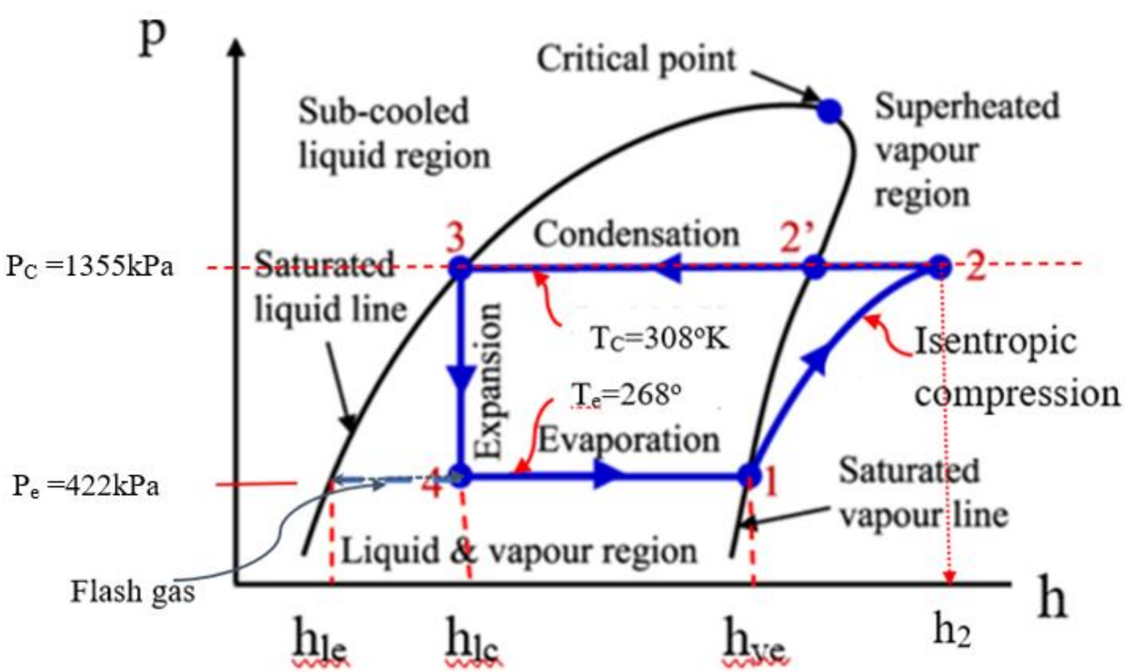
e.g.: A refrigerator producing 15kw of refrigeration operates at an evaporator temperature of (-5°C) & condenser temperature of (35°C). calculate:

a) $\dot{m}$, b) $\dot{\upsilon}$, c) W, d) Q_{out}, e) f, f) cop, if the refrigerant used is R-22.

Sol:



Points 1&3 from table only & (h_3=h_4).[point 2 from chart].

From table: P_c=1355kPa & P_e=422kPa.

h_1= 403.15kJ/kg (saturated vapour).

h_4=h_3=243.1kJ/kg (saturated liquid).

h_2=434 kJ/kg from P-h diagram.

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To obtain (h_2), extend the horizontal straight line at (T_c=308°K or P_c=1355kPa) to the superheated vapour region, then locate point (1) on the saturated vapour line at intersection with line (T_e=268°K). Then follow the isentropic compression curve until intersecting with line (T_C=308°K). Locate point (2) & read (h_2).

a) $\dot{m} = \frac{X}{Q_{ref.}} = \frac{15}{h_1 - h_4} = \frac{15}{403.15 - 243.1} = 0.0937$kg/sec.

b) $\dot{\upsilon} = \dot{m}(\upsilon_g)_1 = 0.0937 * 55.325 * 10^{-3} = 0.00518 m^3/sec.$, [$(\upsilon_g)_1 = 55.325 * 10^{-3}$ m^3/kg from table at -5°C].

c) $W = \dot{m}(h_2 - h_1) = 0.0937\ (434 - 403.15) = 2.89$ kw.

d) $Q_{out} = \dot{m}(h_2 - h_3) = 0.0937\ (434 - 243.1) = 17.887$kw.

e) $f = \frac{h_3 - h_{le}}{h_1 - h_{le}}$, saturated liquid at -5°C →h_{le}=194.15kJ/kg.

