Refrigeration & Air Conditioning Course

Chapter 1

Refrigeration and Refrigeration methods

Refrigeration:

The process of cooling of bodies or fluids to temperatures lower than surroundings at a particular time and place.

All practical refrigeration processes involve reducing the temperature of a system from its initial value to the required temperature that is lower than the surroundings, and then maintaining the system at the required low temperature.

Due to the reason that once the temperature of a system is reduced, a potential for heat transfer is created between the system and surroundings, and in the absence of a "perfect insulation" heat transfer from the surroundings to the system takes place resulting in increase in system temperature which needs to be extracted continuously.

Thus in practice refrigeration systems have to first reduce the system temperature and then extract heat from the system at such a rate that the temperature of the system remains low.

Refrigeration methods

1- Phase change processes

- Melting of water ice and

-Vapor compression system

2- Absorption system

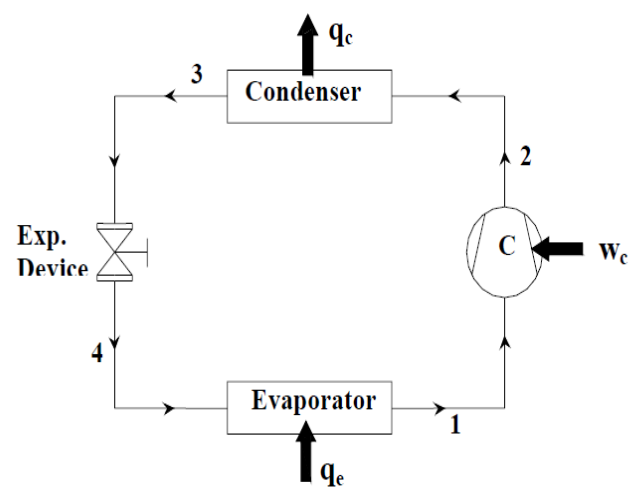
Phase change processes

Melting of water ice and dry ice CO2

When water ice melts it produces a refrigeration effect in the surroundings by absorbing heat. The amount of refrigeration produced and the temperature at which refrigeration is produced depends on the substance undergoing phase change. It is well-known that pure water ice at 1 atmospheric pressure melts at a temperature of about 0^0C and extracts about 335 kJ/kg of heat from the surroundings. At 1 atmospheric pressure, dry ice (solid carbon dioxide) undergoes sublimation at a temperature of -78.5^0C, yielding a refrigeration effect of 573 kJ/kg. Both water ice and dry ice are widely used to provide refrigeration in several applications.

- **Vapor compression system**

In these systems shown in Figure 1.1, the working fluid (refrigerant) provides refrigeration effect to collect the heat from cold space and its state is changed from liquid to vapor in the evaporator. The vapor is then compressed to elevate its temperature above the surrounding. The compressed gas rejects heat and the phase can be changed to liquid. The condensated liquid is throttled where its pressure is dropped and consequently its temperature decreases to absorbs again.



3. Absorption system

Vapor Absorption Refrigeration Systems belong to the class of vapor cycles similar to vapor compression refrigeration systems. In vapor compression refrigeration systems requires work to operate the system. The required input to absorption systems is in the form of

heat. Hence these systems are also called as heat operated or thermal energy driven systems.

Application of refrigeration

1. Storage of food above or below the freezing
2. Transportation of food above or below the Industrial air conditioning
3. Comfort air conditioning
4. Ice making
5. Chemical and related industries
6. Manufacturing and treatment of metals
7. Medical and surgical aids
8. Heat pump

Chapter 2

Vapor Compression Refrigeration cycles

Simple Vapor Compression Refrigeration System (SVCRS)

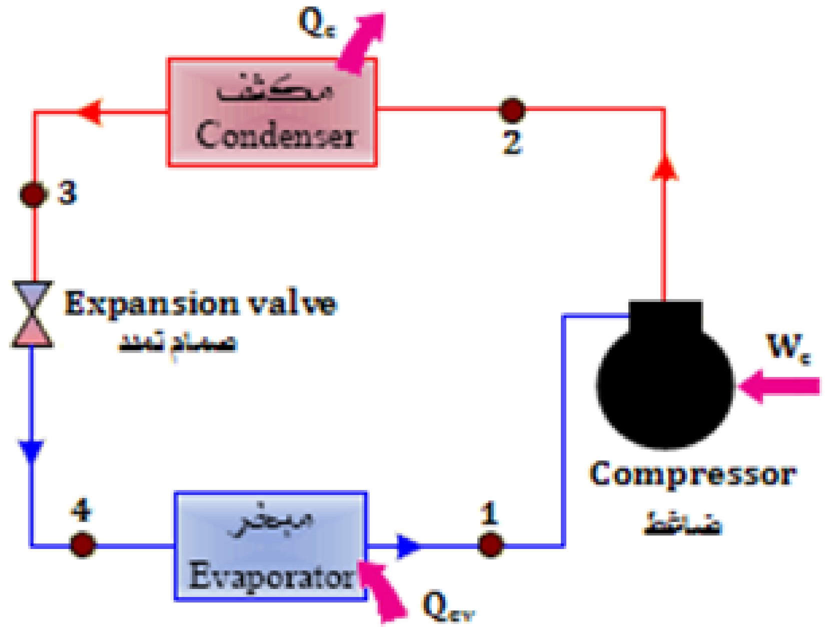
the simple vapor compression refrigeration system consists of the main following equipments:

i) Compressor

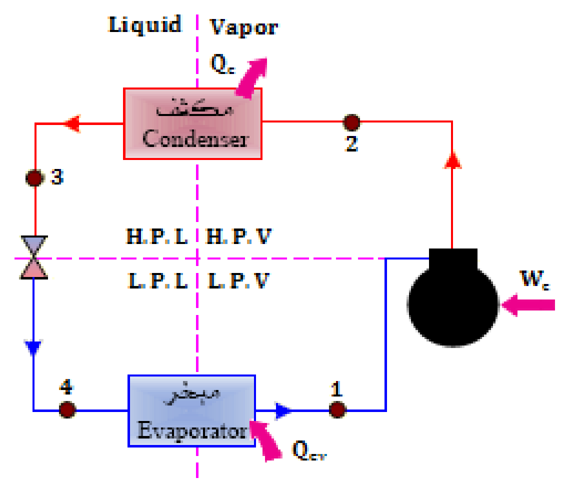
ii) Condenser

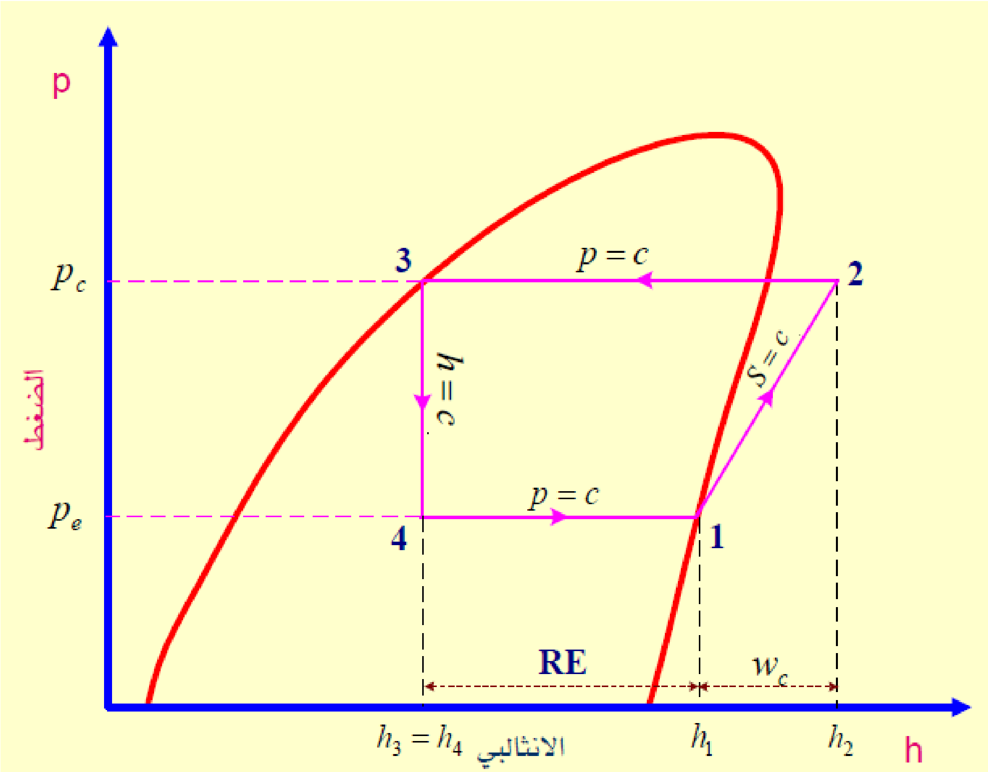
iii) Expansion valve

iv) Evaporator.

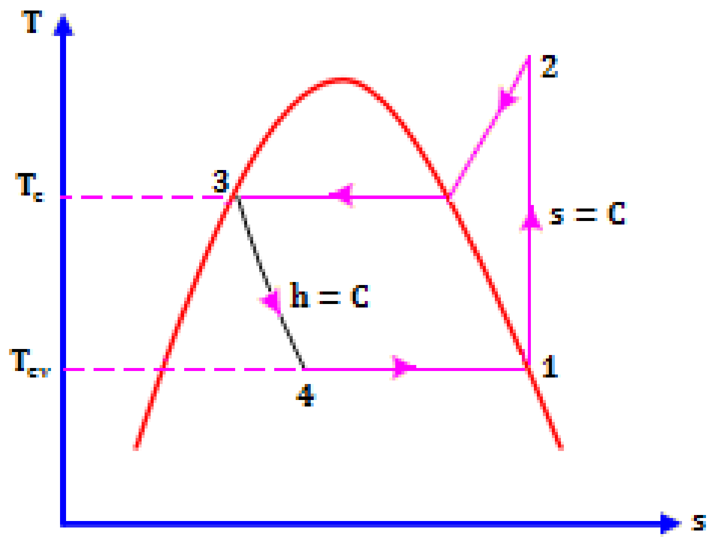


The schematic diagram of the arrangement is as shown in Figure 2.2. The low temperature, low pressure vapor at state (1) is compressed by a compressor to high temperature and pressure vapor at state (2). This superheated vapor losses its heat and condensed into high pressure liquid at state (3) in the condenser and then passes through the expansion valve. Here, the refrigerant is throttled down to a low pressure mixture (4) at low temperature and passed on to an evaporator, where it can absorb heat from the surroundings (cold space). The refrigerant vaporizes into low pressure vapor at state 1.





