Northern Technical University
Technical Institute of Kirkuk
Power Mechanic Technique
Ref. & Air Conditioning

PRINCIPLES OF AIR CONDITIONING

Refrigeration - Temperature and its measurement - Properties of liquid and vapor

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Subject Lecturer

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Fundamental Proprieties of Air and Water vapour Mixture

Refrigeration

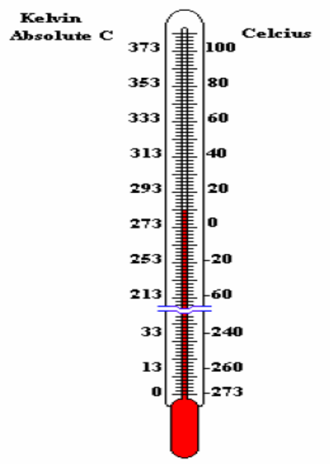
- The science that deals with the processes of lowering the temperature of the body or space.
- Temperature of the body is lower than the surrounding medium while maintaining that temperature.

Heat

- Form of energy which is exchanged between the system and its environment
- Heat can be converted into other forms of energy and other forms of energy can be converted into heat.

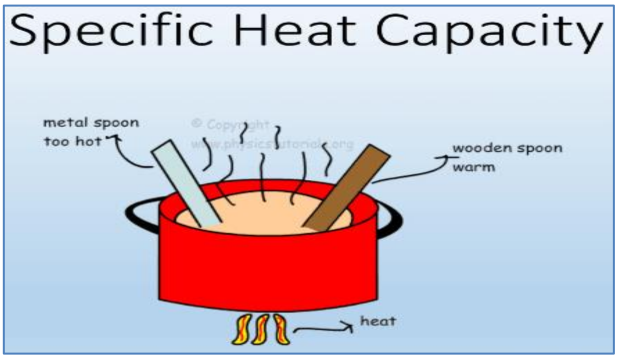
Temperature and its measurement

- Temperature is a property of mater it is the measure of the intensity of heat or heat level and it has a relative value.
- Measured by a **thermometer**.



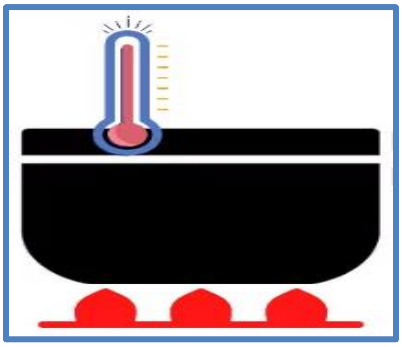
Specific heat

- The heat required by a unit mass of substance to rise in temperature one degree.
- called heat capacity of substance.



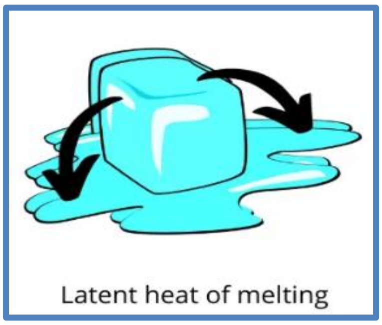
Sensible heat (Qs)

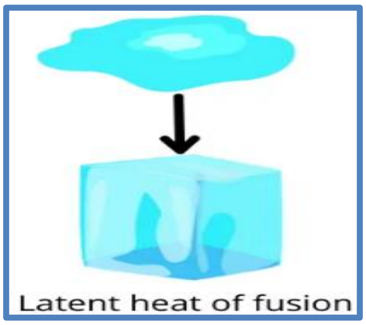
- Quantity of heat added or removed from substance, which caused change in temperature of substance.



Latent heat (QL)

- Quantity of heat added or removed from substances which caused change in phase of substance.





Properties of liquid and vapor

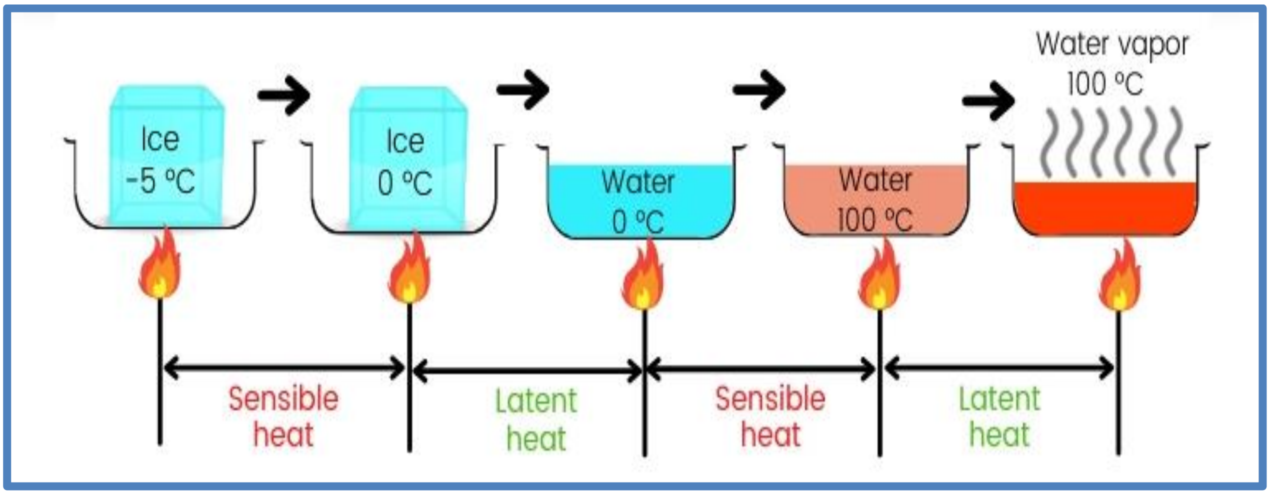
Unsaturation liquid: liquid at temperature less than the saturation temperature

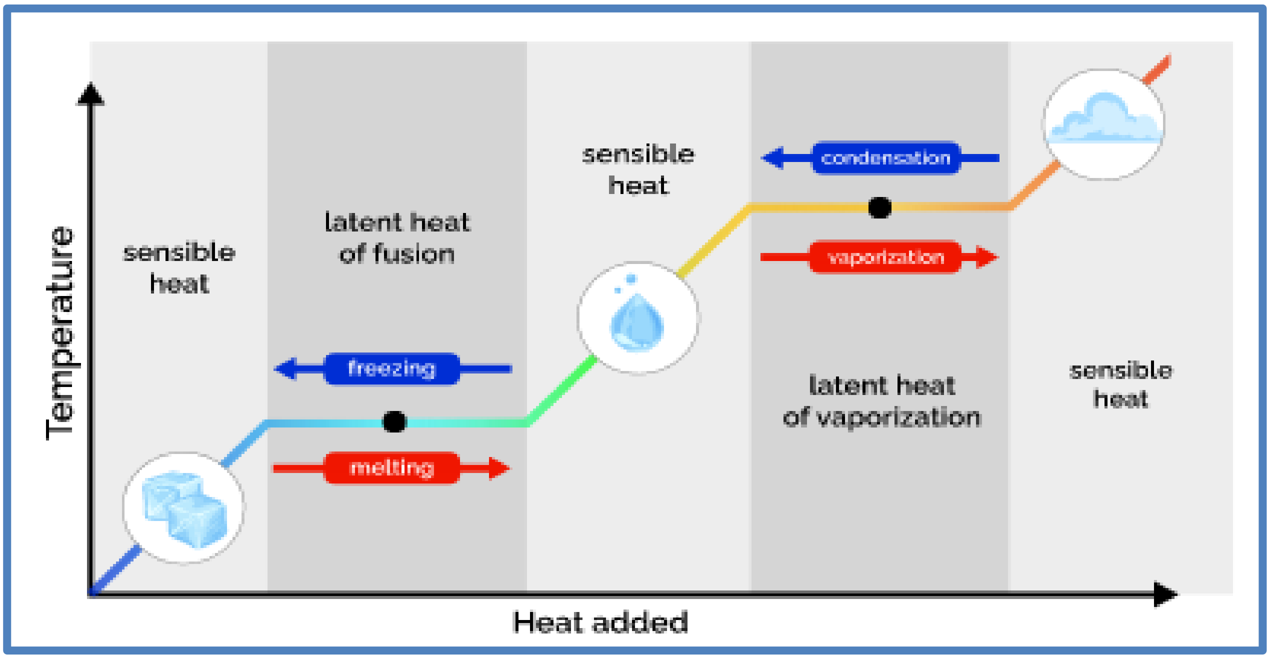
Saturation liquid: liquid at temperature existing saturation temperature and pressure.