$f = \frac{243.1 - 194.15}{403.15 - 194.15} = 0.234$

i.e. approximately 23% of liquid is vapourized at the expansion valve before entering the evaporator.

f) $Cop = \frac{h_1 - h_4}{h_2 - h_1} = \frac{403.15 - 243.1}{434 - 403.15} = 5.188$

or $Cop = \frac{X}{W} = \frac{15}{2.89} = 5.19$

Recall $(Cop)_{Carnot.} = 6.7$

∴ Cop reduced in standard vap. Comp. cycle (ideal).

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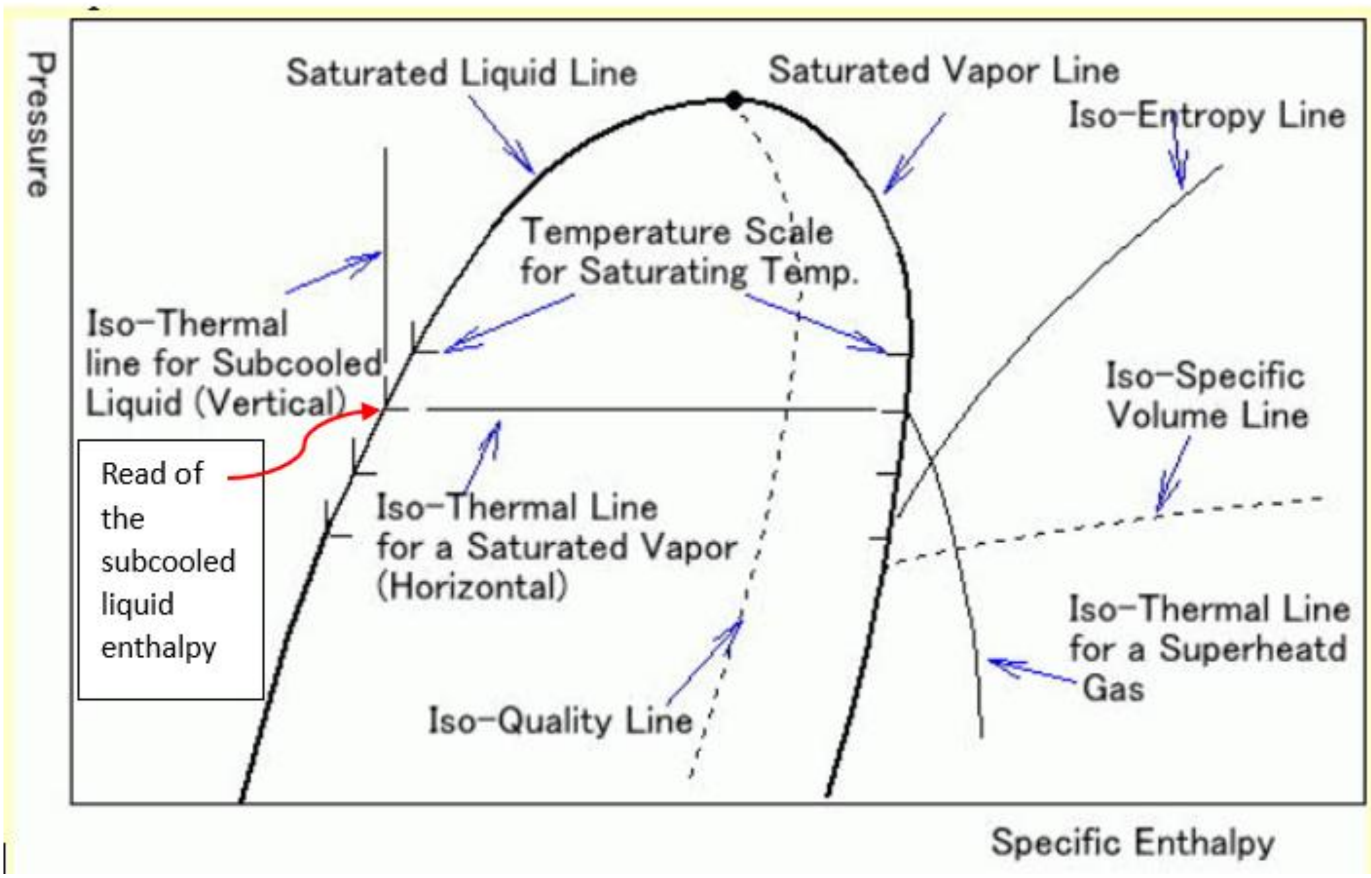
5- Refrigerant properties on a P-h diagram.