p
p_c
p_e
الضغط
3
2
$p = c$
$h = c$
$S = c$
4
1
RE
w_c
$h_3 = h_4$
الانثالبي
h_1
h_2
h



T
2
3
T_c
s = C
h = C
1
4
s

a) Isentropic compression : During the isentropic compression process , the work($\dot{W}_c$) is supplied to the system from the surroundings . There is no change in the entropy in this process .

$$\dot{W}_c = \dot{m}_{ref}(h_2 - h_1), \qquad s_1 = s_2$$

b) Heat Rejection: During this process the heat carried with the refrigerant is rejected (Q_{con}) to a hot medium and heat lost from the refrigerant leads to its condensation at constant pressure.

$$Q_{con} = \dot{m}_{ref}(h_2 - h_3) = Q_{ev} + \dot{W}_c$$

$$P_2 = P_3$$

c) There is no exchange of heat during throttling process through the expansion valve as this process occurs at constant enthalpy.

$$h_3 = h_4$$

d) Heat addition: During this process the absorbed heat (Q_{ev}) from a cold space and transferred to the refrigerant at constant pressure. During this process, an evaporation the refrigerant due to the absorbed heat.

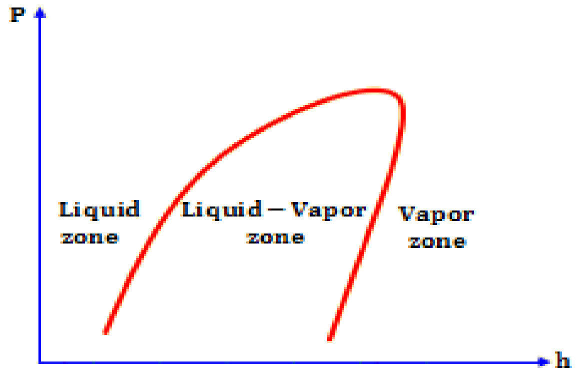
$$Q_{ev} = \dot{m}_{ref}(h_1 - h_4)$$

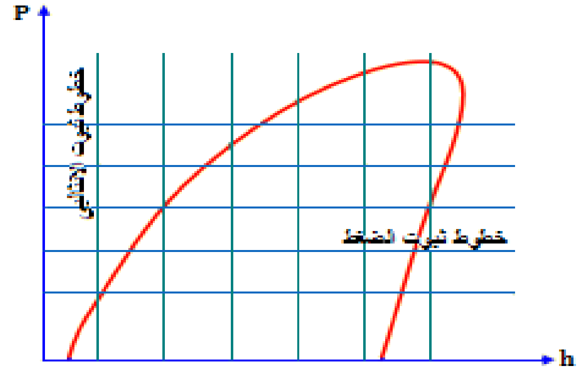
$$P_1 = P_4$$

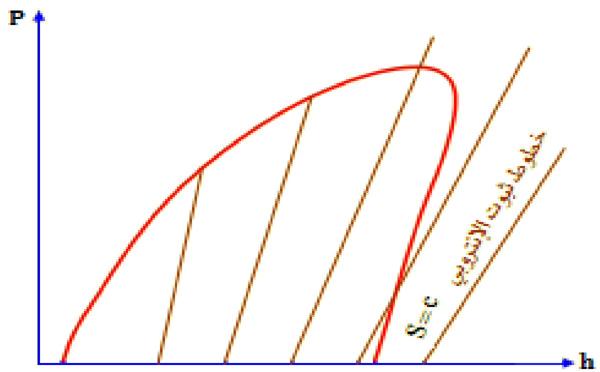
State of The Four Points in The Ideal Cycle

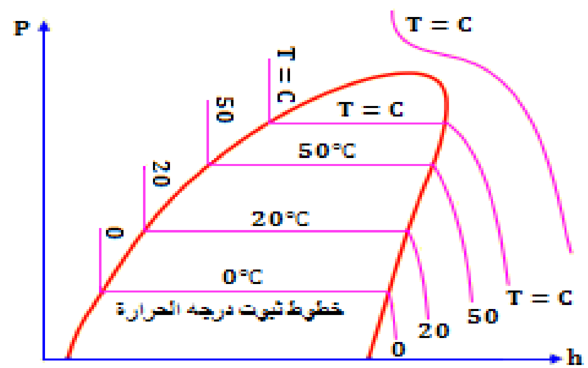
Point	X	Phase
1	1	Saturated vapor
2	–	Superheated vapor
3	0	Saturated liquid
4	$0 \le x \le 1$	Mixture of vapor and liquid

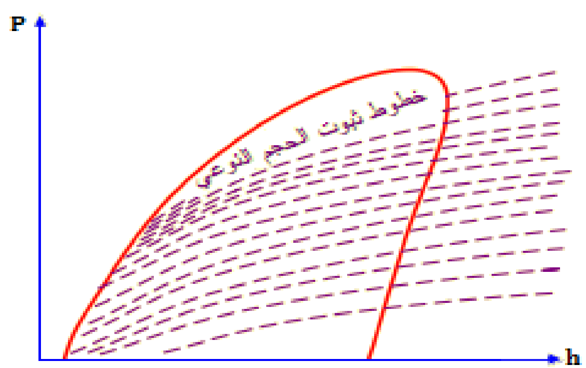
Where, h1, h2, h3, h4: the specific enthalpy at different points