Wet-unsaturation vapor: saturation vapor containing liquid droplets in suspension.

Dry-saturation vapor: vapor at saturation temperature corresponding to the existing pressure and without any liquid phase.

Super heat vapor: Vapor at temperature great than the saturation temperature.





Methods of Refrigeration

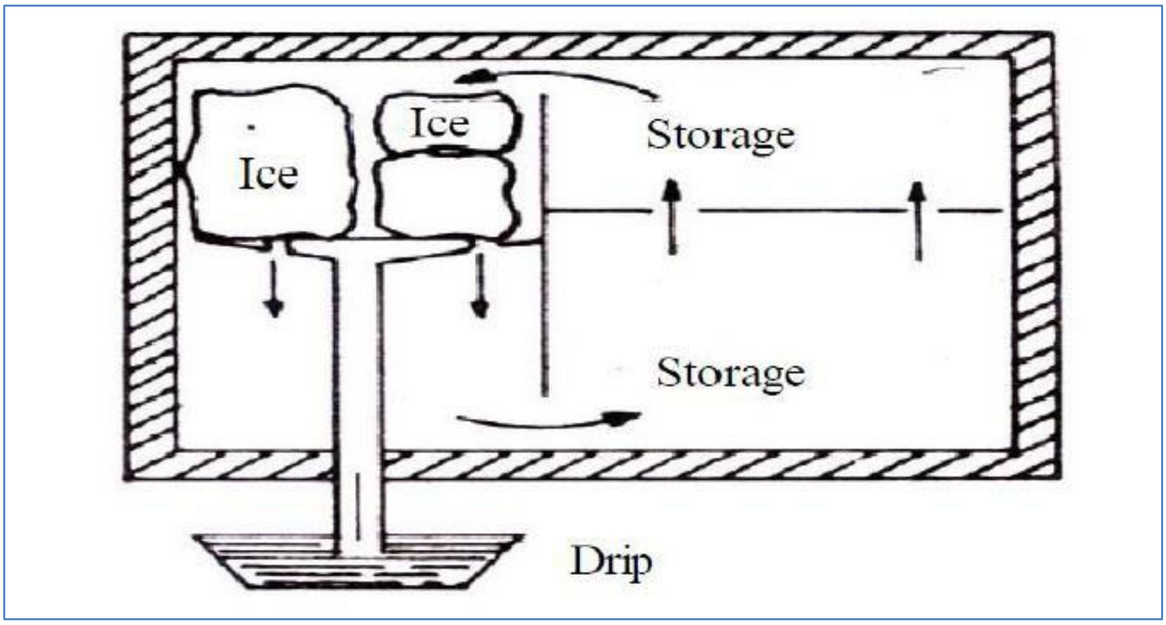
- **Ice refrigeration**
- **vapor compression refrigeration**
- **expansion air cooling**
- **steam – jet refrigeration**
- **Absorption refrigeration**
- **vortex tube refrigeration**
- **Thermo-electrical refrigeration**

Ice refrigeration

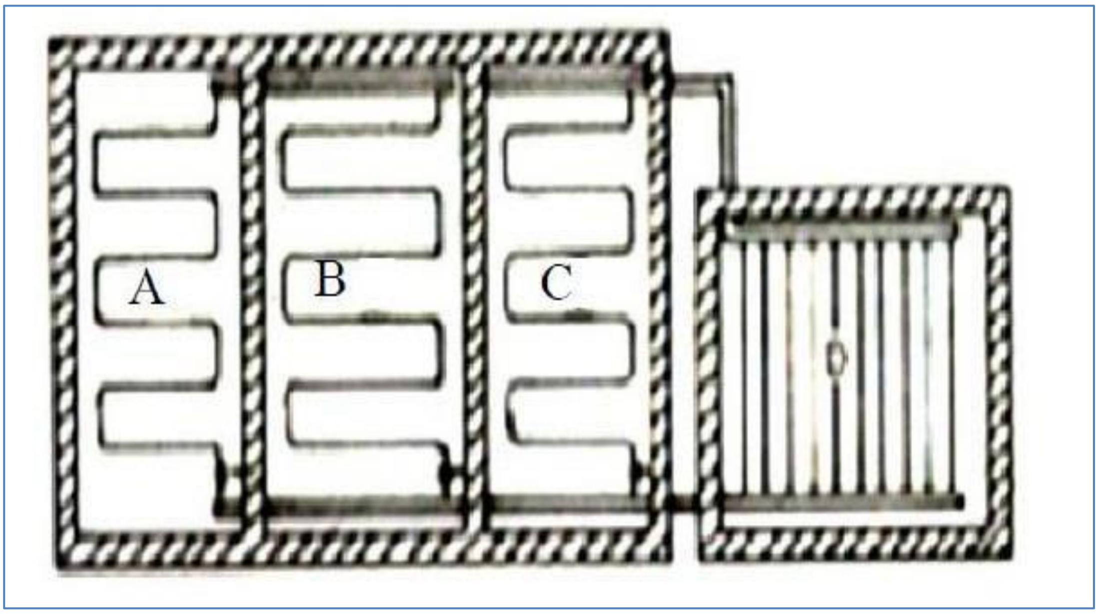
Consist of an insulated cabinet equipped with a tray or tank at the top, for holding blocks of ice pieces. Shelves for food are located below the ice compartment.

Ice method divided into two ways:

1-Direct method 2-indirect method

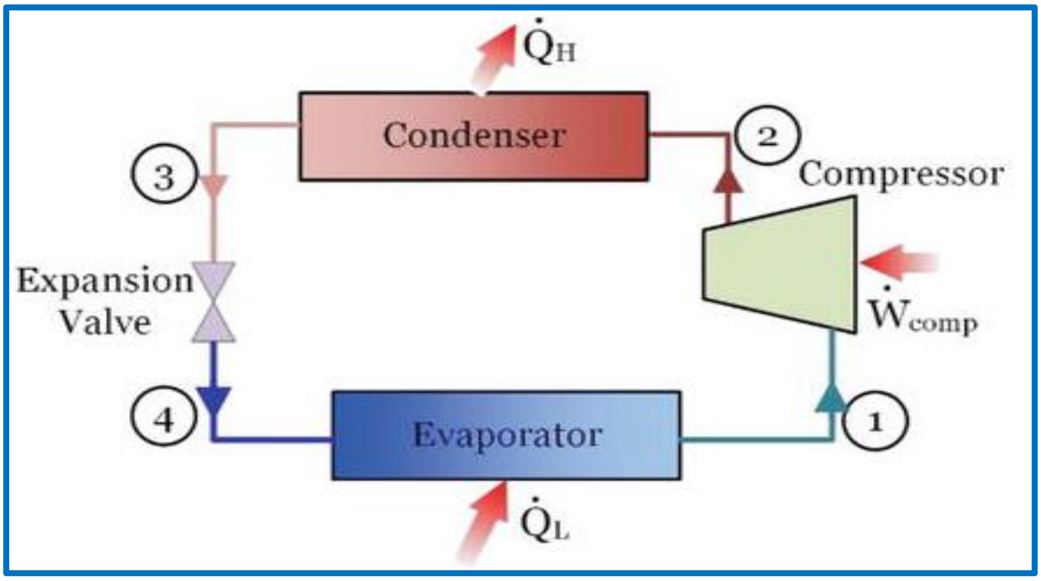


Direct method of ice Refrigeration



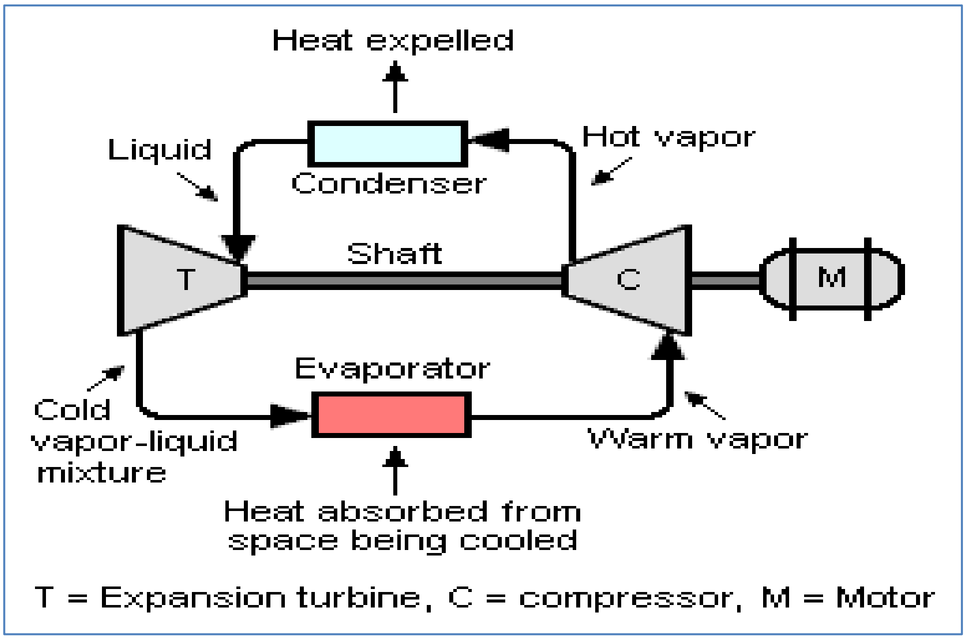
Indirect method of ice Refrigeration

Vapor compression refrigeration



Vapor compression refrigeration system

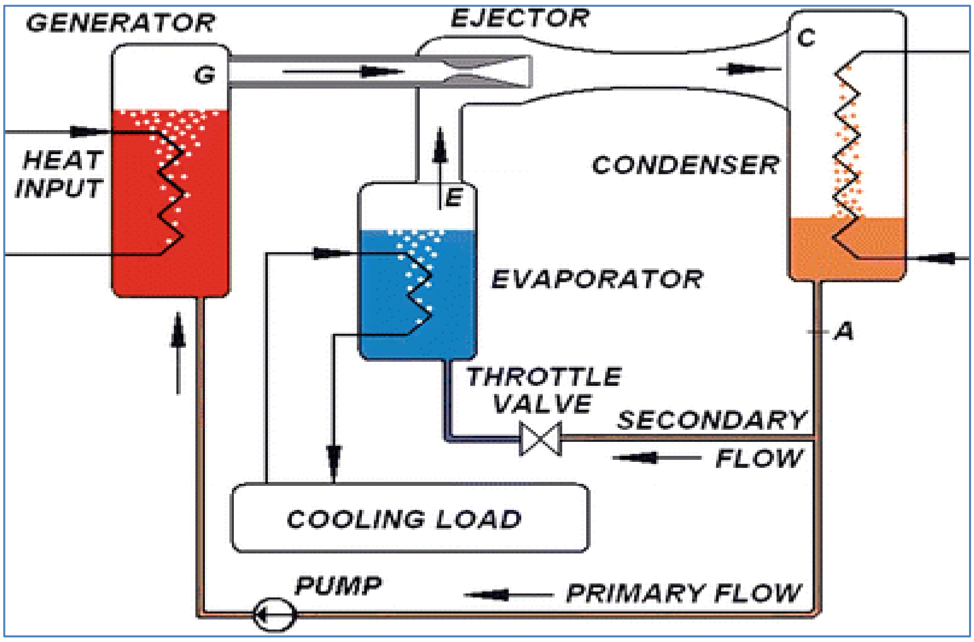
Expansion air-cooling



Expansion air cooling system

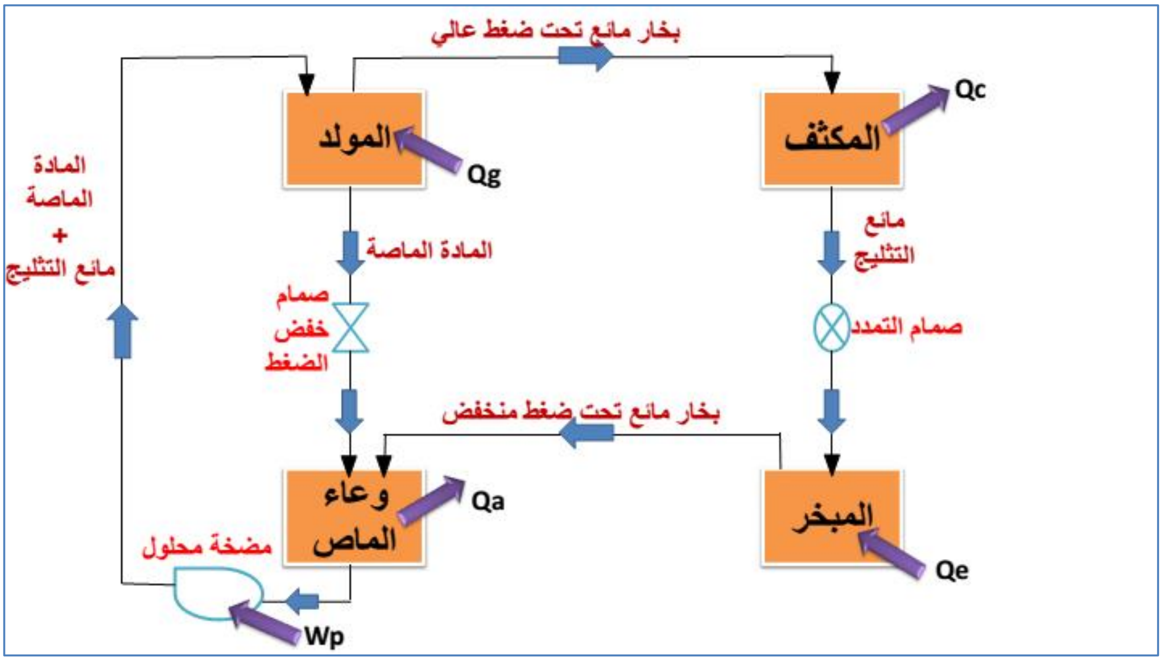
Steam – jet refrigeration

- The principle of steam jet refrigeration is that the boiling point of water can be reduced by reducing the pressure



