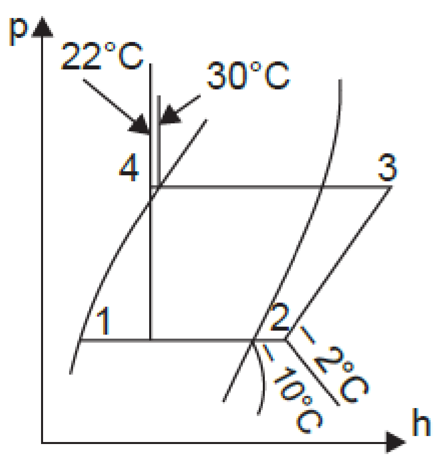
FAQs

1. A R-12 refrigerator works between the temperature limits of – 10°C and + 30°C. The compressor employed is of 20 cm × 15 cm, twin cylinder, single-acting compressor having a volumetric efficiency of 85%. The compressor runs at 500 r.p.m. The refrigerant is sub-cooled and it enters at 22°C in the expansion valve. The vapour is superheated and enters the compressor at – 2°C. Work out the following:; (i) The amount of refrigerant circulated per minute ; (ii) The tonnes of refrigeration ; (iii) The C.O.P. of the system.

Solution:



(i) Mass of a refrigerant circulated per minute:
The values of specific enthalpies and specific volume read from p-h diagram are as under:

$$h_2 = 352\,\frac{kJ}{kg};\ \ h_3 = 374\ kJ/kg$$

$$h_4 = h_1 = 221\ kJ/kg\,;\ v_2 = 0.08\ m^3/kg$$

Refrigerants per kg = $h_2 - h_1 = 352 - 221 = 131\ kJ/kg$
Volume of refrigerant admitted per minute,

$$= \frac{\pi}{4} D^2 L \times r \times p.m. \times 2 \times \eta_{vol}\ \text{, for twin cylinder, single acting}$$

$$= \frac{\pi}{4}(0.2)^2 \times 0.15 \times 500 \times 2 \times 0.85 = 4\ m^3/min$$

Mass of refrigerant per minute= $\frac{4}{0.08} = 50\ \ kg/min$

(ii) Cooling capacity of refrigeration in tonnes

Cooling capacity = $50(h_2 - h_1) = 50 \times 131$

$$= 6550 \text{ kJ/min or } 393000 \frac{\text{kJ}}{\text{h}}$$

$$= \frac{393000}{14000} = 28.07 \text{ TR}$$

(because 1 tonne of refrigeration (TR)= 14000 kJ/h

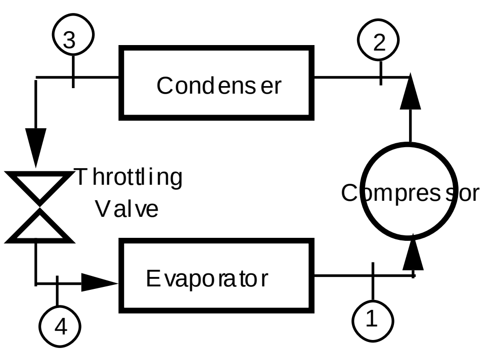
Work per kg $= h_2 - h_1$

$$= 374 - 352 = 22 \text{ kJ/kg}$$

$$\text{C.O.P.} = \frac{131}{22} = 5.95$$

2. A refrigerator uses R-134a as the working fluid and operates on an ideal vapor-compression refrigeration cycle between 0.12 and 0.7 MPa. The mass flow rate of the refrigerant is 0.05 kg/s. Determine (a) the rate of heat removal from the refrigerated space and the power input to the compressor, (b) the rate of heat rejection to the environment, and (c) the coefficient of performance.

Solution: We can find the enthalpy values from tables A-11 to A-13



The state points for the cycle are shown on the diagram. For the ideal cycle there is no pressure drop or work in a heat transfer device so $P_1 = P_4 = 0.12$ MPa and $P_2 = P_3 = 0.7$ MPa. The compressor is assumed to be isentropic so $s_2 = s_1$. State 1 is a saturated vapor and state 3 is a saturated liquid.