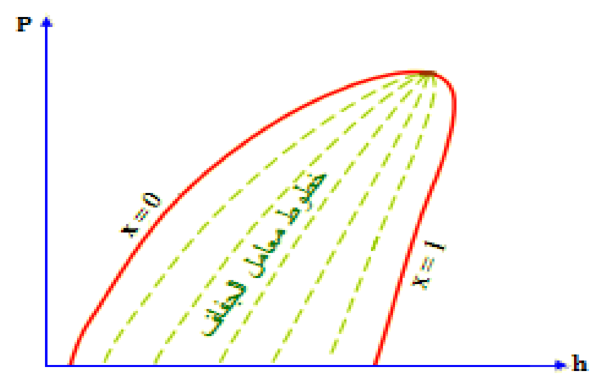

P
h
Liquid zone
Liquid – Vapor zone
Vapor zone


P
h
خطوط ثبوت الإنثالبي
خطوط ثبوت الضغط


P
h
خطوط ثبوت الإنتروبي
S=c


P
h
T = C
T = C
T = C
T = C
50°C
20°C
0°C
50
20
0
خطوط ثبوت درجه الحرارة
0
20
50


P
h
خطوط ثبوت الحجم النوعي


P
h
x = 0
خطوط معامل الجفاف
x = 1

2.2.1 Performance Simple Vapor Compression Refrigeration cycle

- **Refrigeration effect (RE)**

The heat absorbed by 1 kg of the refrigerant until leaving the evaporator.

$$RE = h_1 - h_4 \qquad kJ/kg$$

- **Evaporator Load (Q_{ev})**

The rate of heat removed by the evaporator from the product or the cold space.

$$Q_{ev} = \dot{m}_{ref}(h_1 - h_4) \qquad \mathbf{kW}$$

- **Coefficient of performance**

The ratio between the Refrigeration effect and the compressor work.

$$COP_{vapor\ compreesion} = \frac{RE}{\dot{W}_c} = \frac{h_1 - h_4}{h_2 - h_1}$$

Volume flow rate

The volume flow rate is variable through the cycle. The volume flow rate at compressor inlet can be obtained from;

$$\dot{V}_{ref} = v_1 * \dot{m}_{ref} = \frac{\dot{m}_{ref}}{\rho_1}$$

The volume flow rate is variable through the cycle since the density changes from point to another

Example 2

A Freon-12 refrigerating system is operating with a condensing temperature 30°C and an evaporating temperature of −4°C. Determine (a) the refrigeration effect, (b) COP and

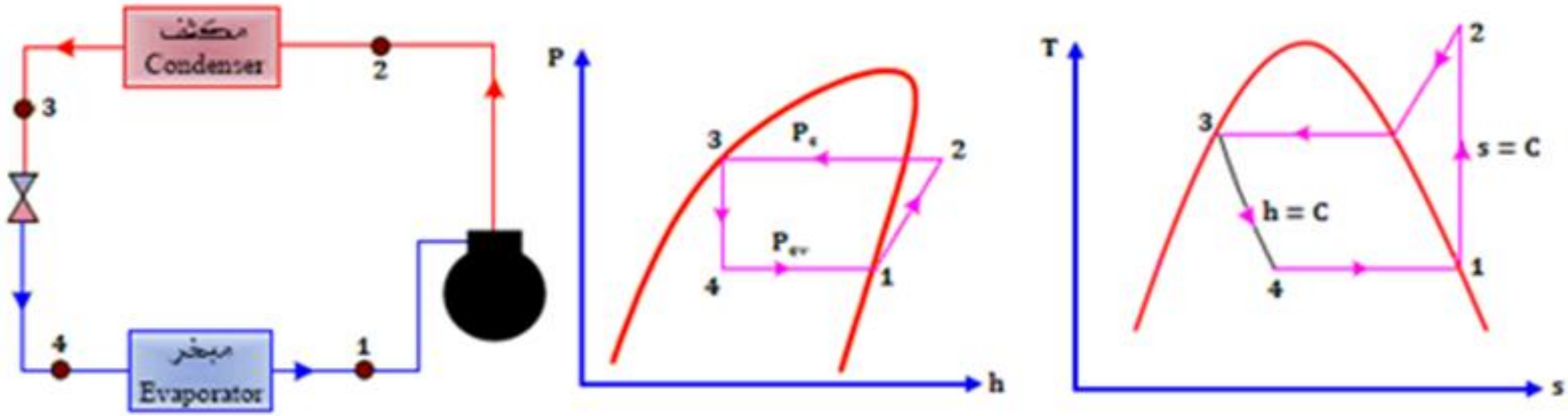
Solution

1. Given

(R – 12) $T_c = 30°C = 303$ K

$T_{ev} = -4°C = 269$ K

R.E =?? COP =??



