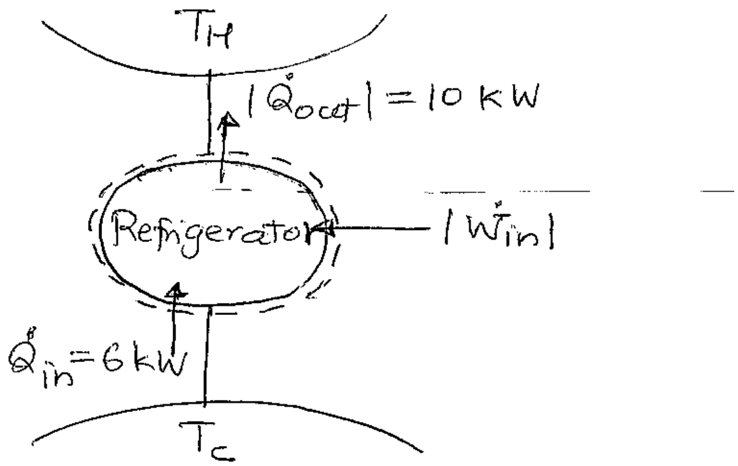
Given

A refrigeration cycle operating at steady state

Find

Coefficient of performance of the cycle

System



Assumptions

- Steady state

Basic Equations

$$\cancel{\left.\frac{dE}{dt}\right|_{system}}^{\,0} = \cancel{\sum_{in} \dot{m}_{in}(h+ke+pe)_{in}} - \cancel{\sum_{out} \dot{m}_{out}(h+ke+pe)_{out}} + \dot{Q} - \dot{W}$$

Solution

Considering energy balance for the cycle:

$$\dot{Q}_{in} + |\dot{W}_{in}| = |\dot{Q}_{out}| \Rightarrow |\dot{W}_{in}| = |\dot{Q}_{out}| - \dot{Q}_{in} = 4\ kW$$

Coefficient of performance of the refrigeration cycle:

$$COP_R = \frac{\dot{Q}_C}{\dot{W}_{net,in}} = \frac{\dot{Q}_{in}}{|\dot{W}_{in}|} = \frac{6\ kW}{4\ kW}$$

$$\boxed{COP_R = 1.5}$$

Given

A heat pump cycle operating at steady state

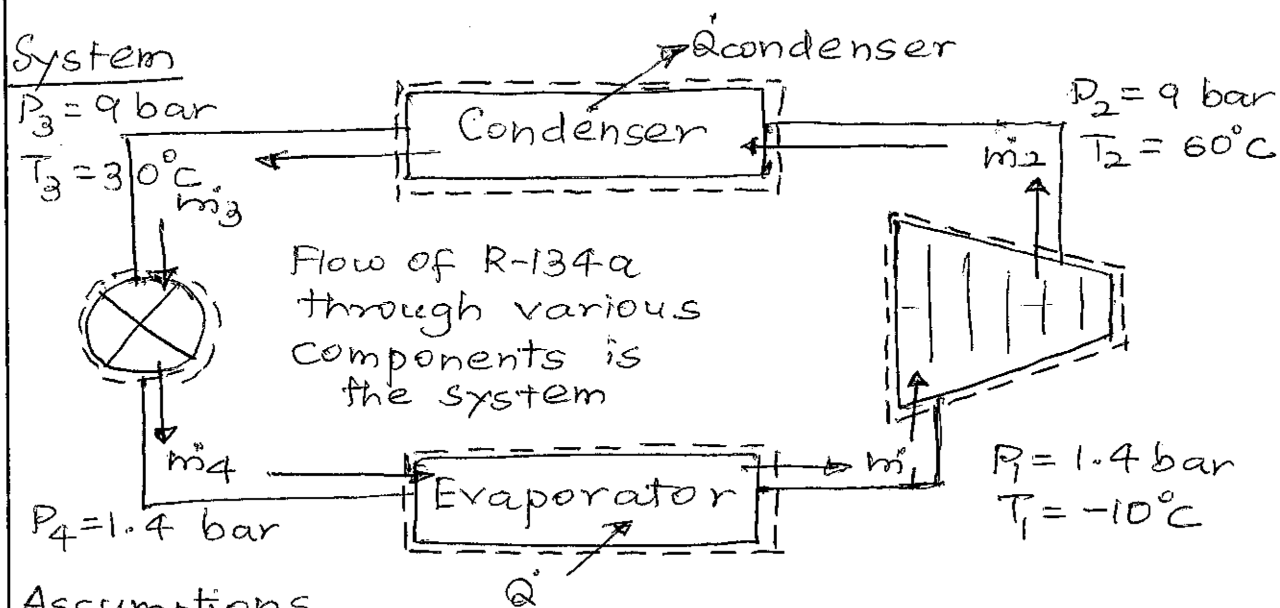
Find

(a) Net specific heat transfer ($\frac{kJ}{kg}$) for the cycle

(b) Net specific work ($\frac{kJ}{kg}$) for the cycle

(c) Coefficient of performance for the cycle

System



Assumptions

- Open system
- Steady state, steady flow
- 1-D, uniform flow
- Ignore change in KE and PE
- Evaporator and condenser: $\dot{W} = 0$
- Compressor: $\dot{Q} = 0$
- Throttling valve: $\dot{Q} = 0$, $\dot{W} = 0$

