

State 1

$h_1 = h_g$ at 2.077 bar 5K superheated.

$$h_1 = 1422.7 + (1538.2 - 1422.7) \left(\frac{260 - 255}{305 - 255} \right)$$

$$h_1 = 1434.25 \text{ kJ/kg}$$

$$s_1 = 5.593 + (6.008 - 5.593) \left(\frac{260 - 255}{305 - 255} \right)$$

$$s_1 = 5.6345 \text{ kJ/kg}\cdot\text{K}$$

State 2

$$s_1 = s_2 = 5.6345 \text{ kJ/kg}\cdot\text{K}$$

h_2 is located between 50K and 100K superheated.

$$h_2 = h_{50\text{K}} + (h_{100\text{K}} - h_{50\text{K}}) \left(\frac{s_2 - s_{50\text{K}}}{s_{100\text{K}} - s_{50\text{K}}} \right)$$

$$h_2 = 1702.8 \text{ kJ/kg}$$

State 3

$h_3 = h_f$ at $P = 12.37$ bar.

$$h_3 = 332.8 \text{ kJ/kg}$$

State 4

$$h_3 = h_4 = 332.8 \text{ kJ/kg}$$

$$\text{COP}_{\text{ref}} = \frac{Q_L}{\dot{W}}$$

$$= \frac{h_1 - h_4}{h_2 - h_1}$$

$$= 4.10$$

$$\begin{aligned} \text{Refrigerating effect} &= h_1 - h_4 \\ &= 1011.45 \text{ kJ/kg} \end{aligned}$$

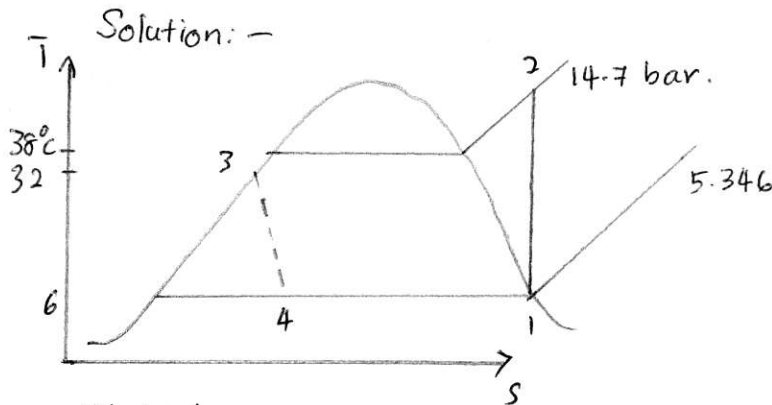
$$\text{COP}_{\text{ref Reversed Carnot}} = \frac{t_1}{t_2 - t_1}$$

$$= \frac{255}{305 - 255}$$

$$= 5.1$$

14.3 A heat pump using ammonia as the refrigerant operates between saturation temperatures of 6 and 38°C. the refrigerant is compressed isentropically from dry saturation and there is 6K undercooling in the condenser. Calculate:

- the COP_{HP}
- the mass flow of refrigerant per kilowatt power input
- the heat available per kilowatt power input



State 1

$$h_1 = h_g \text{ at } 6^\circ\text{C} \quad P = 5.346 \text{ bar}$$

$$h_1 = 1450.6 \text{ kJ/kg}$$

$$s_1 = s_g = 5.263 \text{ kJ/kg}\cdot\text{K}$$

State 2

$$s_1 = s_2 = 5.263 \text{ kJ/kg}\cdot\text{K}$$

From the table R 717 s_2 is between saturated and 50K superheated.

$$\therefore h_2 = h_g + (h_{50K} - h_g) \left(\frac{s_2 - s_g}{s_{50K} - s_g} \right)$$