Steam -jet refrigeration system

Absorption refrigeration

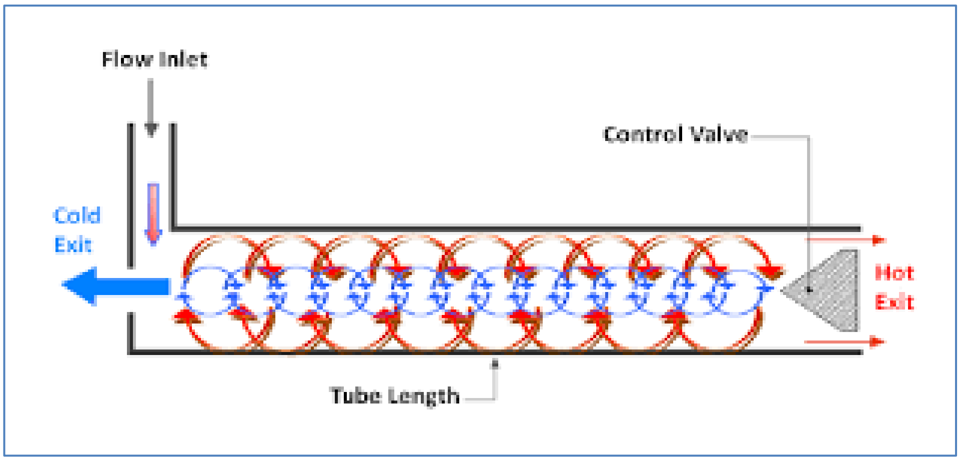


Basic Absorption refrigeration unit

Vortex tube refrigeration

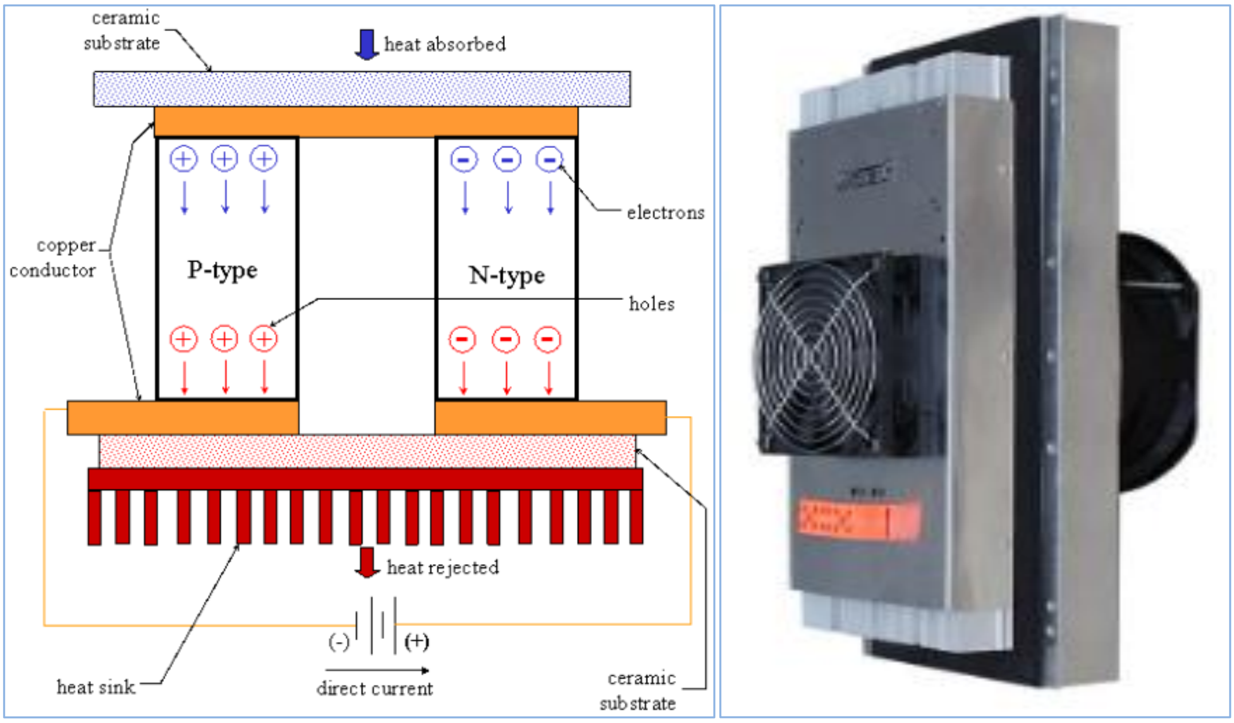
A mechanical device separates compressed gases into cold gas and hot gas without any moving parts.

نظرا لكفائتها المنخفضة فعادة يتم استخدمها في الصناعات التي تنتج هواء مضغوط فيتم ادخالها في خط الإنتاج للاستفاده منه.



Vortex tube refrigeration system

Thermo-electrical refrigeration



Thermo-electrical refrigeration

Refrigeration

Basic concepts of refrigerating principles

- There are three main items in materials: **Solids, Liquids** and **Gasses**. All these items affected by pressure change or temperature change and by it the energy can transfer.
- **Solid:** incompressible.
- **Liquid:** relatively incompressible.
- **Gas:** compressible.

The compassion of Air

Dry air is a mixture of five main compounds gases to gather with traces of a number of other gases.

It is reasonable to consider all these one homogeneous substances but ideal separately with the water vapour present because the latter is condensable associated dry gases are not.

The General Gas Low:-

$$PV = m.R.T$$

Where:-

P= the pressure of the gas in (Pa)
V= the volume of the gas in (m^3)
M= the mass of the gas in (Kg)
R = a constant of the proportionality
T = the absolute temperature of the gas in (°K).

Dalton's law of partial pressure

1-The Pressure exerted by each gas in a mixture of gases is in depending of the pressure of the other gases.

2-The total pressure exerted by a mixture of gas equals the sum of the partial pressure.

V		V		V
Dry-Air Only	+	Water vapour Only	=	Dry Air + Water vapour Only
a		b		c

a

T= 20 °c
Ma= 1 Kg
Ms= 0 kg
Pa= 1 bar
Ps = 0

b

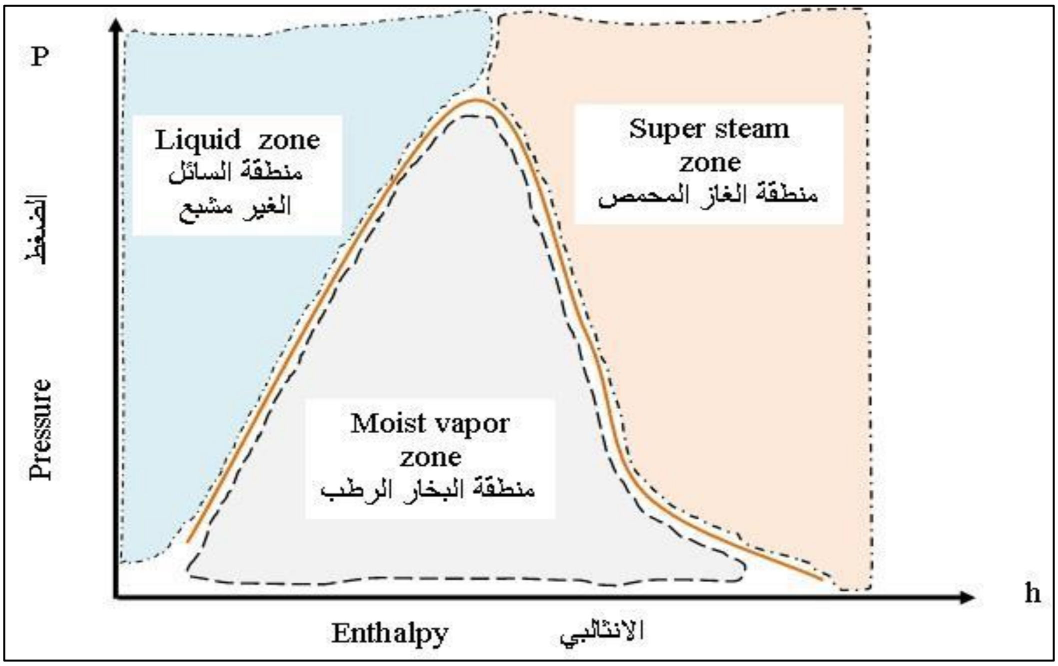
T= 20 °c
Ma= 0 Kg
Ms= 0.0073 kg
Pa= 0 bar
Ps = 0.01325 bar