Basic Equations

$$\left.\frac{dm}{dt}\right|_{system} = 0 = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out}$$

$$\left.\frac{dE}{dt}\right|_{system} = 0 = \sum_{in} \dot{m}_{in}(h + \cancel{ke} + \cancel{pe})_{in} - \sum_{out} \dot{m}_{out}(h + \cancel{ke} + \cancel{pe})_{out} + \dot{Q} - \dot{W}$$

Solution

State 1 $P_1 = 1.4$ bar, $T_1 = -10°C$

$T_{sat}(P_1) < T_1 \Rightarrow$ superheated vapor

$v_1 = 0.14606 \frac{m^3}{kg}$, $h_1 = 246.36 \frac{kJ}{kg}$

State 2 $P_2 = 9$ bar, $T_2 = 60°C$

$T_{sat}(P_2) < T_2 \Rightarrow$ superheated vapor

$v_2 = 0.026146 \frac{m^3}{kg}$, $h_2 = 295.13 \frac{kJ}{kg}$

State 3 $P_3 = 9$ bar, $T_3 = 30°C$

$T_{sat}(P_3) > T_3 \Rightarrow$ sub-cooled (compressed) liquid

$v_3 \cong v_f(T_3) = 0.00084213 \frac{m^3}{kg}$

$h_3 \cong h_f(T_3) + v_f(T_3)\left[P_3 - P_{sat}(T_3)\right]$

$\cong 93.578 \frac{kJ}{kg} + 0.00084213 \frac{m^3}{kg} * (9 - 7.7020) \times 100\, kPa$

$\cong 93.69 \frac{kJ}{kg}$

State 4 $P_4 = 1.4$ bar

Throttling valve: $h_4 = h_3 = 93.69 \frac{kJ}{kg}$

$h_f(P_4) < h_4 < h_g(P_4) \Rightarrow$ saturated liquid-vapor mixture

$$x_4 = \frac{h_4 - h_f(P_4)}{h_g(P_4) - h_f(P_4)} = \frac{93.69 - 27.10}{239.18 - 27.10} = 0.314$$

$$x_4 = \frac{v_4 - v_f(P_4)}{v_g(P_4) - v_f(P_4)} \Rightarrow 0.314 = \frac{v_4 - 0.00073830}{0.14015 - 0.00073830}$$

$$v_4 = 0.044514 \frac{m^3}{kg}$$

(a) Evaporator

Mass balance: $0 = \dot{m}_4 - \dot{m}_1 \Rightarrow \dot{m}_1 = \dot{m}_4 = \dot{m}$

Energy balance: $0 = \dot{m}_4 h_4 - \dot{m}_1 h_1 + \dot{Q}_{evaporator}$

$\Rightarrow \dot{Q}_{evaporator} = \dot{m}_1 h_1 - \dot{m}_4 h_4$

$= \dot{m}(h_1 - h_4)$

Specific heat transfer for the evaporator:

$$q_{evaporator} = \frac{\dot{Q}_{evaporator}}{\dot{m}} = h_1 - h_4 = +152.67\ \frac{kJ}{kg}$$

$q > 0 \Rightarrow$ heat transfer into evaporator

Condenser

Mass balance: $0 = \dot{m}_2 - \dot{m}_3 \Rightarrow \dot{m}_2 = \dot{m}_3 = \dot{m}$

Energy balance: $0 = \dot{m}_2 h_2 - \dot{m}_3 h_3 + \dot{Q}_{condenser}$

$$\Rightarrow \dot{Q}_{condenser} = \dot{m}_3 h_3 - \dot{m}_2 h_2$$
$$= \dot{m}(h_3 - h_2)$$

Specific heat transfer for the condenser:

$$q_{condenser} = \frac{\dot{Q}_{condenser}}{\dot{m}} = h_3 - h_2 = -201.44\ \frac{kJ}{kg}$$