$$h_2 = 1594.40 \text{ kJ/kg}$$

State 3

$$h_3 = h_f \text{ at } T = 38^\circ\text{C}$$

$$h_3 = 332.8 \text{ kJ/kg}$$

State 4

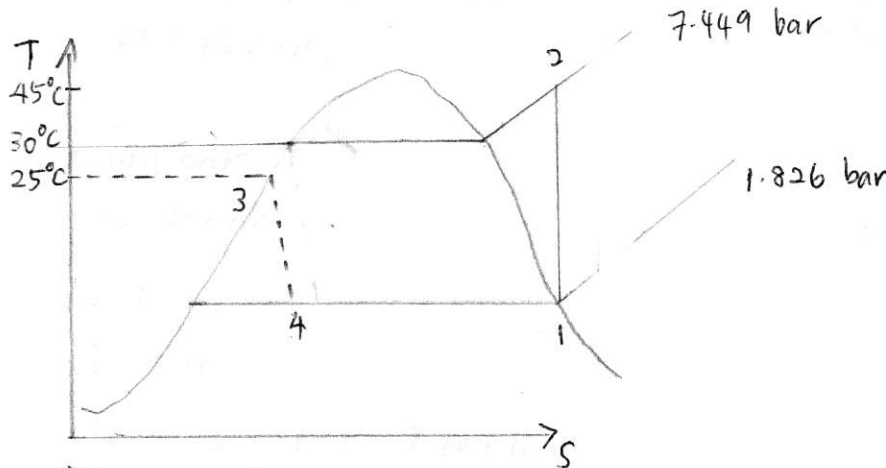
$$h_4 = h_3 = 332.8 \text{ kJ/kg}$$

$$\begin{aligned} \text{i) } COP_{HP} &= \frac{Q_H}{\dot{W}} \\ &= \frac{h_1 - h_3}{h_2 - h_1} \\ &= 8.77 \quad \checkmark \end{aligned}$$

$$\begin{aligned} \text{ii) } \dot{m} &= \frac{1}{\dot{W}} \times 3600 \\ &= 6.96 \times 10^{-3} \text{ kg/s} \quad (\text{@ } 25.03 \text{ kg/h}) \quad \checkmark \end{aligned}$$

$$\begin{aligned} \text{iii) } \dot{Q} &= \dot{m} (Q_H) \\ &= \dot{m} (h_2 - h_3) \\ &= 8.77 \end{aligned}$$

- 14.4 (a) in a refrigerating plant using R12 the vapour leaves the evaporator dry saturated at 1.826 bar and is compressed to 7.449 bar. The temperature of the vapour leaving the compressor is 45°C. The liquid leaves the condenser at 25°C and is throttled to the evaporator pressure. Calculate:
- the refrigerating effect
 - the specific work input
 - the COP_{ref}
- (b) compare the result found in (a) with plant using R134a between the same saturation temperatures, with the same maximum cycle temperature and the same degree of undercooling of the condensate.



a) State 1
 $h_1 = h_g$ at 1.826 bar
 $h_1 = 180.97 \text{ kJ/kg}$
 $s_1 = s_g$ at 1.826 bar
 $s_1 = 0.7051 \text{ kJ/kg}\cdot\text{k}$

State 2
 $s_1 = s_2 = 0.7051 \text{ kJ/kg}\cdot\text{k}$

h_2 is between saturated and 15 k superheated.

$$h_2 = h_g + (h_{15k} - h_g) \left(\frac{s_2 - s_g}{s_{15k} - s_g} \right)$$

$$h_2 = 205.76 \text{ kJ/kg}$$

$h_2 = 210.63 \text{ kJ/kg}$ at 15k superheated.

State 3

$$h_3 = h_f \text{ at } 25^\circ\text{C}$$

$$h_3 = 59.70 \text{ kJ/kg}$$

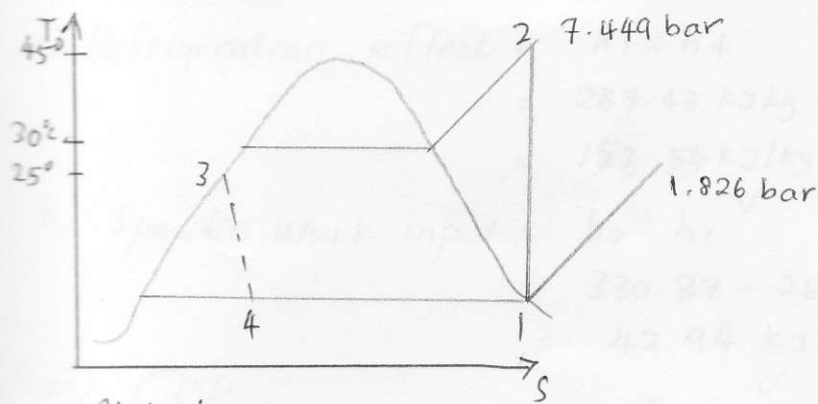
State 4

$$h_3 = h_4 = 59.70 \text{ kJ/kg}$$

i) Refrigerating effect = $h_1 - h_4$
 $= 180.97 - 59.70$

ii) Specific Work input = $h_2 - h_1$
 $= 210.63 - 180.97$

iii) $COP_{ref} = \frac{h_1 - h_4}{h_2 - h_1} = \frac{29.66 \text{ kJ/kg}}{29.66 \text{ kJ/kg}} = 4.09$