We apply the first law for open systems assuming steady flow and negligible changes in kinetic and potential energies; each device has one inlet and one outlet. Thus our first law for each device is $\dot{Q} = \dot{W} + \dot{m}(h_{out} - h_{in})$

$h_1 = h_g(P_{evap} = 120 \text{ kPa}) = 236.97$ kJ/kg $\qquad s_1 = s_g(P_{evap} = 120 \text{ kPa}) = 0.94779$ kJ/kg·K

$h_2 = h(P_2 = P_{cond} = 700 \text{ kPa},$

$s_2 = s_1$= 0.94779 kJ/kg·K) = 273.54 kJ/kg·K by interpolation.

$h_3 = h_f(P_{cond}$ = 700 kPa) = 88.82 kJ/kg

For the throttling valve, $h_4 = h_3$ so, $h_4 = h_f$ (P_{cond} = 700 kPa) = 88.82 kJ/kg

Since there is no useful work in the evaporator, we can find the heat removed from the refrigerated space (the evaporator) using the first law as follows.

$$\dot{Q}_{evap} = \dot{m}(h_1 - h_4) = \frac{0.05\,kg}{s}\left(\frac{236.97\,kJ}{kg} - \frac{88.82\,kJ}{kg}\right)\frac{kW\cdot s}{1\,kJ}$$

$$Q_{evap} = 7.41\text{ kW}$$

Since there is no heat transfer to the compressor, we can find the compressor power input using the first law as follows.

$$\left|\dot{W}_{comp}\right| = \left|\dot{m}(h_1 - h_2)\right| = \left|\frac{0.05\,kg}{s}\left(\frac{236.97\,kJ}{kg} - \frac{273.54\,kJ}{kg}\right)\frac{kW\cdot s}{1\,kJ}\right|$$

W_{comp} = 1.83kW

The heat rejected to the environment is the evaporator heat transfer. We can find this high temperature heat transfer from the general cycle relationship: $\left|\dot{Q}_H\right| = \left|\dot{Q}_L\right| + \left|\dot{W}\right|$. For the refrigeration cycle, this becomes.

$$\left|\dot{Q}_H\right| = \left|\dot{Q}_{cond}\right| = \left|\dot{Q}_L\right| + \left|\dot{W}\right| = \left|\dot{Q}_{cond}\right| + \left|\dot{W}_{comp}\right| = 7.41\,kW + 1.83\,kW$$

$\left|\dot{Q}_H\right|$ = 9.24kW

Finally, we find the coefficient of performance the values computed above for work and heat.

$$COP = \frac{\left|\dot{Q}_{evap}\right|}{\left|\dot{W}_{comp}\right|} = \frac{7.41\,kW}{1.83\,kW} \qquad \text{COP} = 4.05$$

3. In a standard vapour compression refrigeration cycle, operating between an evaporator temperature of – 10°C and a condenser temperature of 40°C, the enthalpy of the refrigerant, Freon-12, at the end of compression is 220 kJ/kg. Calculate :
(i) The C.O.P. of the cycle.
(ii) The refrigerating capacity and the compressor power assuming a refrigerant flow rate of 1 kg/min. You may use the extract of Freon-12 property table given below:

T (^{0}C)	P (MPa)	h_f (kJ/kg)	H_g (kJ/kg)

-10 40	0.2191 0.9607	26.85 74.53	183.1 203.1

Given: Evaporator temperature = – 10°C
Condenser temperature = 40°C
Enthalpy at the end of compression, h_3 = 220 kJ/kg
From the table given, we have
h_2 = 183.1 kJ/kg ; $h_1 = h_{f4}$ = 26.85 kJ/kg

(i) The C.O.P. the cycle:

$$\text{C.O.P.} = \frac{h_2 - h_1}{h_3 - h_2}$$

$$= \frac{183.1 - 74.53}{220 - 183.1} = 2.94$$

(ii) Refrigerating capacity:
Refrigerating capacity = $m(h_2 - h_1)$
[where m = mass flow rate of refrigerant = 1 kg/min ...(Given)]
= 1 × (183.1 – 74.53)
= 108.57 kJ/min