Pressure – enthalpy diagrams are the most used for refrigeration practice. They provide easier representation of the vapour-compression cycle.



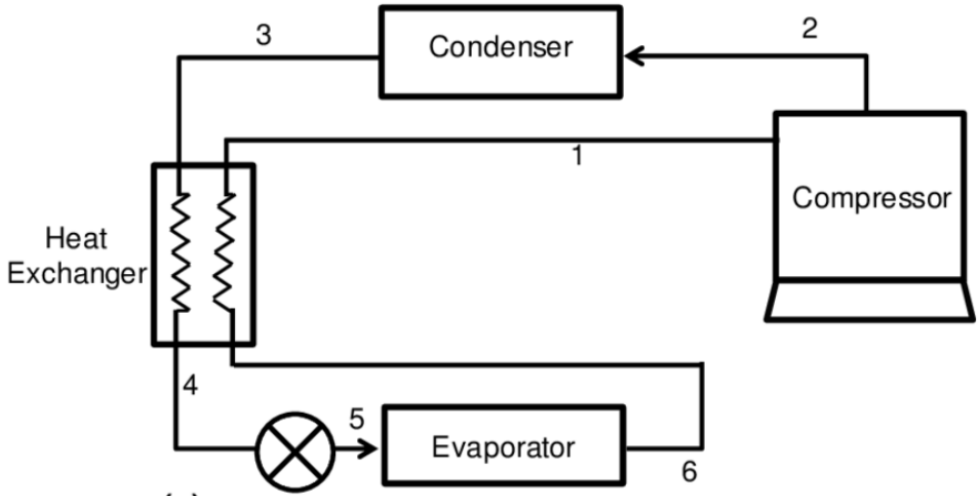
Note:

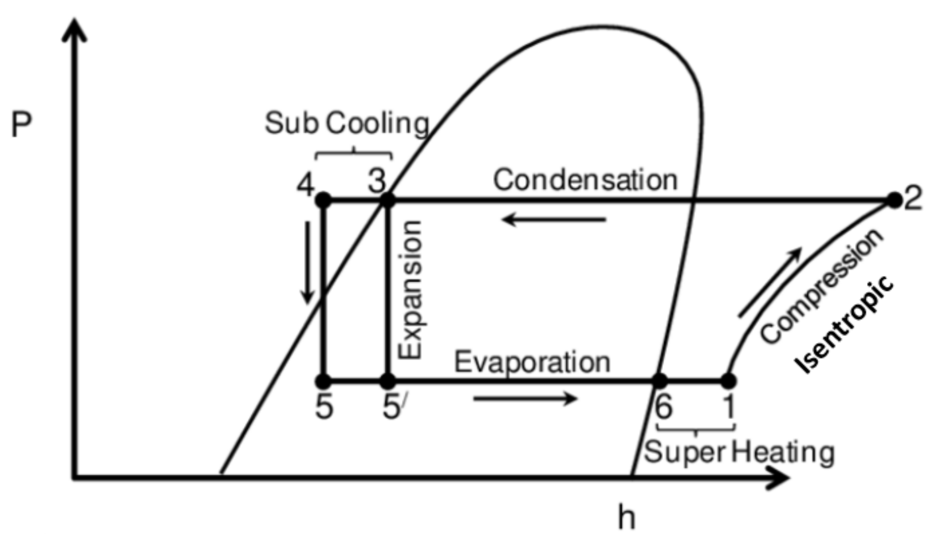
1. temperature line is horizontal inside the phase envelope; vertical in subcooled region; drops to the right in superheated region.
   - In subcooled region enthalpy is read at the saturation temperature regardless of pressure. i.e. The temperature determines the enthalpy and not the pressure. Thus,
     $h_{\text{sub cooled liquid}} = h_{\text{saturated liquid at existing temp.}}$