State 1

Find h_1 Using Interpolation

$$h_1 = 285.94 + (288.86 - 285.94) \left(\frac{1.826 - 1.6389}{2.0051 - 1.6389} \right)$$

$$h_1 = 287.43 \text{ kJ/kg}$$

State 2

$$P = 7.449 \text{ bar} \quad T = 45^\circ\text{C}$$

h_2 is define at Superheated between 20k and 10k

$$T_2 = 25 + (30 - 25) \left(\frac{7.449 - 6.637}{7.6752 - 6.637} \right)$$

$$T_2 = 28.91^\circ\text{C}$$

Find h_{10k} at $P = 7.449 \text{ bar}$

$$\frac{28.91 - 25}{30 - 25} = \frac{h_{10k} - 321.08}{324.12 - 321.08}$$

$$h_{10k} = 323.46 \text{ kJ/kg}$$

Find h_{20k} at $P = 7.449$.

$$\frac{28.91 - 25}{30 - 25} = \frac{h_{20k} - 332.25}{335.46 - 332.25}$$

$$h_{20k} = 334.81 \text{ kJ/kg}$$

$T = 45^\circ\text{C}$ is 16.09 k superheated. Find h_2

$$\therefore \frac{16.09 - 10}{20 - 10} = \frac{h_2 - 323.46}{334.81 - 323.46}$$

$$h_2 = 330.37 \text{ kJ/kg}$$

State 3

$$h_3 = h_f \text{ at } T = 25^\circ\text{C}$$

$$h_3 = 133.89 \text{ kJ/kg}$$

State 4

$$h_4 = h_3 = 133.89 \text{ kJ/kg}$$

$$\begin{aligned} \text{i) Refrigeration effect} &= h_1 - h_4 \\ &= 287.43 \text{ kJ/kg} - 133.89 \text{ kJ/kg} \\ &= 153.54 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} \text{ii) Specific Work input} &= h_2 - h_1 \\ &= 330.37 - 287.43 \\ &= 42.94 \text{ kJ/kg} \end{aligned}$$

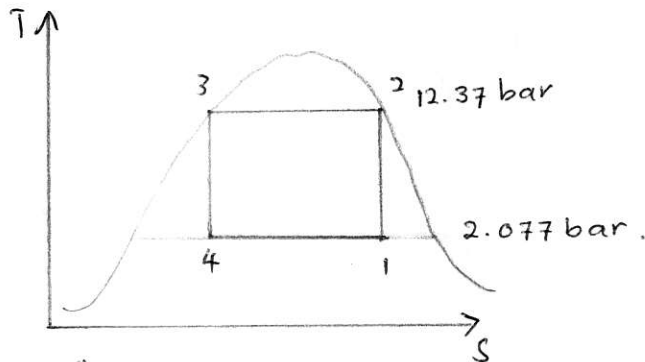
$$\begin{aligned} \text{iii) COP}_{\text{refrigeration}} &= \frac{Q_L}{\sum W} \\ &= \frac{153.54}{42.94} \\ &= 3.57 \end{aligned}$$

14.2 An ammonia vapour-compression refrigerator operates between an evaporator pressure of 2.077 bar and a condenser pressure of 12.37 bar. The following cycles are to be compared; in each case there is no undercooling in the condenser, and isentropic compression may be assumed:

- the vapour has a dryness fraction of 0.9 at the entry to the compressor;
- the vapour is dry saturated at entry to the compressor;
- the vapour has 5K of superheat at entry to the compressor.

In each case calculate the COP_{ref} and the refrigerating effect per unit mass. What would be the COP_{ref} of reversed Carnot cycle operating between the same saturation temperatures?

