Work\ Input} = \frac{Q_1}{W}$$

For a reversible engine:

$$COP_{Ref} = \frac{T_L}{T_H - T_L}$$



Calculation:

Given:

T_H = 308 K, T_L = 258 K

$$COP_{Ref} = \frac{T_L}{T_H - T_L}$$

$$COP_{Ref} = \frac{258}{308 - 258}$$

COP = 5.16

METHODS OF REFRIGERATION

There are number of methods by which the refrigeration can be achieved.

1. **Ice Refrigeration**: In this method the ordinary ice is used for keeping the space at temperature below the surrounding temperature. The temperature of ice is considered to be 0 degree Celsius hence it can be used to maintain the temperatures of about 5 to 10 degree Celsius. To use the ice for refrigerating effect a closed and insulated chamber is required. On one side of the chamber ice is kept while on the other side there is a space which is to be cooled where some material to be cooled can be placed. If the temperature below 0 degree Celsius is required, then the mixture of ice and salt is used. This method of cooling is still being used for cooling the cold drinks, keeping the water chilled in thermos, etc.

In the Direct method, the ice is kept in the same compartment with the articles to be cooled . Ice is placed at elevated position and cools the surrounding air. Cold air due to high density descends below displacing warmer air towards the ice. In the storage space cold air is warmed by absorption of heat from the products to be cooled. And rises through the storage space due to light density. It returns to the ice space. A circulation of air is maintained so long as air cooled on ice space and the cycle is repeated. Direct method of ice refrigeration is shown in fig. This method is used in hotels for cooling the drinks.

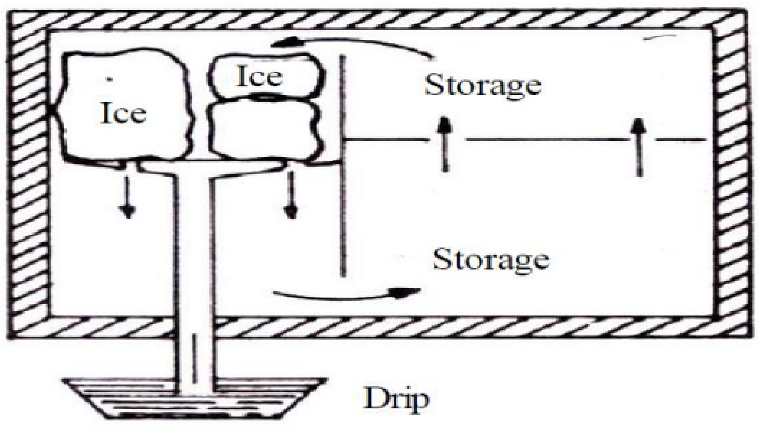


Figure 1 Ice Refrigeration (Direct Method)

2. **Dry ice refrigeration**: Dry ice is the solid carbon dioxide having the temperature of -78 degree Celsius. Dry ice is the solidified form of CO_2. It evaporates directly from solid to vapour without liquid phase. This phenomenon is called sublimation. In this, the dry ice in the form of flakes or slabs Is placed on the cartons containing food stuffs. When dry ice

sublimates, it will absorb heat from food stuff in the cartons and thus keeps them in a frozen condition. This is used for preservation of frozen foods and ice creams in storage and transportation. It has twice the heat absorbing capacity of ice refrigeration. However its cost is high.

3. Evaporative Cooling

In an evaporative cooling system, hot outside air is forced through wet cooling pads by means of a motor-driven fan. The cooling pads are moistened continuously by a water pump that delivers water to the cooling pads. The cooled down air is then blown into the building. The outcoming air can then be cooled down between 60 and 90 % of the wet-bulb depending on the effectiveness of the evaporative media. The outcoming air is cooled down 10 to 15 °C but contains a high amount of humidity. Therefore direct evaporative cooling is not recommended for cooling in work and living environments.

As the name indicates, evaporative cooling is the process of reducing the temperature of a system by evaporation of water. Human beings perspire and dissipate their metabolic heat by evaporative cooling if the ambient temperature is more than skin temperature. Animals such as the hippopotamus and buffalo coat themselves with mud for evaporative cooling. Evaporative cooling has been used in India for centuries to obtain cold water in summer by storing the water in earthen pots. The water permeates through the pores of earthen vessel to its outer surface where it evaporates to the surrounding, absorbing its latent heat in part from the vessel, which cools the water.

4. Gas Throttling Refrigeration

When the gas is throttled from very high pressure to low pressure in the throttling valve, its temperature reduces suddenly while its enthalpy remains constant. This principle is used in gas refrigeration system.