From R – 12 (P – h) chart

at $T_{ev} = 269$ K	and	sat. vapor line	get	$h_1 \cong 568.5$ kJ/kg
at $T_c = 303$ K	and	sat. lines	get	P_c line
at P_c	and	$s_1 = s_2$	get	$h_2 \cong 586.5$ kJ/kg
at $T_c = 303$ K	and	sat. liquid line	get	$h_3 = h_4 \cong 446.5$ kJ/kg

R. E. $= q_{ev} = h_1 - h_4 = 568.5 - 446.5 \cong \boxed{122\ \text{kJ/kg}}$ $w_c = h_2 - h_1 = 586.5 - 568.5$

$\cong 18$ kJ/kg

$$COP_{ref} = \frac{q_{ev}}{w_c} = \frac{h_1 - h_4}{h_2 - h_1} \cong \boxed{6.78}$$

Effect of operating parameters on (S V CRS))

•Effect of Evaporator Pressure

Gives low temperatures

Decreasing the P_{ev}

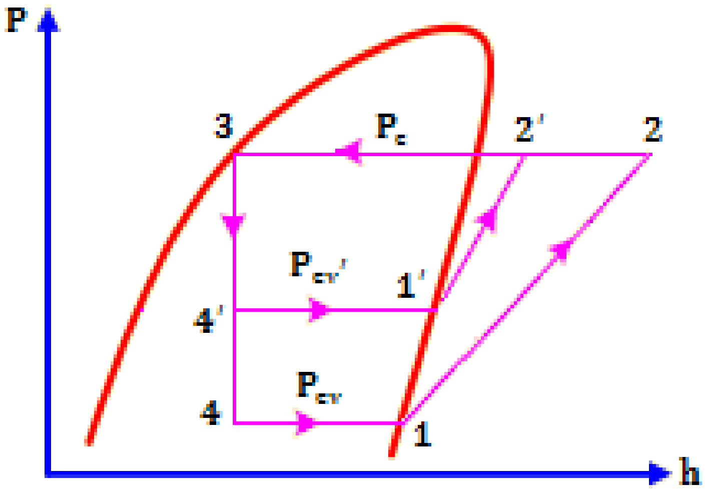
leads to

$(h_1 - h_4) > (h_{1'} - h_{4'})$

For compressor work;

$(h_2 - h_1) > (h_{2'} - h_{1'})$

$C.O.P > C.O.P'$



•Effect of Condenser Pressure

increasing the condenser pressure increases the compressor work   and decreases the refrigeration effect.

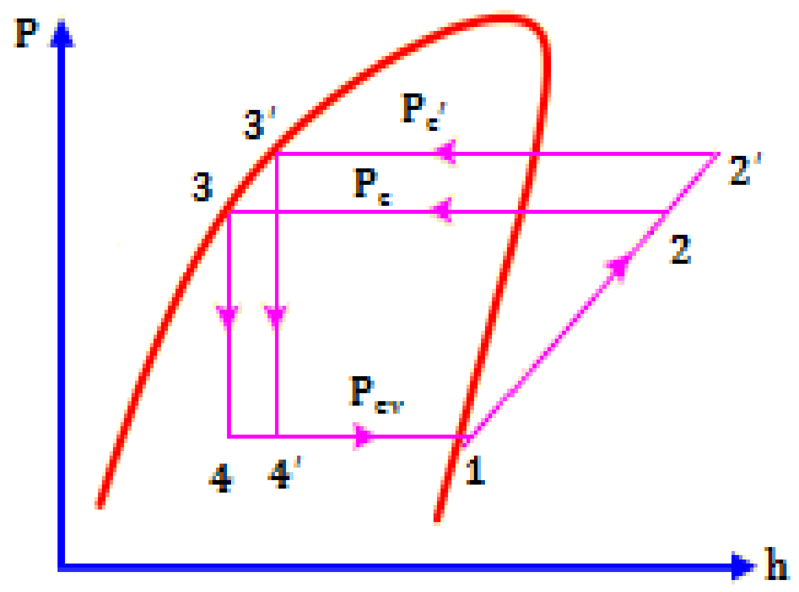
For Refrigeration effect;

$$(h_1 - h_{4'}) < (h_1 - h_4)$$

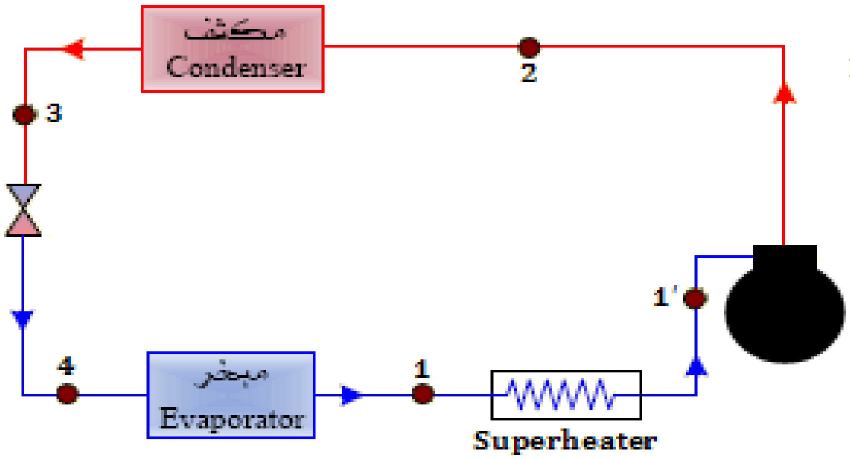
For compressor work;