$q < 0 \Rightarrow$ heat transfer out of condenser

Net specific heat transfer for the cycle:

$$q_{net} = q_{evaporator} + \cancel{q_{comp.}}^{0} + q_{condenser} + \cancel{q_{throttling\ valve}}^{0}$$

$$\boxed{q_{net} = -48.77\ \frac{kJ}{kg}}$$

(b) Compressor

Mass balance: $0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}$

Energy balance: $0 = \dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{W}_{comp.}$

$$\Rightarrow \dot{W}_{comp} = \dot{m}_1 h_1 - \dot{m}_2 h_2$$
$$= \dot{m}(h_1 - h_2)$$

Specific work for the compressor:

$$w_{comp.} = \frac{\dot{W}_{comp.}}{\dot{m}} = h_1 - h_2 = -48.77\ \frac{kJ}{kg}$$

$w < 0 \Rightarrow$ work done on compressor

Net specific work for the cycle:

$$w_{net} = \cancel{w_{evaporator}}^{0} + w_{comp.} + \cancel{w_{condenser}}^{0} + \cancel{w_{throttling\ valve}}^{0}$$

$$\boxed{w_{net} = -48.77 \ \frac{kJ}{kg}}$$

Note

$q_{net} = w_{net}$ for the cycle!

(c) Coefficient of performance for the heat pump cycle:

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{|q_{condenser}|}{|w_{comp}|} = \frac{201.44 \ \frac{kJ}{kg}}{48.77 \ \frac{kJ}{kg}}$$

$$\boxed{COP_{HP} = 4.13}$$

Given

A rigid tank containing R-134a with a leak

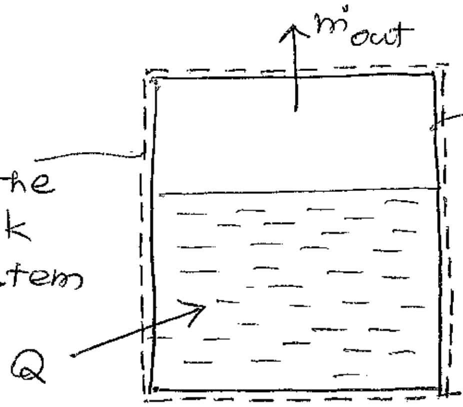
Find

(a) Mass (kg) of R-134a leaving the tank

(b) Heat transfer (kJ) during the process

System

R-134a in the rigid tank is the system



$T_{out} = 20^\circ C$, sat. vapor

$V = 0.0189\ m^3$

$T_1 = 20^\circ C$, $x_1 = 0.10$

$\downarrow$

$T_2 = 20^\circ C$, sat. vapor

Assumptions

- Open system
- Unsteady state, steady flow
- 1-D, uniform flow at outlet
- Ignore KE and PE effects
- Rigid tank : $\dot{W} = 0$

Basic Equations

$$\left.\frac{dm}{dt}\right|_{system} = \cancel{\sum_{in} \dot{m}_{in}} - \sum_{out} \dot{m}_{out}$$

$$\left.\frac{dE}{dt}\right|_{system} = \cancel{\sum_{in} \dot{m}_{in}(h + ke + pe)_{in}} - \sum_{out} \dot{m}_{out}(h + \cancel{ke} + \cancel{pe})_{out} + \dot{Q} - \cancel{\dot{W}}$$

$$\frac{d}{dt}(U + \cancel{KE} + \cancel{PE})$$

Solution

State 1 $\quad T_1 = 20^\circ C$, $x_1 = 0.10$

$$x_1 = \frac{v_1 - v_f(T_1)}{v_g(T_1) - v_f(T_1)} = \frac{u_1 - u_f(T_1)}{u_g(T_1) - u_f(T_1)}$$

$$0.10 = \frac{v_1 - 0.00081610}{0.035997 - 0.00081610} = \frac{u_1 - 78.857}{241.02 - 78.857}$$

$$v_1 = 0.0043342\ \frac{m^3}{kg}, \quad u_1 = 95.1\ \frac{kJ}{kg}$$

$$m_1 = \frac{V}{v_1} = \frac{0.0189\ m^3}{0.0043342\ \frac{m^3}{kg}} = 4.36\ kg$$

State 2

$T_2 = 20°C$, sat. vapor

$$v_2 = v_g(T_2) = 0.035997\ \frac{m^3}{kg}$$

$$u_2 = u_g(T_2) = 241.02\ \frac{kJ}{kg}$$

$$m_2 = \frac{V}{v_2} = \frac{0.0189\ m^3}{0.0043342\ \frac{m^3}{kg}} = 0.525\ kg$$