2. Entropy lines steep & slope upward. Increase with increasing enthalpy & decreasing pressure.
3. Volume lines slope slightly upward to the right, increase with decreasing pressure.
   S = 1kJ/kg for saturated liquid at 0^oC.
   h= 200kJ/kg for saturated liquid at 0^oC.

6- Liquid subcooling and vapour superheating:

The refrigerant vapor out of the evaporator (6→1) is used to cool the saturated liquid leaving the condenser (3→4). Thus, liquid entering evaporator is subcooled & vapour entering the compressor is superheated.





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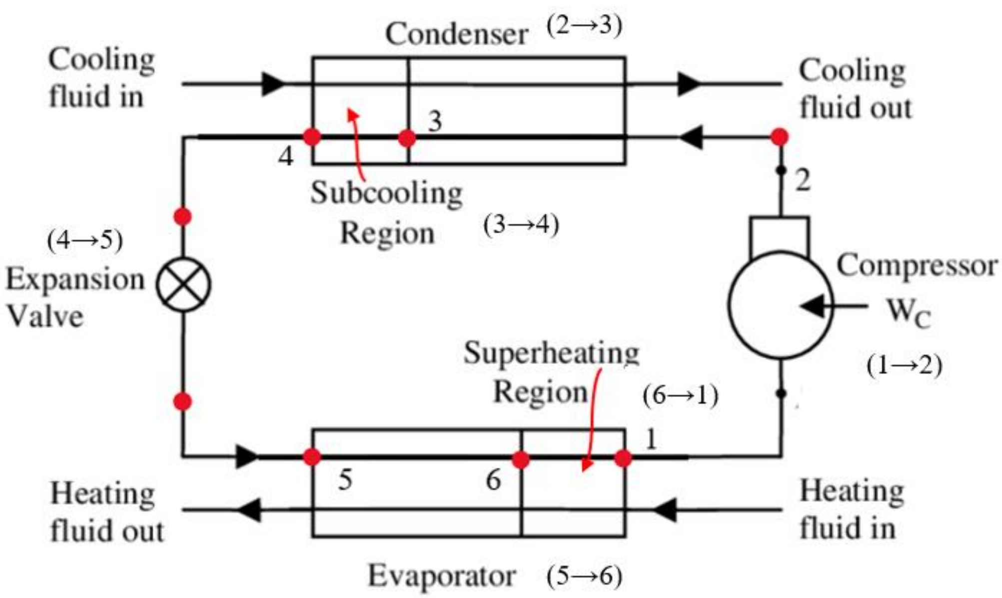
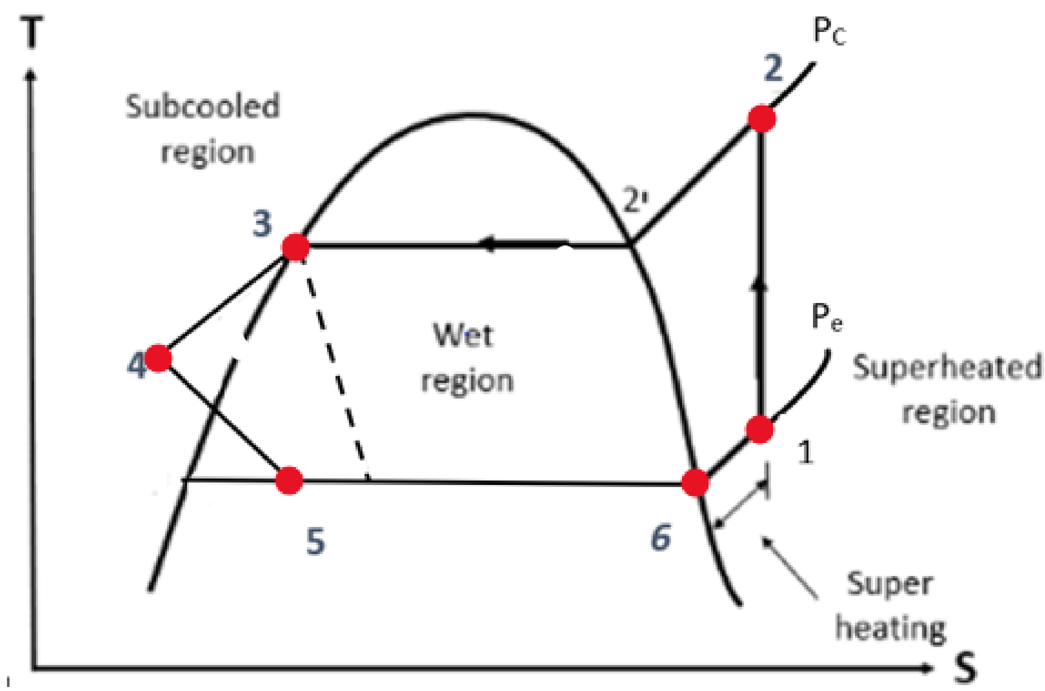