In this system instead of using Freon or ammonia as the refrigerant, the gas is used as the refrigerant. Throughout the cycle there are no phase changes of the gas, which are observed in the liquid refrigerants. Air is the most commonly used gas, also called as refrigerant in this case, in the gas refrigeration cycles.

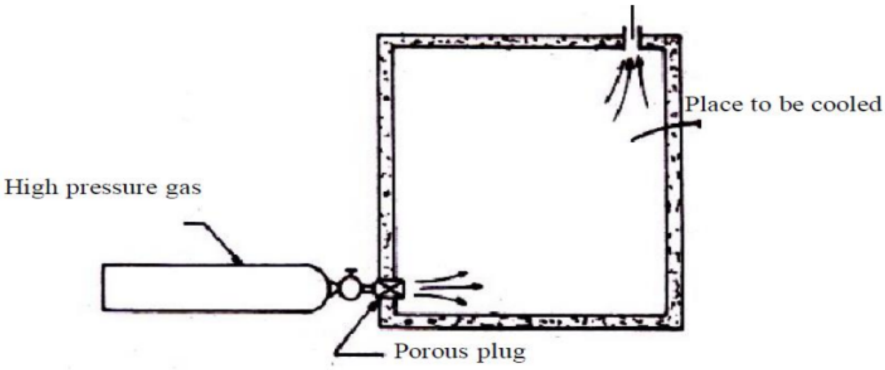


Figure 3 Gas Throttling Refrigeration

5. Mechanical Refrigeration

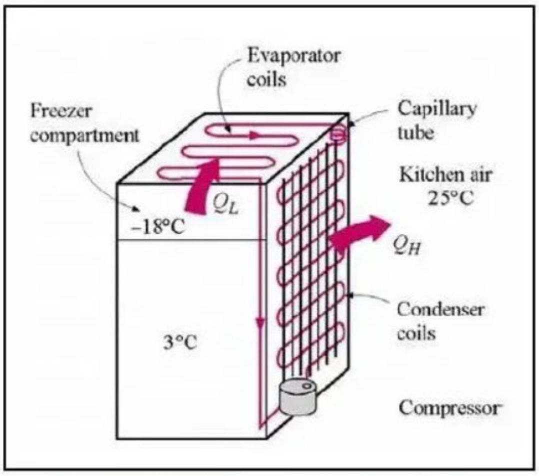
The natural and chemical methods have been successfully replaced by mechanical or heat energy refrigeration techniques. In these methods, the heat is abstracted from the substance or space (which is to be cooled) is pumped to a system (which is at high temperature level) by taking energy from an external source as input to refrigerating machine. The refrigeration system consists of a cycle of processes with the same quantity of working fluid (refrigerant) in continuous circulation.

Mechanical refrigeration systems are broadly classified into

- air or gas refrigeration
- vapour compression system
- vapour absorption system, and
- steam jet refrigeration.

DOMESTIC REFRIGERATOR

The domestic refrigerator is a heat pump that throws the heat of the foods or stuff to be cool to the atmosphere by taking the power of a compressor. The second law of thermodynamics with its Clausius statement suggests, to throw heat from low temperature to high temperature, one must put extra effort in the form of work. The same is done by the compressor in the domestic refrigerator.



Household Refrigerator Cooling Cycle

Primary function of domestic refrigerator: "To provide food storage space or cabinet maintained at low temperature (0°C to 4°C) for the preservation of food." Secondary function of domestic refrigerator: "Formation of ice cubes."

Refrigeration cycle used: Vapour Compression Cycle (V.C.C.).

Commonly used Refrigerant: R -134a.

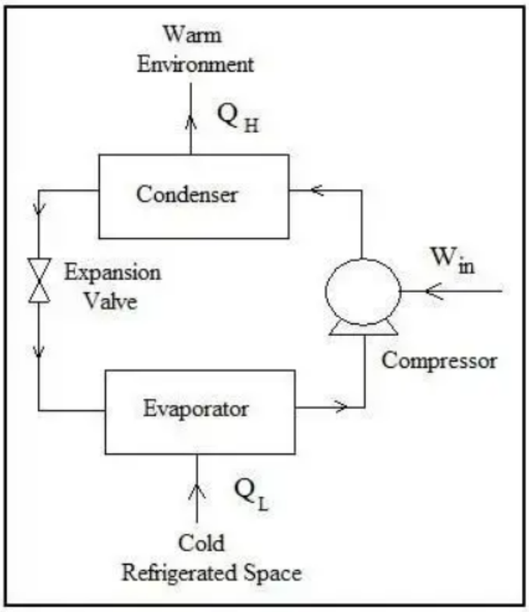
Capacity of domestic refrigerator: It is expressed in terms of "Litres". Standard refrigerators of capacity 90, 165, 210, 300, 420 litres etc. are available in market.

