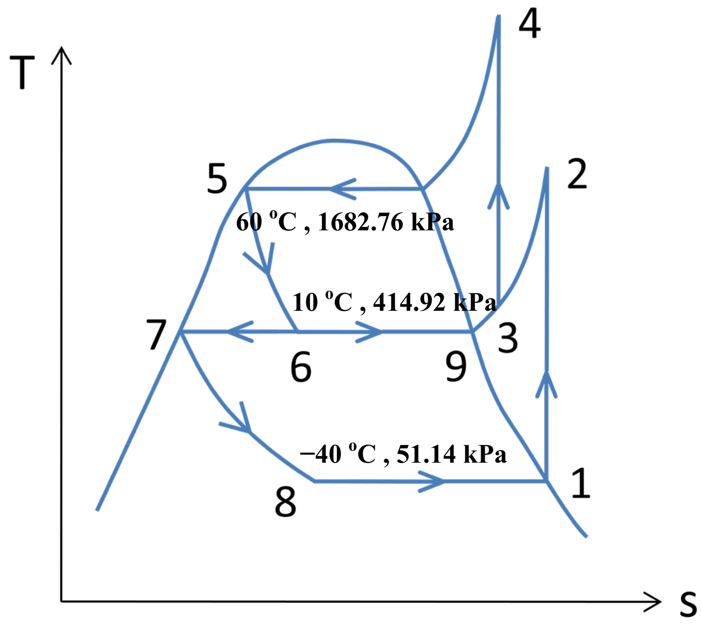
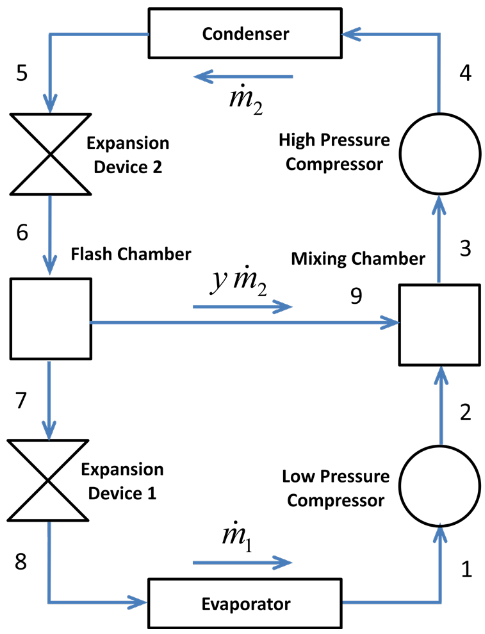
Ex. (1) / A compound ideal refrigeration cycle is used to handle a refrigeration capacity of 2000 W. The cycle consists of a flash chamber, a mixing chamber, an evaporator, a condenser, two expansion devices and two compressors. The prevailing temperatures at the evaporator, the flash chamber and the condenser are −40 °C, 10 °C and 60 °C respectively. If the system works on R-134a then calculate:-

a) The mass flow rate through the evaporator.
b) The mass flow rate of the vapor out of the flash chamber.
c) The total power consumed by the compressors.
d) The Coefficient of Performance COP.





Sol.

at $T_1 = -40\ ^oC \xrightarrow{\text{Sat. Tab.}} h_1 = 374.3$ kJ/kg , $s_1 = 1.7655$ kJ/(kg K) , $s_2 = s_1$

at $T_7 = 10\ ^oC \xrightarrow{\text{Sat. Tab.}} h_7 = 213.6$ kJ/kg , $h_9 = 404.5$ kJ/kg , $h_8 = h_7$

at $T_5 = 60\ ^oC \xrightarrow{\text{Sat. Tab.}} h_5 = 287.9$ kJ/kg , $h_6 = h_5$

at $s_2 = 1.7655$ kJ/(kg K) and $P_2 = 414.92$ kPa $\xrightarrow{\text{Super. Tab.}} h_2 = 415$ kJ/kg

$Q_c = \dot{m}_1 (h_1 - h_8) \longrightarrow 2 = \dot{m}_1 (374.3 - 213.6) \longrightarrow$ $\mathbf{\dot{m}_1 = 0.01244}$ **kg/s**

Energy balance in flash chamber:

$$\begin{pmatrix} Input\ Energy \\ of\ Mixture \end{pmatrix}_{Flash\ Chamber} = \begin{pmatrix} Output\ Energy \\ of\ Vapor \end{pmatrix}_{\substack{to\ Mixing \\ Chamber}} + \begin{pmatrix} Output\ Energy \\ of\ Liquid \end{pmatrix}_{\substack{to\ Expansion \\ Device\ 1}}$$