Subcooled and superheated refrigeration cycle.



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*Saturated liquid is cooled from (3 to 4) by saturated vapour which heats from (6 to 1). i.e.:

h_3-h_4 = h_1-h_6 [heat exchanger only).

*refrigerating effect = h_6-h_5 = h_1-h_3 (for heat exchanger only).

Heat rejected at condenser = h_2-h_3 (for heat exchanger only).

- Liquid subcooling & vapour superheating can also be achieved without a heat exchanger.
  Superheating is done in the evaporator by adjusting the mass flowrate, subcooling is done in the condenser by increasing heat transfer (heat rejected). Then without heat exchanger:
  $Q_{ref.} = h_1 - h_5$
  $Q_{conderser} = h_2 - h_4$

Using the heat exchanger, the refrigeration effect is improved but the compressor work is increased since ($\upsilon_1 > \upsilon_6$). Main advantage is to ensure only vapour enters the compressor. This method is employed mainly in vapour compression machines that employ R -12 & R-22 with increased capacity.

e.g: A system using R-22 produces 15 kw of refrigeration at an evaporator temperature of -5°C and condenser temperature of 35°C. A liquid to vapour heat exchanger is used where the vapour is superheated 5°C before entering the compressor. Determine: a) piston displacement, ($\dot{\upsilon}$). b) $Q_{cond.}$, c) f.
d)W if compression is isentropic. e) Cop.