c

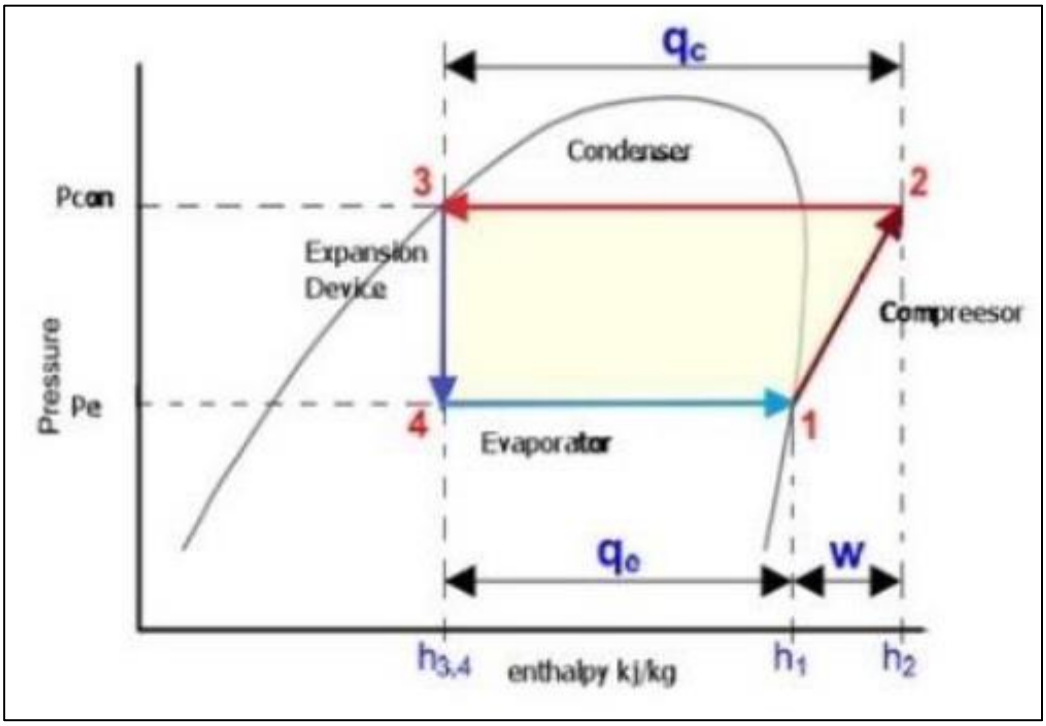
T = 20 °c
Ma = 1 Kg
Ms = 0.0073 kg
MT= Ma+Ms
MT= 1+ 0.0073
MT= 1.0073 Kg
Pa= 1 bar
Ps = 0.01325 bar
PT = Pa +Ps
= 1+0.01325
= 1.01325 bar

(P-H) Daigram

The figure below show the phase change for substance with pressure change and enthalpy



Boiling and Pressure



-This chart applied on refrigerants (وسائط التبريد), this chart are commonly used for analyzing vapor comparison refrigeration cycle (VCRC).

P-h chart are divided into three zones:

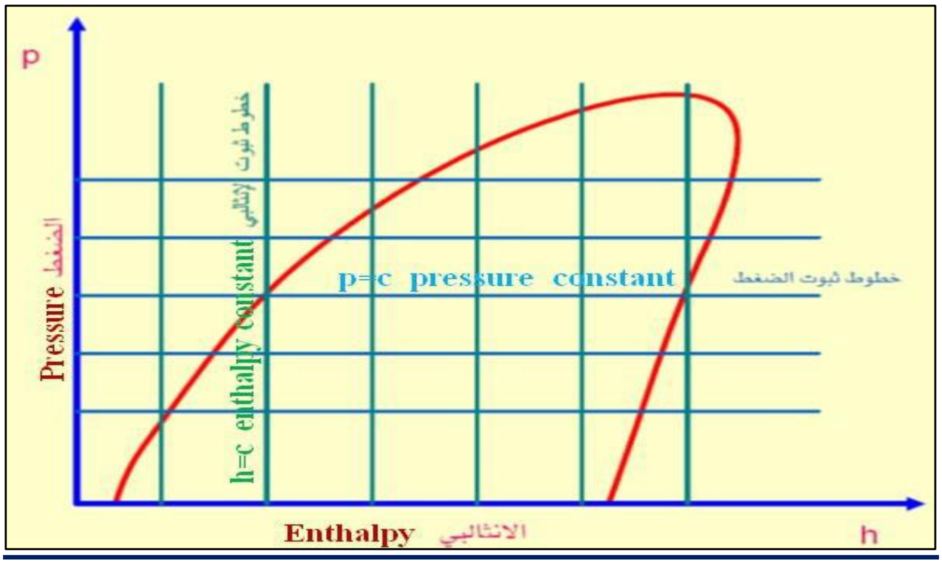
- Unsaturated liquid or sub cooling liquid السائل الغير مشبع أو منطقة التبريد الدوني
- Super heated steam منطقة البخار المحمص
- Intermediate zone or moist vapor zone منطقة البخار الرطب او منطقة الخليط (بخار+سائل)

P-h chart has six constant lines properties:

1- Pressure constant line (p=c), its units is bar

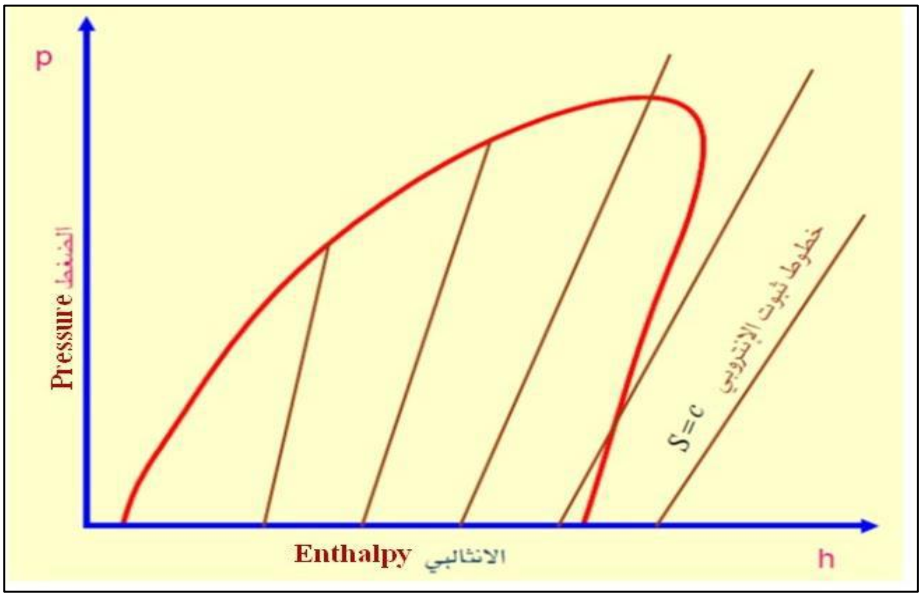
2- Enthalpy constant line (h=c) , its units is kJ/kg