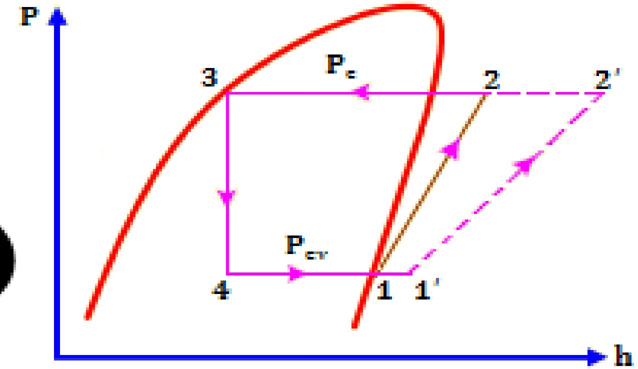
$$(h_{2'} - h_1) > (h_2 - h_1)$$

$$C.O.P' < C.O.P$$



•Effect of Suction Vapor Superheat Outside The Evaporator





For refrigeration effect

$(h_1 - h_4) = \ (h_1 - h_4)$

For Compressor work

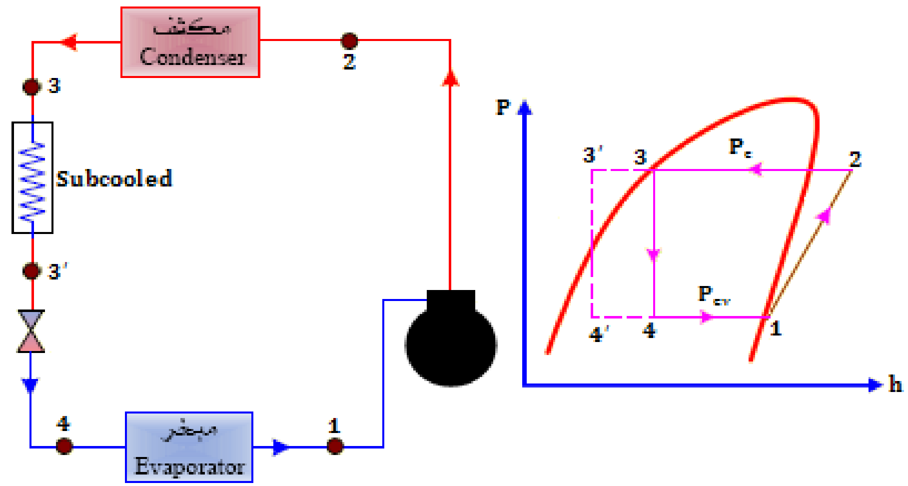
$(h_{2'} - h_{1'}) > (h_2 - h_1)$

The COP of the cycle including superheating ($1', 2', 3, 4$) is lower than that of the ideal vapor compression refrigeration cycle