Construction of domestic refrigerator

The vapor compression cycle consists of 'Evaporator', 'Compressor', 'Condenser' and 'Capillary tube' as main parts. The system works on closed cyclic operation with the help of a heat transfer fluid called 'refrigerant'. This refrigerant changes the phase during passing through the evaporator and condenser to exchange the heat.

Working principle of domestic refrigerator: Vapor Compression Refrigeration Cycle (VCRC)

Domestic refrigerators work on the principle of vapor compression refrigeration. The basic components of a refrigerator include a compressor, condenser, expansion valve, and evaporator. Below is overview of how the vapor compression cycle works:



Vapor Compression Refrigeration Cycle

1. Evaporator: The evaporator is located in the freezer box in the form of a coil. The liquid refrigerant is evaporated in the evaporator by absorbing heat from the contents of the domestic refrigerator in the cabinet. The evaporator consists of copper metal rubbings surrounding the freezing and cooling compartments.

2. Condenser: The condenser is located as zigzag tubes behind the refrigerator on a mesh. In the condenser, the heat from the refrigerant at a higher temperature is rejected into the atmospheric air.

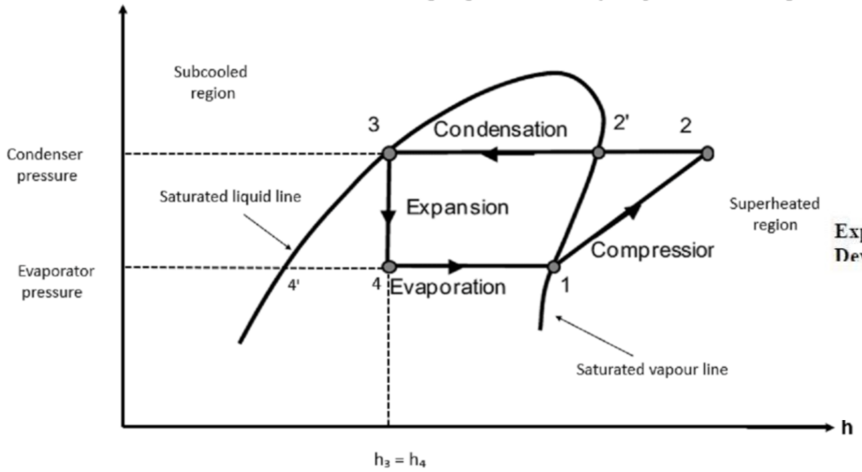
3. Compressor: The compressor is located at the base, at the rear end. It compresses the refrigerant vapour at a high pressure. A reciprocating compressor is used for low capacity domestic refrigerators.

4. Expansion Valve or Throttling Valve: An expansion valve is used to reduce the temperature and pressure of the liquid refrigerant, before it passes to the evaporator. The expansion capillary is located inside the refrigerator body, against the wall. The capillary tube is a small diameter tube used as an expansion device.

This continuous cycle of compression, condensation, expansion, and evaporation creates a heat exchange process that effectively removes heat from the interior of the refrigerator, keeping the contents cool. The heat extracted from the refrigerator's interior is released to the external environment through the condenser coils.