Showed in figure below



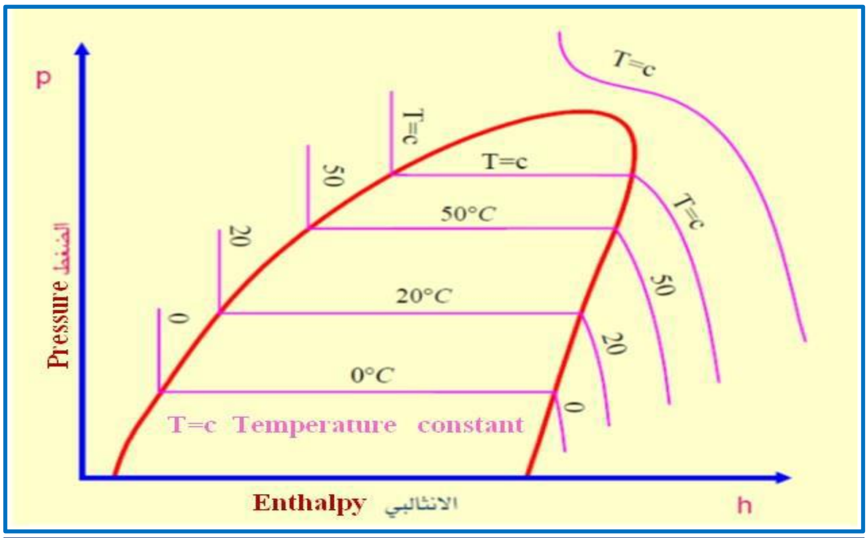
Pressure and enthalpy constant lines

3- Entropy constant lines (s = c), its unit is kJ/kg as shown in figure below:



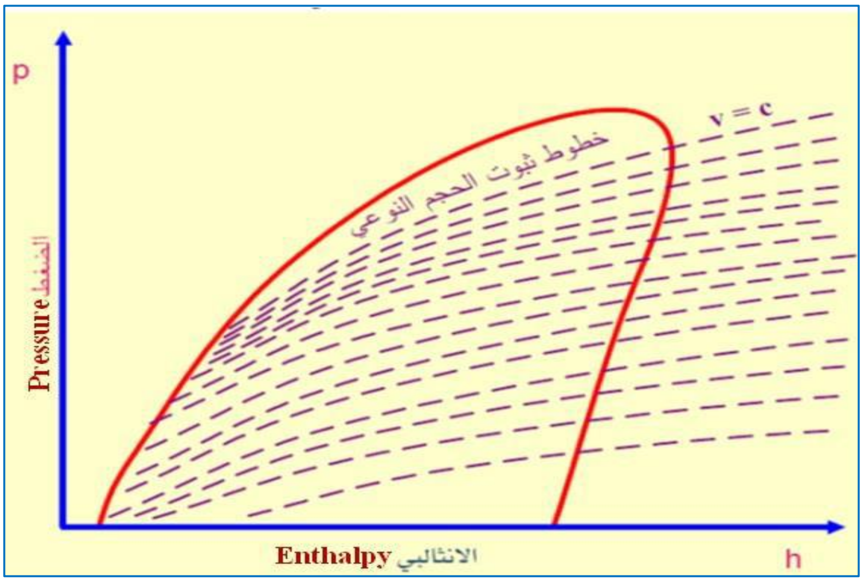
Entropy constant lines

4- Temperature constant lines (T=c), its unit is (°C) as shown in figure below:



Temperature constant lines

5- Constant specific volume lines (V =C), its units is m^3/kg as shown in figure below:



Specific volume constant lines

6- Dryness friction lines (X=c), it has no units and can determined by:-

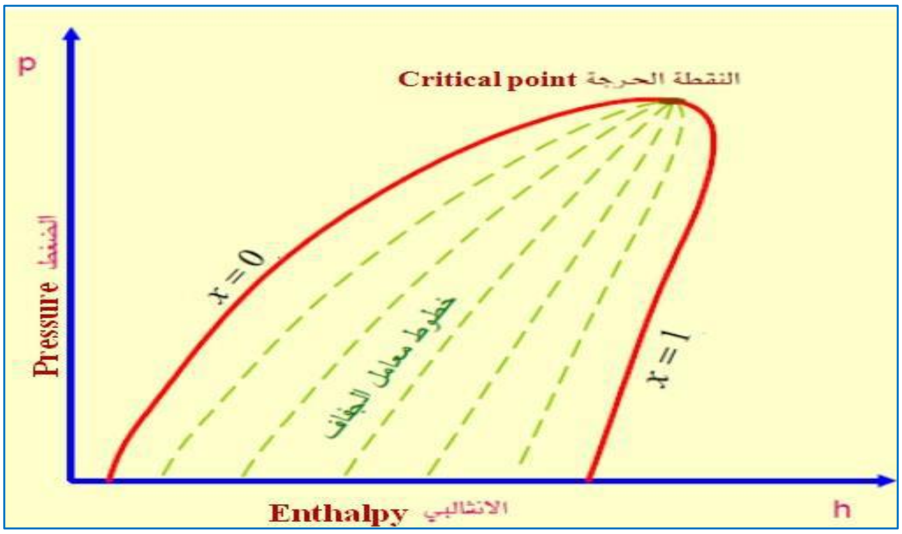
$X = m_{gas}/m_{total}$ and $Y = m_{liquid}/m_{total}$ *Note that* $\mathbf{X+Y=1}$

Where:-

$$m_{total} = m_{liquid} + m_{gas}$$

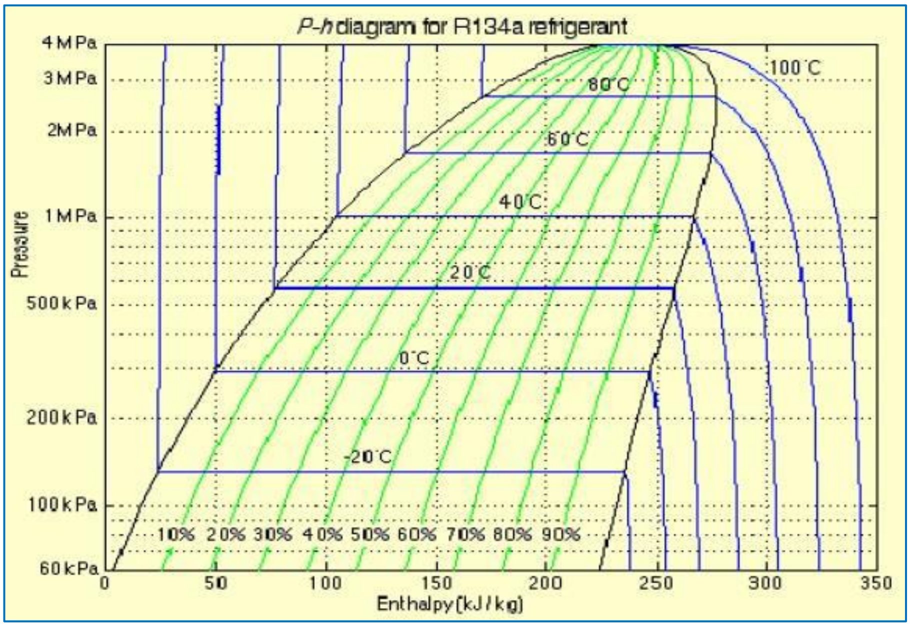
- m_{gas}: mass of gas in the moist vapor
- m_{liquid}: mass of liquid in the moist vapor
- mtotal : total mass of the moist vapor

Dryness friction lines shown in figure below:



Dryness friction constant lines

-Thus the final form of the pH diagram for one of the refrigerant (R134a):



P-h diagram for R134a refrigerant

Vapor compression refrigeration

The Vapor Compression Refrigeration Cycle (VCRc):

The cycle has four main components: evaporator, compressor, condenser, and expansion (or throttle) valve, It is the most widely used refrigeration cycle. In a simple vapor-compression refrigeration cycle, the refrigerant enters the compressor as a saturated vapor and is cooled to the saturated liquid in the condenser. It is then throttled to the evaporator pressure and vaporizes as it absorbs heat from the refrigerated space.