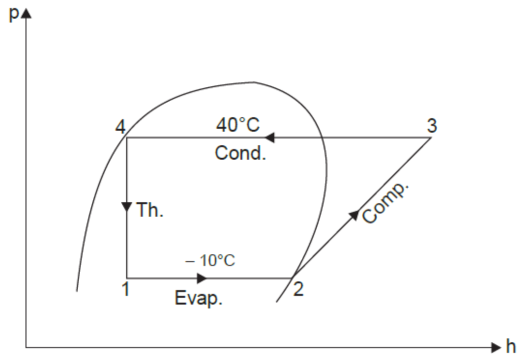
Compressor power :
Compressor power = m(h3 – h2)
= 1 × (220 – 183.1) = 36.9 kJ/min or 0.615 kJ/s
= 0.615 kW.

4. A refrigeration cycle uses Freon-12 as the working fluid. The temperature of the refrigerant in the evaporator is -10^{o}C. The condensing temperature is 40^{o}C. the cooling load is 150W and the volumetric efficiency of the compressor is 80%. The speed of the compressor is 720 rpm. Calculate the mass flow rate of the refrigerant and the displacement volume of the compressor.

Properties of Freon-12

Temperature (^{o}C)	Saturation Pressure (MPa)	Enthalpy (kJ/kg)		Specific volume (m^3/kg) Saturated vapour
		Liquid	Vapour	
-10	0.22	26.8	183.0	0.08
40	0.96	74.5	203.1	0.02

Solution: Given: Cooling load= 150 W**;** η_{vol} = 0.8; N= 720 r.p.m



Mass flow rate of the refrigerant ṁ:

Refriferating effect = h_2-h_1

= 183-74.5= 108.5 kJ/kg

Cooling load = $\dot{m} \times (108.5 \times 1000) = 150$

$$\dot{m} = \frac{150}{108.5 \times 1000} = 0.001382 \text{ kJ/s}$$

Displacement volume of the compressor:

Specific volume at entry to compressor,

v_2= 0.08 m^3/kg

∴ Displacement volume of compressor = $\frac{\dot{v}_2}{\eta_{vol}} = \frac{0.001382 \times 0.08}{0.8}$

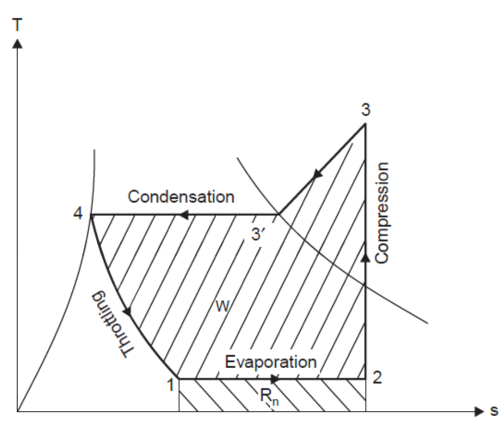
= 0.0001382 m^3/s

5. A simple vapour compression plant produces 5 tonnes of refrigeration. The enthalpy values at inlet to compressor, at exit from the compressor, and at exit from the condenser are 183.19, 209.41 and 74.59 kJ/kg respectively. Estimate:

a. The refrigerant flow rate
b. The C.O.P.
c. The power required to drive the compressor

Solution: total refrigeration effect produced = 5 TR (tones of refrigeration)

$= 5 \times 14000 = 70000$ kJ/h or 19.44 kJ/s



Given: h_2= 183.19 kJ/kg; h_3= 209.41 kJ/kg;

$h_4(=h_1) = 74.59$ kJ/kg (Throttling process)

(i) The refrigeration flow rate, $\dot{m}$:
Net refrigerating effect produced per kg= h_2-h_1

= 183.19-74.59= 108.6 kJ/kg

$\therefore$ Refrigerant flow rate , $\dot{m} = \frac{19.44}{108.6} = 0.179$ kg/s

(ii) The C.O.P $= \frac{R_n}{W} = \frac{h_2 - h_1}{h_3 - h_2} = \frac{183.19 - 74.59}{209.41 - 183.19} = 40142$

(iii) The power required to drive the compressor, P:

$P = \dot{m}(h_3 - h_4) = 0.179(209.41 - 183.19) = 4.69\ kW$

6. A spherical food product is being frozen in an air-blast wind tunnel. The initial product temperature is 10 ^oC and the cold air -15 ^oC. The product has a 7-cm diameter with density of 1,000 kg/m^3. The initial freezing temperature is -1.25 ^oC, and the latent heat of fusion is 250 kJ/kg. Compute the freezing time.