$\dot{m}_2 h_6 = \dot{m}_9 h_9 + \dot{m}_1 h_7$ divide by $\dot{m}_2$

$h_6 = y\, h_9 + (1 - y)\, h_7$ where y = vapor ratio $= \dot{m}_9 / \dot{m}_2$ and $(1 - y)$ = liquid ratio

$287.9 = 404.5\, y + (1 - y)\, 213.6 \longrightarrow y = 0.3892$

$\dot{m}_2 = \dot{m}_1 / (1 - y) = 0.01244 / (1 - 0.3892) \longrightarrow \dot{m}_2 = 0.02037$ kg/s

$\dot{m}_9 = y\, \dot{m}_2 = 0.3892 * 0.02037 \longrightarrow$ **$\dot{m}_9 = 0.00793$ kg/s**

Energy balance in mixing chamber:

$$\begin{pmatrix} Input\ Energy \\ of\ Superheated \\ Vapor \end{pmatrix}_{\substack{Out\ of\ Low \\ Press.\ Comp.}} + \begin{pmatrix} Input\ Energy \\ of\ Saturated \\ Vapor \end{pmatrix}_{\substack{Out\ of\ Flash \\ Chamber}} = \begin{pmatrix} Output\ Energy \\ of\ Superheated \\ Vapor \end{pmatrix}_{\substack{To\ High \\ Press.\ Comp.}}$$

$\dot{m}_1 h_2 + \dot{m}_9 h_9 = \dot{m}_2 h_3 \longrightarrow 0.01244 * 415 + 0.00793 * 404.5 = 0.02037 * h_3$

$h_3 = 410.91$ kJ/kg

Entropy balance in mixing chamber:

$$\begin{pmatrix} Input\ Entropy \\ of\ Superheated \\ Vapor \end{pmatrix}_{\substack{Out\ of\ Low \\ Press.\ Comp.}} + \begin{pmatrix} Input\ Entropy \\ of\ Saturated \\ Vapor \end{pmatrix}_{\substack{Out\ of\ Flash \\ Chamber}} = \begin{pmatrix} Output\ Entropy \\ of\ Superheated \\ Vapor \end{pmatrix}_{\substack{To\ High \\ Press.\ Comp.}}$$

$\dot{m}_1 s_2 + \dot{m}_9 s_9 = \dot{m}_2 s_3 \longrightarrow 0.01244 * 1.7655 + 0.00793 * 1.7229 = 0.02037 * s_3$

$s_3 = 1.7489$ kJ/(kg K) $s_4 = s_3$

at $s_4 = 1.7489$ kJ/(kg K) and $P_4 = 1682.76$ kPa $\xrightarrow{\text{Super. Tab.}} h_4 = 445$ kJ/kg

$W_1 = \dot{m}_1 (h_2 - h_1) \longrightarrow W_1 = 0.01244 * (415 - 374.3) \longrightarrow W_1 = 0.5065$ kW

$W_2 = \dot{m}_2 (h_4 - h_3) \longrightarrow W_2 = 0.02037 * (445 - 410.91) \longrightarrow W_2 = 0.6945$ kW

$W_t = W_1 + W_2 \longrightarrow W_t = 0.5065 + 0.6945 \longrightarrow$ **$W_t = 1.201$ kW**

$COP = Q_c / W_t = 2 / 1.201 \longrightarrow$ **COP = 1.665**

Homework:- Repeat the problem for the following cases

Case 1: Using R-410a instead of R-134a

Case 2: Keep R-134a and increase evap. temp. to −20 ^oC

Case 3: Keep R-134a and Evap. Temp. is −40 ^oC and decrease cond. temp. to 40 ^oC

Answers:-

Case 1: $\dot{m}_1 = 0.01045$ kg/s $\dot{m}_9 = 0.00861$ kg/s $W_t = 1.2344$ kW COP = 1.62

Case 2: $\dot{m}_1 = 0.01154$ kg/s $\dot{m}_9 = 0.007358$ kg/s $W_t = 0.781$ kW COP = 2.56

Case 3: $\dot{m}_1 = 0.01244$ kg/s $\dot{m}_9 = 0.003618$ kg/s $W_t = 0.8336$ kW COP = 2.4