Cycle Processes:

1) The saturated vapor refrigerant (low pressure and temperature) enters the compressor at state(1) where it is compressed isentropicaly (S_1=S_2) to (high P&T) super heated vapor state(2).

2) Cools down the refrigerant and condenses it at the condenser (heat rejection at high pressure) to state(3) high P&T saturated liquid refrigerant, (p=c).

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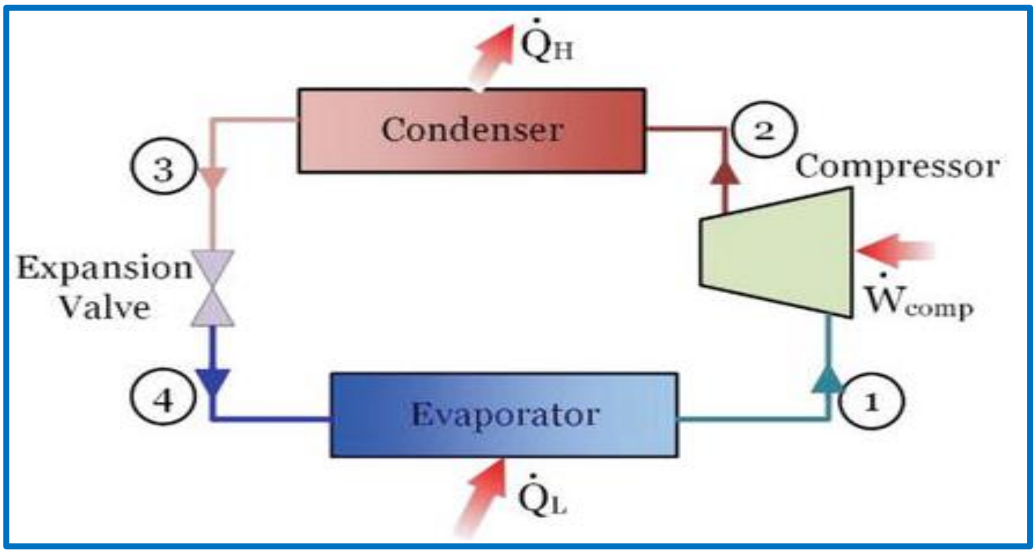
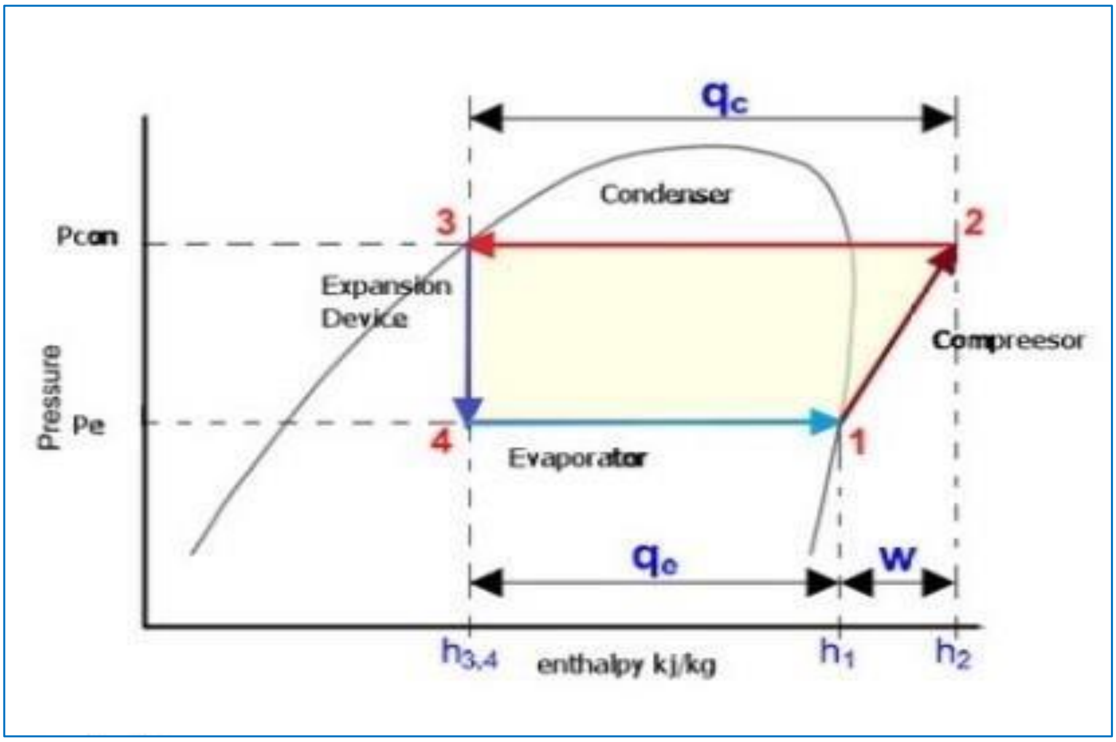
3) Saturated liquid refrigerant expands at the expansion device to low P&T to state (4) wet vapor at constant enthalpy(h_3=h_4).

4) Liquid refrigerant evaporated in the evaporator due to the heat extracted from refrigerated space(Latent heat of evaporation) where it converted to low P&T vapor at constant pressure(p_4=p_1), state(1), as shown in the fig. below:





Cycle analysis :-

1) Compressor power $\dot{W} = \dot{m}_r(h_2 - h_1)$ (kw)

2) Heating capacity or total heat rejected at condenser:

$Q_{rej} = \dot{m}_r(h_2 - h_3)$ (kw)

3) Expansion at expansion valve : $h_3 = h_4$

4) Cooling capacity or Refrigeration capacity at evaporator:

$$Q_e = \dot{m}_r (h_1 - h_4) \quad \text{(kw)}$$

5) Coefficient of performance:

a) Refrigerator: $COP_R = \frac{Refrigeration\ effect}{Work\ done}$, $COP_R = \frac{(h_1 - h_4)}{(h_2 - h_1)}$

or: $COP_R = \frac{Refrigeration\ capacity\ (Q_e)}{\text{Compressor power}\ (\dot{W})}$, $COP_R = \frac{\dot{m}_r (h_1 - h_4)}{\dot{m}_r (h_2 - h_1)}$

Refrigeration effect: Amount of cooling produced by the cycle or amount of heat removed from the space by 1 kg of the refrigerant (Kj/Kg).

b) Heat pump : $COP_{HP} = \frac{Heating\ effect}{Work\ done}$, $COP_{HP} = \frac{(h_2 - h_3)}{(h_2 - h_1)}$

or: $COP_{HP} = \frac{Heating\ Capacity(Q_{rej})}{\text{Compressor power}\ (\dot{W})}$, $COP_{HP} = \frac{\dot{m}_r (h_2 - h_3)}{\dot{m}_r (h_2 - h_1)}$

Heating effect: Amount of heat added to the space by 1 kg of the refrigerant (or heat rejected from the refrigerant at the condenser Kj/Kg)

Where : $\dot{m}_r$: Mass flow rate of refrigerant (kg/s)

h : Specific enthalpy kj/kg

Calculations per **unit mass (per 1 kg of refrigerant):**

1) Work done required for the compressor: w= ($h_2 - h_1$) kj/kg

2) Heating effect or heat rejected at condenser: q_{rej} = ($h_2 - h_3$) kj/kg

3) Refrigeration effect : q_e = ($h_1 - h_4$) kj/kg

Refrigeration systems are rated with a **SEER** number or **Seasonal Adjusted Energy Efficiency Ratio**. The SEER is defined as the Btu/hr of heat transferred per Watt of work energy input. The Btu is the British Thermal Unit and is equivalent to 778 ft-lbf of work (1 W = 3.4122 Btu/hr).