Given: Initial product temperature T_i = 10 ^oC
Air temperature T_α= -15 ^oC (Not – 40^oC)
Initial freezing temperature T_F = -1.25 ^oC
Product diameter a = 7 cm (0.07 m)
Product density ρ = 1000 kg/m^3
Thermal conductivity of frozen product k = 1.2 W/m.k
Latent heat H_L = 250 kJ/kg
Shape constants for spheres: P' = 1/6, R' = 1/24
Convective heat-transfer coefficient h_c = 50 W/m^2.k
Solution: calculate the freezing time

$$t_F = \frac{\rho H_L}{T_F - T_\infty}\left(\frac{P'a}{h_c} + \frac{R'a^2}{k}\right)$$

$$t_F = \frac{1000\,kg/m^3 \times 250\,kJ/kg}{[-1.25\ ^oC - (-15\ ^oC)]}\left[\frac{0.07\,m}{6\times(50\ W/m^2.K)} + \frac{(0.07\,m)^2}{24\times(1.2\ W/m.K)}\right]$$

$$= 18182\ \frac{kJ}{m^3.^oC} \times [2.33\times10^{-4}\ \frac{m^3.K}{W} + 1.7\times10^{-4}\ \frac{m^3.K}{W}]$$

$$= 7.33\ \ kJ/W$$

$$Since\ \ 1KJ = 1000\,J\ \ and\ \ 1W = 1\ \ J/s$$

$$t_F = \frac{7.33\times1000\ \ J}{1\ J/s} = 7.33\times10^3\ s = 2.04\ \ hr$$

7. Lean beef block with dimensions of $1m \times 0.25m \times 0.6m$, $h_c = 30\frac{W}{m^2K}$, $T_0 = 5^0C, T = -10^0C, T_\infty = -30^0C$

$\rho = 1050\,\frac{kg}{m^3}$, $L_V = 333.22$ Kj/Kg, m.c. = 74.5 %, $k_1 = 1.108\left(\frac{W}{mK}\right)$, $T_f = -1.75^0C$. Find freezing time using Plank's equation.

Solution:

$$\beta_1 = \frac{0.6}{0.25} = 2.4, \beta_2 = \frac{1}{0.25} = 4, \qquad \therefore P = 0.3, \qquad R = 0.085$$

$$t = \frac{(1050)(333.22 \times 0.745)}{[-1.75-(-30)]3600\ s/h}\left[\frac{0.3(0.25)}{30} + \frac{0.085(0.025)^2}{1.108}\right] = 18.7h$$

8. Name most common refrigerant.
Ans. R-12 or Freon-12

9. What is Plank's equation used for?
Ans. To calculate the freezing time

10. What are the limitations of Plank's equation?
Ans. It neglects the time required to remove sensible heat above the initial freezing point.
It does not consider the gradual removal of latent heat over a range of temperatures during the freezing process.
Constant thermal conductivity assumed for frozen material.

11. What is refrigeration effect?
Ans. Refrigerating effect is the amount of heat absorbed by therefrigerant in its travel through the evaporator.

12. What is a p-h diagram?
Ans. The P-H diagram is a graphical representation of the refrigerant as it travels through the refrigeration system. It can be used to predict several system conditions, such as the pressure and temperature for the refrigerant at various locations within the system.

13. What is an isentropic process?
Ans. The process during which the entropy remains constant is an isentropic process.
$\Delta S = 0$ or $s_1 = s_2$ for a process

14. What is dry ice?
Ans. It is solid carbon dioxide and mostly used as a cooling agent.