Solution: -



State 1

$$x_2 = 0.9$$

$$h_1 = h_f + x_2 h_{fg}$$

$$h_1 = 98.8 + 0.9(1422.7 - 98.8)$$

$$h_1 = 1290.31 \text{ kJ/kg}$$

$$s_1 = s_f + x_2 s_{fg}$$

$$= 0.404 + 0.9(5.593 - 0.404)$$

$$s_1 = 5.0741 \text{ kJ/kg}\cdot\text{k}$$

State 2

$$h_2 = h_g \text{ at } 12.37 \text{ bar}$$

$$h_2 = 1469.9 \text{ kJ/kg}$$

State 3

$$h_3 = h_f \text{ at } 12.37 \text{ bar}$$

$$h_3 = 332.8 \text{ kJ/kg}$$

$$s_3 = s_f = 1.235 \text{ kJ/kg}\cdot\text{k}$$

State 4

$$s_3 = s_4 = 1.235 \text{ kJ/kg}\cdot\text{k}$$

$$s_3 = s_f + x_3 s_{fg}$$

$$1.235 = 0.404 + x_3(5.593 - 0.404)$$

$$x_3 = 0.16$$

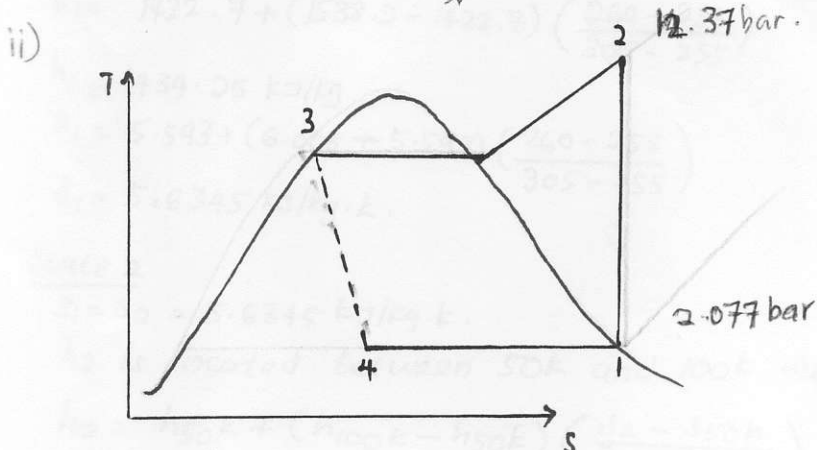
$$h_4 = h_f + x_3 h_{fg}$$

$$h_4 = 98.8 + 0.16(1422 - 98.8)$$

$$h_4 = 310.82 \text{ kJ/kg}$$

$$\begin{aligned}
 \text{i) } \text{COP}_{\text{ref}} &= \frac{Q_{\text{in}}}{\sum W} \\
 &= \frac{h_1 - h_4}{(h_2 - h_1) + (h_3 - h_4)} \\
 &= \frac{4.86}{*}
 \end{aligned}$$

$$\begin{aligned}
 \text{Refrigerating effect} &= h_1 - h_4 \\
 &= 979.49 \text{ kJ/kg}
 \end{aligned}$$



State 1

$$\begin{aligned}
 s_1 &= s_g \text{ at } 2.077 \text{ bar} \\
 s_1 &= 5.593 \text{ kJ/kg.k.} \\
 h_1 &= h_g \text{ at } 2.077 \text{ bar} \\
 h_1 &= 1422.7 \text{ kJ/kg}
 \end{aligned}$$

State 2

$$\begin{aligned}
 s_1 &= s_2 = 5.593 \text{ kJ/kg.k.} \\
 5.593 \text{ kJ/kg.k. at } 12.37 \text{ bar} &\text{ between } 50\text{k and } 100\text{k} \\
 &\text{Superheated.} \\
 \text{So, } h_2 &\text{ will find with interpolation.}
 \end{aligned}$$

$$\begin{aligned}
 \frac{h_2 - h_{50\text{k}}}{h_{100\text{k}} - h_{50\text{k}}} &= \frac{s_2 - s_{50\text{k}}}{s_{100\text{k}} - s_{50\text{k}}} \\
 h_2 &= 1613.0 + (1739.3 - 1613) \left(\frac{5.593 - 5.397}{5.731 - 5.397} \right) \\
 h_2 &= 1687.12 \text{ kJ/kg}
 \end{aligned}$$

State 3

$$\begin{aligned}
 h_3 &= h_f \text{ at } 12.37 \text{ bar} \\
 &= 332.8 \text{ kJ/kg}
 \end{aligned}$$

State 4

$$h_3 = h_4 = 332.8 \text{ kJ/kg}$$

$$\begin{aligned}
 \text{COP}_{\text{ref}} &= \frac{Q_{\text{in}}}{\sum W} \\
 &= \frac{h_1 - h_4}{h_2 - h_1} \\
 &= 4.12
 \end{aligned}$$

$$\begin{aligned}
 \text{Refrigerating effect} &= h_1 - h_4 \\
 &= 1089.9 \text{ kJ/kg}
 \end{aligned}$$