Vapour Compression Refrigeration System Cycle

Fig: Representation of dry compression on P-h diagram



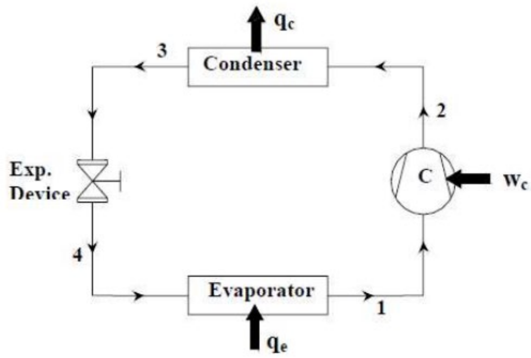
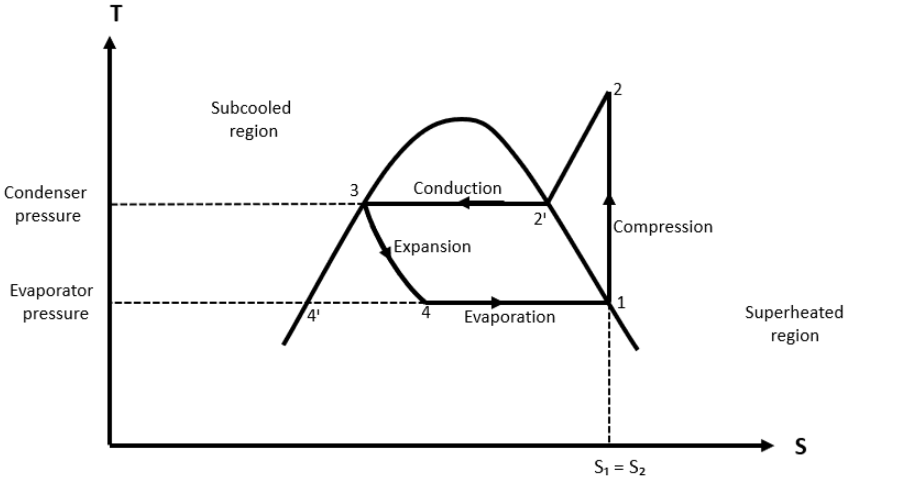


Fig: Representation of dry compression on T-S diagram



Standard single stage saturated vapour compression refrigeration system consists of the following four processes:

Process 1-2: Isentropic compression of saturated vapour in compressor

Process 2-3: Isobaric heat rejection in condenser

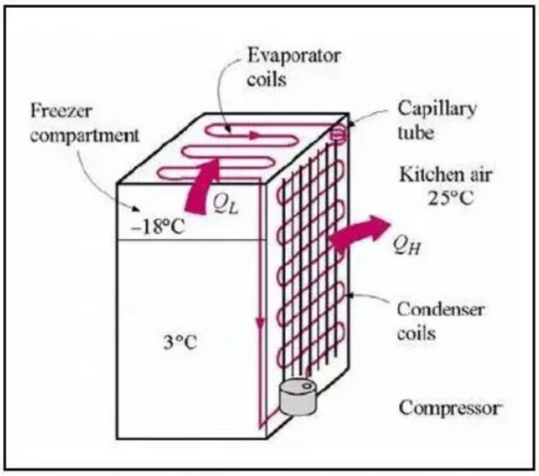
Process 3-4: Isenthalpic expansion of saturated liquid in expansion device

Process 4-1: Isobaric heat extraction in the evaporator

- The Dry Saturated Vapour Refrigerant (*Vapor Refrigerant*) entering the compressor at point (1) is compressed **Isentropically** to point (2), which increases the pressure from Evaporator pressure to Condenser pressure.

- At point (2), the Superheated Vapour Refrigerant enters the Condenser, where it rejects the heat to atmosphere at **Constant Pressure**. Due to rejection of sensible heat, the temperature of Vapour Refrigerant decreases from superheat temperature T_2 to saturation temperature T'_2 then, the change of phase takes place at **constant temperature** i.e. latent heat is removed during process 2' – 3 and reaches to liquid saturation temperature point (3).
- Then this liquid refrigerant is passes through **Expansion Valve**, where it is throttled (*expanded*) keeping the Enthalpy constant and reducing the pressure. Due to Throttling, some heat is evolved and the part of liquid refrigerant gets evaporated. Therefore, we get **liquid- vapour mixture** of refrigerant (*i.e. wet vapour refrigerant*) at the outlet of Expansion Valve.
- This Wet Vapour Refrigerant (*or Wet Vapor Refrigerant*) enters into Evaporator at point (4), where it absorbs latent heat during process 4-1 and gets converted into Dry Saturated Vapour Refrigerant and cycle is completed.

Applications of Vapour Compression Refrigeration System (VCRS)



Household Refrigerator Cooling Cycle

Storage of Fruits and Vegetables:

- Some ***perishable items like fruits and vegetable*****e** are rotten on high temperature because some kinds of bacteria are grow very rapidly in them. The growth of bacteria is reduced at low temperature. So refrigerator extends the storage life of fruits and vegetables.
- ***Meat and poultry:*** These kind of items like fish, chicken and meat also require refrigeration after slaughter because the growth rate of bacteria is very high in these items. Short-term storage is done at 0^{o}C. Long-term storage requires storage at -25^{o}C.
- ***Dairy Products:*** Some dairy products are milk, butter, curd and ice cream. For storage and supply milk is kept in refrigerators. In refrigerators the growth of bacteria is slow down and milk can be stored for two to three days after pasteurization process. To maintain good quality of other dairy products like butter, curd and ice cream they also require refrigerators.
- ***Beverages***: Some beverages like beer, wines and soft drinks taste good when they are chilled. Fruits juices are also require refrigerators to maintain their nutrition value and taste. While Brewing and wine making refrigeration also requires because these are done by fermentation and fermentation is an exothermic process but these processes should be done at specific temperature. To maintain desirable temperature refrigerators are used.