Or : **EER** = Tons x 12 / (total kW input)

Ton of Refrigeration (TR):

It is the rate of cooling produced by the fusion of one American ton of ice at 0^o through a period of 24 hours. (1 ton (USA) = 2000 Ib = 907.2 kg)

Latent heat of ice fusion = 334.9 kj/kg

$$1\ TR = \frac{907.2\ kg\ x\ 334.9 kj/kg}{24hr\ x\ 3600sec/hr} = 3.516\ kj/s\ (\text{ or } = 3.516\ kw)$$

Also 1TR = 211 kj/min

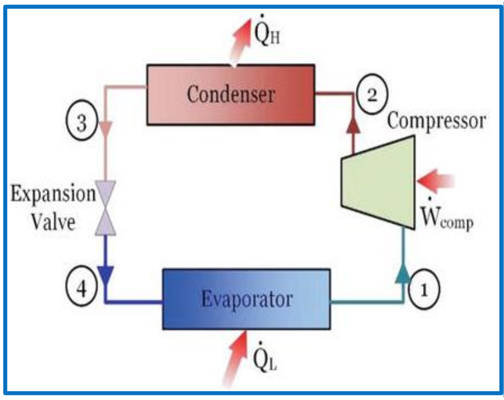
In British units : 1TR = 12000 Btu/hr =200 Btu/min

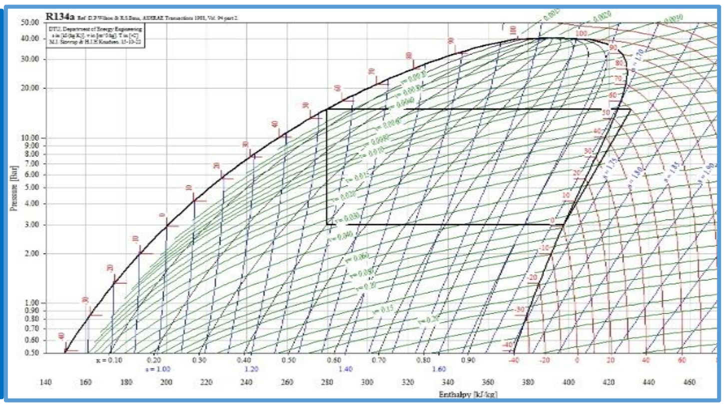
EX1// A compressive refrigeration unit operating with R-134a refrigerant has a condensing pressure (15 bar), while the evaporation pressure is (3) bar. If you know that the refrigerant enters the compressor in a state of saturated vapor, find:

1 -Drawing a cycle on a (p-h) diagram
2- The Refrigeration effect
3-The compressor work
4-The heat reject in the condenser
5 -Coefficient of Performance C.O.P
6- Dryness fraction (X)
7 -Fluid Temperature entering the compressor
8- Fluid temperature when leaving the condenser

Soll//

1 -Drawing a cycle on a (p-h) diagram





h1= 398 kj|kg , h2=431 kj|kg , h3=h4=280 kj|kg

2-Qe =h1-h4

Qe= 398-280= 118 kj|kg

3- Wc=h2-h1

Wc = 431-398= 33 kj|kg

4- Qc= h2-h3

Qc = 431-280= 151 kj|kg

5- C.O.P= Qe/Wc

C.O.P = (h1-h4)/(h2-h1)

118/33= 3.57

6-X4= 0.4

7-T1=0.6 °C

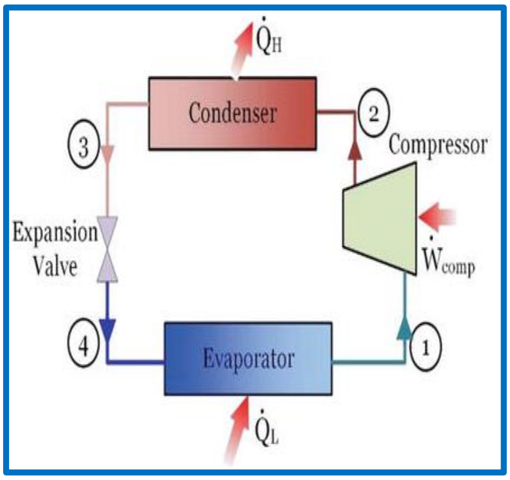
8-T3=55 °C

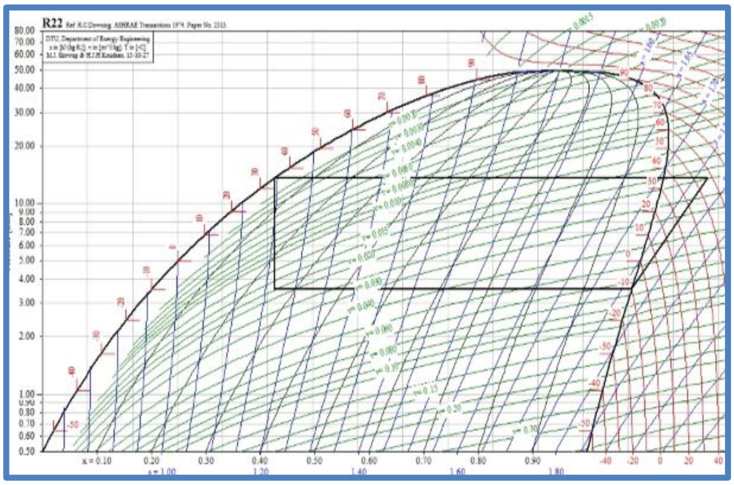
EX2// Theoretical vapor compression cycle give (45kw) of refrigeration, using refrigerant R-22 at a condensation temperature (35°C) and an evaporation temperature (-10°C), Calculate:

1-Draw cycle on a (P-h) diagram
2- Refrigeration quantity in units Kj|kg
3-Mass flowrate of refrigerant
4- Compressor work in KW
5- Heat in the condenser in KW
6- Dryness fraction
7-C.O.P
8- Volumetric Flow Rate
9-Fluid temperature entering the comp.
10-Fluid temperature leaving the condenser

sol//

1-Draw cycle on a (P-h) diagram





- **h1=401 kj|kg** - **h2=435 kj|kg** - **h3=h4=243 kj|kg**
- **Qe=45 kw**

2-Qe= h1-h4 → **401-243=158 kj|kg**

3-Qe=m (h1-h4) → **m=Qe|h1-h4)** → **m=158|45=0.284 kg\s**

4- Wc =m (h2-h1) → **0.284(435-401) =9.6 kw**

5- Qc =m (h2-h3) → **0.284(435-243) =54.5 kw**

6-X4=0.27

7-C.O.P= Qe|wc → **C.O.P = 45|9.6 =4.6**

8-ϑ=0.065 m|kg → **V=m x ϑ** → **0.284 x 0.065=0.0184 m|s**

9-T1= -10°C

10-T3= 35°C