$C.O.P' \ < C.O.P$

Superheat should be limited to avoid any harm to the compressor

•Effect of Sub-Cooling on the cycle



For refrigeration effect

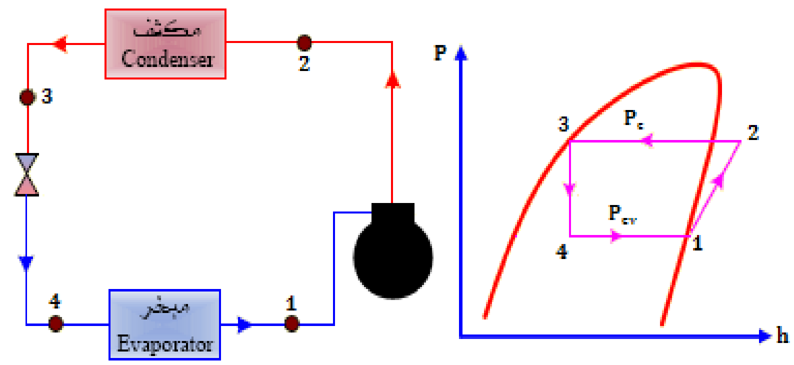
$(h_1 - h_{4'}) > (h_1 - h_{4'})$

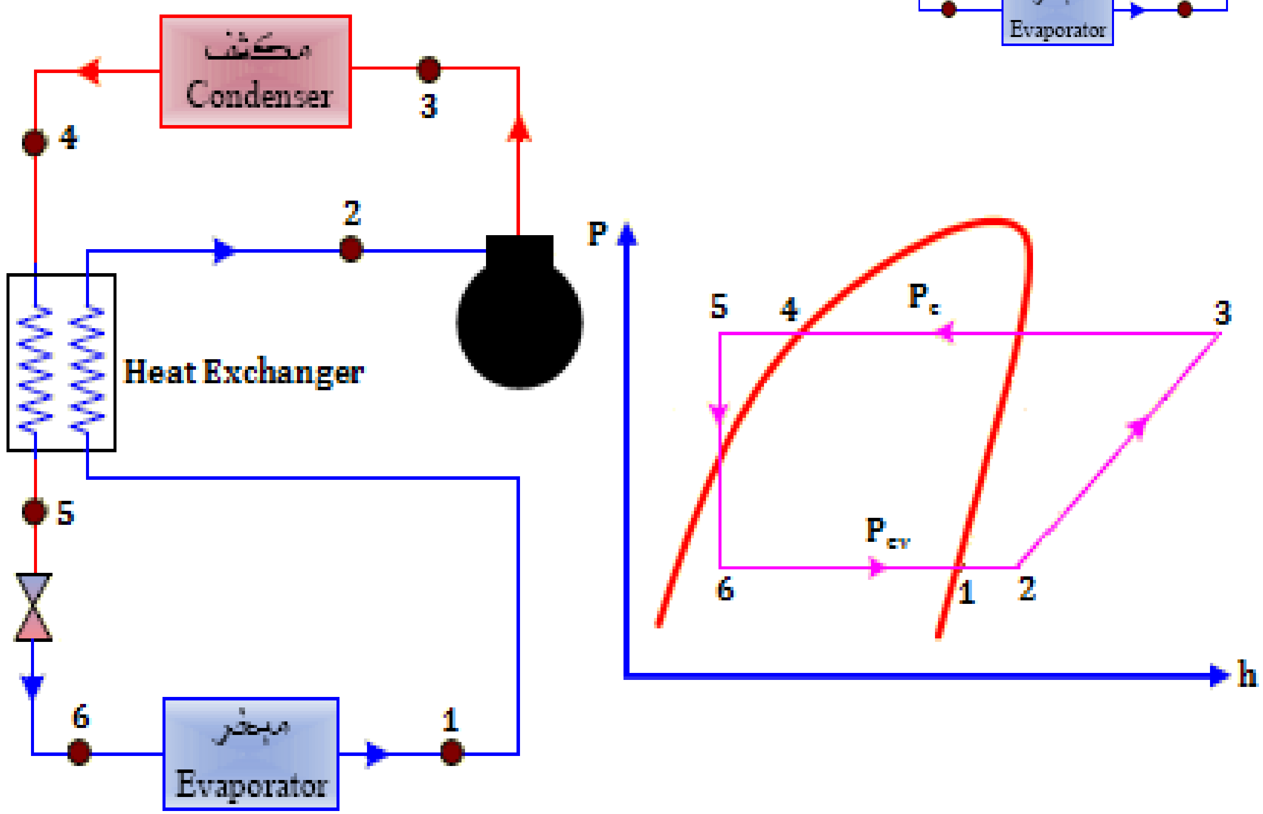
work compressor $(h_2 - h_1)$ is const

The COP of the cycle including subcooling effect (1,2,3′,4′) is higher than that of the ideal vapor compression refrigeration cycle

$C.O.P' > C.O.P$

Modified Vapor Compression Refrigeration cycle





For the modified cycle,

Heat balance for the heat exchanger :

$$h_4 - h_5 = h_2 - h_1$$

$$T_2 - T_1 \neq T_4 - T_5$$

evaporator:

$$R.E = (h_1 - h_6) \qquad Q_{ev} = \dot{m}_{ref}(h_1 - h_6)$$

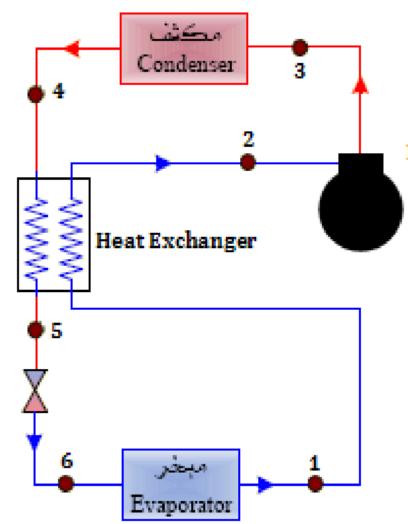
condenser:

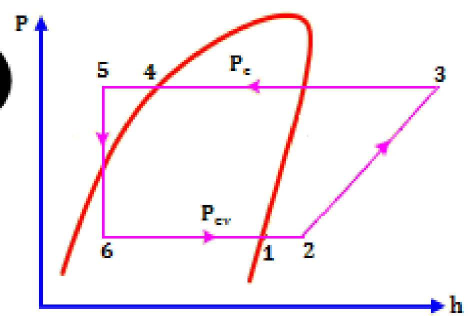
$$Q_{cond} = \dot{m}_{ref}(h_3 - h_4)$$

Compressor:

$$W_c = \dot{m}_{ref}(h_3 - h_2)$$

$$COP = \frac{Q_{ev}}{\dot{W}_c} = \frac{h_1 - h_6}{h_3 - h_4}$$





Example 3

An ideal vapor compression system uses R-12 is operating with a condensing temperature 32°C and an evaporating temperature of −12°C. The same cycle is modified to include a liquid-suction heat exchanger. The heat exchange cools the saturated liquid coming out of the condenser to 22°C. If the compressor is capable of pumping 0.025 m^3/s of refrigerant measured at the compressor inlet and the compression is assumed to be isentropic in both cases, determine (a) the refrigerating capacity in kW in both cases, (b) the heat rejected in the condenser in kW in both cases, (c) the compressor power in kW in both cases and (d) COP

Given

Ideal V.C.S — R − 12

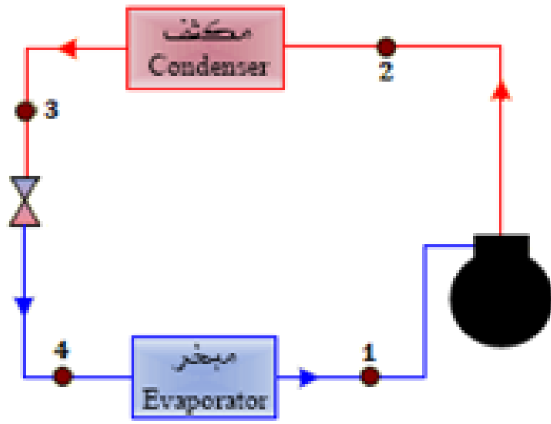
$T_c = 32°C = 305\ K$ — $T_{ev} = -12°C = 261\ K$