Industrial applications:

- Condensation of gases: Gases are condensed to liquid state by cooling process. Liquefied gases can be easily stored and transported. In liquid state gases requires less space.
- In preservation: Many compounds decompose at room temperature or these are evaporate at a very fast rate like some drugs, chemicals, explosive and natural rubbers by using refrigerator they can be stored for long period of time.
- In Construction: Setting of concrete is an exothermic process. If the heat is not removed the concrete will expand and produce cracks in the structure. This can be done by cooling sand and water or by passing chilled water through the pipes embedded in the concrete.

Some other applications

- ***Ice Manufacture:*** This was the classical application of refrigerators. Ice was manufactured in plants by dipping water containers in chilled brine for some time. In these plants ice is manufactured in large scale which is used further areas. But these days by using refrigerator we can easily manufacture ice. Ice can be easily manufactured by using domestic refrigerators for domestic use.
- ***In medical science:*** Blood plasma and some antibiotics are manufactured and stored at low temperature. Some other drugs also require less temperature for storage which can't be stored at room temperature.

<u>NOTE</u>

- **Some technical points of a domestic refrigerator**

a) Compressor used in a domestic refrigerator are of a reciprocating type and is hermetically sealed which means the compressor and the electric motor are a single unit enclosed in a container. The electric power consumed by this compressor is less than that of an air conditioner compressor of the same type. This is because of different heat-removing capacities

b) Capillary tube is a simple copper tube having a very less diameter of a few millimeters and a longer length in terms of a few feet. This low diameter and higher length increase friction and this is the reason why high-pressure liquid refrigerant is converted to low-pressure one due to pressure drop in the capillary itself.

c) Except compressor, there are no moving parts in a domestic refrigerator, this is the reason why the refrigerator lasts long

d) Condenser and evaporator are simply heat exchangers where the refrigerator changes the phase by rejecting and accepting heat from condenser and evaporator respectively. The compressor and capillary tube change the pressure accordingly to get the boiling point in range to be able to change the phase

e) Refrigerator capacity is defined in 'Litre'. The litre is the volume of storage space.

f) The entire domestic refrigerator is a closed thermodynamic system with a flow of heat and work in and out of the system but no mass flow is allowed across the system boundary i.e. no refrigerant leakage is permitted

- **What is the refrigerant, and how does each kind of refrigerant differ?**

Refrigerant is the media (fluid) used for heat transfer in a refrigerating system that absorbs heat during evaporation from the region of low temperature and pressure, and releases heat during condensation at a region of higher temperature and pressure.

- **Desirable Properties of an Ideal Refrigerant**

A refrigerant is said to be ideal it has all of the following properties:

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

Types:

Chlorofluorocarbons (CFCs):

CFC refrigerants, such as R11, R12, and R115, contain chlorine. These were once commonly used but were banned in the early 1990s due to their harmful impact on the environment.

Hydrochlorofluorocarbons (HCFCs):

HCFCs, like R22, R123, and R124, replaced CFCs. While they also contain chlorine, they are considered less harmful to the environment, with lower Ozone Depletion Potential (ODP).

Hydrofluorocarbons (HFCs):

HFCs, including R410A, R407C, R134A, R32, and R454B, do not contain chlorine and thus do not deplete the ozone layer. However, they have a greater impact on global warming compared to traditional refrigerants.

Natural Refrigerants:

Natural refrigerants, like ammonia (R717), carbon dioxide (R744), and hydrocarbons (R290, R600a), are eco-friendly options with minimal environmental impact. They are gaining popularity as more environmentally responsible alternatives.

- **How do domestic and commercial refrigerators differ?**

A commercial refrigerator is designed to be used much more frequently. A house refrigerator can be opened only a dozen times a day, while, over a few hours, a commercial refrigerator can be constantly opened. Commercial refrigerators are equipped with powerful compressors, construction that is much more robust and are often supported by fans. This commercial refrigerator makes an unwanted noise, which is a disturbing factor.