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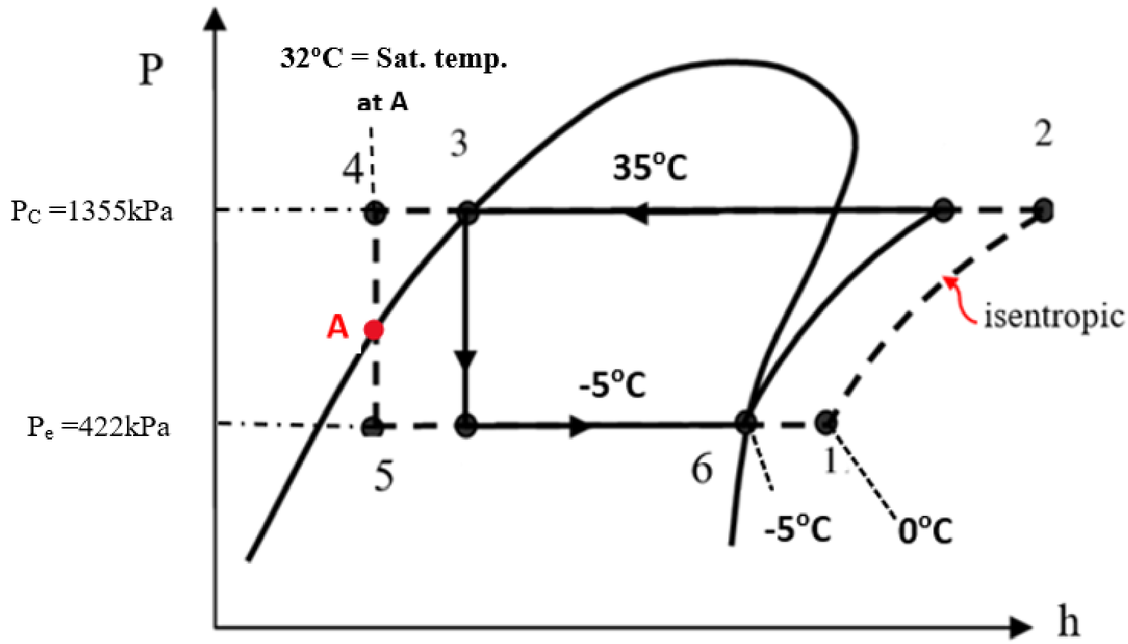
Sol:



From tables for R-22.

h_6=403.15 kJ/kg. (Saturated vapour at -5°C).

P_e=422 kPa. (Saturated vapour at -5°C).

h_3 =243.1 kJ/kg . (Saturated liquid at 35°C).

P_c=1355 kPa. . (Saturated liquid at 35°C).

From chart:

h_1=407kJ/kg (at p_e & 0°C).

T_A=32°C (Saturated temperature at point A) [note: obtained from knowing h_4, which equal to h_f (from table)]. As follows:

$h_1-h_6=h_3-h_4$

$h_4 = h_3-(h_1-h_6)=(243.1-(407-403.15) = 239.25\text{kJ/kg} = h_5 \rightarrow t_4=32°C$ (from table).

$T_A=t_4=32°C$. (Vertical temperature line 4→A in the subcooled region until saturation line).

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a) $\dot{\upsilon}=\dot{m}.\upsilon_1$, $\dot{m}=\frac{X}{Q_{ref}}=\frac{15}{h_6-h_5}=\frac{15}{(403.15-239.25)}=0.0915$ kg/sec.

$\upsilon_1=0.057\ m^3/kg$ from chart at point 1. ($h_5= h_4= 239.25$kJ/kg).

$\dot{\upsilon}=\frac{X}{Q_{ref}}\upsilon_1=\frac{15}{h_6-h_5}*\upsilon_1=0.0915*0.057=0.005216m^3/sec.$

b) $Q_{out}=\dot{m}(h_2-h_3)$

h_2=439 kJ/kg, from chart at point 2, (from 1→2 constant entropy line).

Q_{out} =0.0915* (439-243.1) =17.924 kw.

c) $h_4=h_5=f*h_6+(1-f)*h_{le}$

h_{le}=194.15 kJ/kg (from table at -5°C).

$f=\frac{h_5-h_{le}}{h_6-h_{le}}=\frac{239.25-194.15}{403.15-194.15}=0.215=21.5\%$.

d) $w=\dot{m}(h_2-h_1)=0.0915*(439-407)=2.928$kw.

or $W=Q_{out}-Q_{in}=17.924-15=2.924$ kw.

e) $Cop=\frac{X}{W}=\frac{15}{2.924}=5.13$ (decreased in comparation with a previous example as the work increased to pump more refrigerant).

$$Cop=\frac{(h_6-h_5)\dot{m}}{(h_2-h_1)\dot{m}}$$