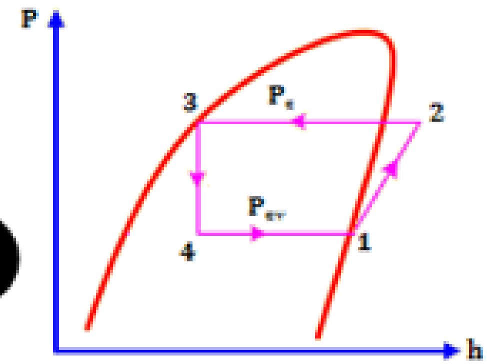
$\dot{V}_{ref} = 0.025\ m^3/s$ — (b)with H.E. $T_s = 22°C = 295\ K$

$Q_{ev} = ??$ $Q_c = ??$ $W_c = ??$ [both cases] $\Delta R.E\% = ??$ $\Delta COP\% = ??$

Solution

(a)**Without H.E.**





From R − 12 (P − h)chart

at $T_{ev} = 261\ K$	and	sat. vapor line	get	$h_1 \cong 564.38\ kJ/kg$	$\rho_1 \cong 12.4\ kg/m^3$
at $T_c = 305\ K$	And	sat. lines	get	P_c line	
at P_c	And	$s_1 = s_2$	get	$h_2 \cong 590\ kJ/kg$	
at $T_c = 305\ K$	And	sat. liquid line	get	$h_3 = h_4 \cong 448.75\ kJ/kg$	

$\therefore R.E = h_1 - h_4 = 564.38 - 448.75 \cong 115.63 kJ/kg$ — $\dot{m}_{ref} = \rho_1 \dot{V}_{ref} = 12.4 * 0.025 \cong 0.31\ kg/s$

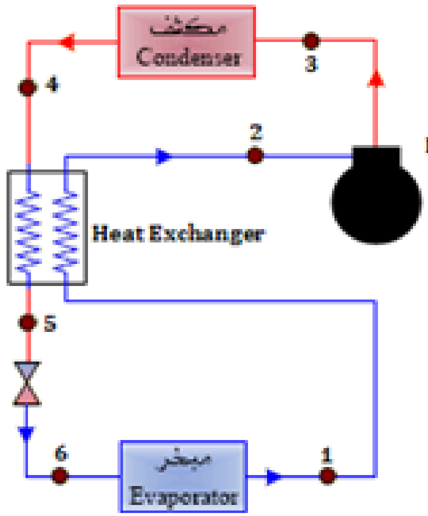
$\therefore Q_{ev} = \dot{m}_{ref}(h_1 - h_4) = 0.31(564.38 - 448.75) \cong \boxed{35.85\ kW}$

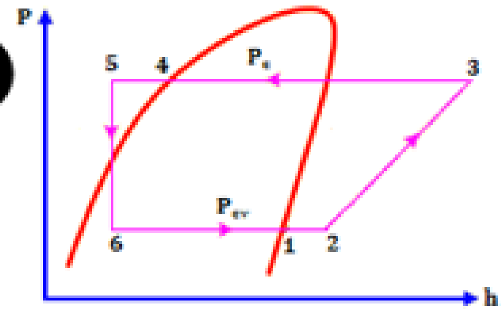
$\therefore W_c = \dot{m}_{ref}(h_2 - h_1) = 0.31(590 - 564.38) \cong \boxed{7.94\ kW}$

$\therefore Q_c = \dot{m}_{ref}(h_2 - h_3) = 0.31(590 - 448.75) \cong \boxed{43.79\ kW}$

$\therefore COP = \frac{Q_{ev}}{\dot{W}_c} = \frac{35.85}{7.94} \cong \boxed{4.52}$

(b) With H. E.





From R − 12 (P − h) chart

at $T_{ev} = 261$ K	And	sat. vapor line	get	$h_1 \cong 564.38$ kJ/kg
at $T_c = 305$ K	And	sat. lines	get	P_c line
at $T_c = 305$ K	And	sat. liquid line	get	$h_4 \cong 448.75$ kJ/kg
at $T_5 = 295$ K	And	P_c	get	$h_5 = h_6 \cong 437.8$ kJ/kg

Apply H.E. energy balance

$\therefore h_4 - h_5 = 448.75 - 437.8 = 10.6 = h_2 - h_1$ $\quad \therefore 10.95 = h_2 - 564.38$ $\quad \therefore h_2 \cong 575.33$ kJ/kg

at point (1)	and	sat. lines	get	P_{ev} line	
at $h_2 \cong 575.33$ kJ/kg	and	P_{ev}	get	point (2)	$\rho_2 \cong 11.48$ kg/m^3
at point (4)	and	sat. lines	get	P_c line	
at P_c	and	$s_2 = s_3$	get	$h_3 \cong 600.67$ kJ/kg	

$\therefore$ R. E $= h_1 - h_6 = 564.38 - 437.8 \cong 126.58$ kJ/kg $\quad \dot{m}_{ref} = \rho_2 \dot{V}_{ref} = 11.48 * 0.025 \cong 0.287$ kg/s

$\therefore Q_{ev} = \dot{m}_{ref}(h_1 - h_6)) = 0.287(564.38 - 437.8) \cong \boxed{36.33\ \text{kW}}$

$\therefore W_c = \dot{m}_{ref}(h_3 - h_2) = 0.287(600.67 - 575.33) \cong \boxed{7.27\ \text{kW}}$

$\therefore Q_c = \dot{m}_{ref}(h_3 - h_4) = 0.287(600.67 - 448.75) \cong \boxed{43.6\ \text{kW}}$

$$\therefore COP = \frac{Q_{ev}}{\dot{W}_c} = \frac{36.33}{7.27} \cong \boxed{5}$$