Outlet

$T_{out} = 20°C$, sat. vapor

$$h_{out} = h_g(T_{out}) = 261.60\ \frac{kJ}{kg}$$

(a) Integrating mass balance: $m_2 - m_1 = -m_{out}$

Mass of R-134a leaving the tank: $m_{out} = m_1 - m_2$

$$\boxed{m_{out} = 3.84\ kg}$$

(b) Integrating energy balance: $U_2 - U_1 = -m_{out}h_{out} + Q$

Heat transfer during the process:

$$Q = m_2 u_2 - m_1 u_1 + m_{out} h_{out}$$

$$= 0.525\ kg * 241.02\ \frac{kJ}{kg} - 4.36 * 95.1\ \frac{kJ}{kg} + 3.84\ kg * 261.60\ \frac{kJ}{kg}$$

$$\boxed{Q = +716.4\ kJ}$$

$Q > 0 \Rightarrow$ heat transfer into the tank

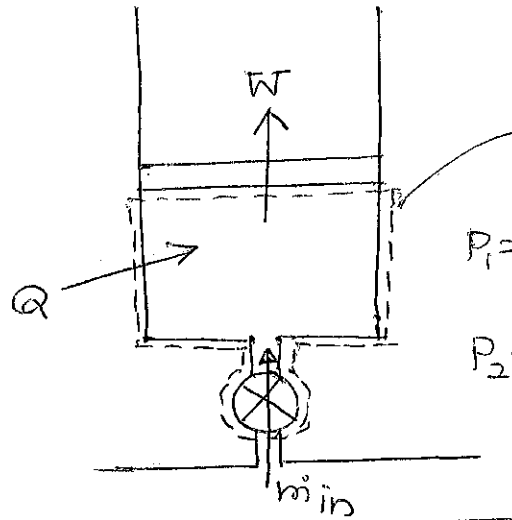
Given

A piston-cylinder device containing water substance connected to a supply line

Find

Heat transfer (kJ) during the process

System



Water substance inside the cylinder is the system

$P_1 = 10$ bar, $V_1 = 0.1\ m^3$, $m_1 = 0.6$ kg

$\downarrow$

$P_2 = 10$ bar, $V_2 = 0.2\ m^3$, $T_2 = 240°C$

Supply Line

$P_{in} = 40$ bar, $T_{in} = 500°C$

Assumptions

- Open system
- Unsteady state, steady flow
- 1-D, uniform flow at inlet
- Ignore KE and PE effects
- Neglect friction between piston and cylinder wall

Ignore mass/volume associated with the valve

Basic Equations

$$\left.\frac{dm}{dt}\right|_{system} = \cancel{\sum_{in}} \dot{m}_{in} - \cancel{\sum_{out} \dot{m}_{out}}$$

$$\left.\frac{dE}{dt}\right|_{system} = \sum_{in} \dot{m}_{in}(h + \cancel{ke} + \cancel{pe})_{in} - \cancel{\sum_{out} \dot{m}_{out}(h + ke + pe)_{out}} + \dot{Q} - \dot{W}$$

$$\frac{d}{dt}(U + \cancel{KE} + \cancel{PE})$$

Solution

State 1 $\quad P_1 = 10$ bar, $v_1 = \frac{V_1}{m_1} = \cancel{0.167}\ 0.16667\ \frac{m^3}{kg}$

$v_f(P_1) < v_1 < v_g(P_1) \Rightarrow$ saturated liquid-vapor mixture

$$x_1 = \frac{v_1 - v_f(P_1)}{v_g(P_1) - v_f(P_1)} = \frac{0.16667 - 0.0011272}{0.19436 - 0.0011272} = 0.857$$

$$x_1 = \frac{u_1 - u_f(P_1)}{u_g(P_1) - u_f(P_1)} \Rightarrow 0.857 = \frac{u_1 - 761.39}{2582.7 - 761.39}$$

$$u_1 = 2322.3\ \frac{kJ}{kg}$$

State 2

$P_2 = 10\ bar,\ T_2 = 240°C$

$T_2 > T_{sat}(P_2) \Rightarrow$ superheated vapor

$v_2 = 0.22756\ \frac{m^3}{kg}$

$u_2 = 2693.3\ \frac{kJ}{kg}$

$$m_2 = \frac{V_2}{v_2} = \frac{0.2\ m^3}{0.22756\ \frac{m^3}{kg}} = 0.879\ kg$$

Inlet

$P_{in} = 40\ bar,\ T_{in} = 500°C$

$T_{in} > T_{sat}(P_{in}) \Rightarrow$ superheated vapor

$h_{in} = 3446\ \frac{kJ}{kg}$

Integrating mass balance: $m_2 - m_1 = m_{in}$

$m_{in} = 0.279\ kg$

Integrating energy balance: $U_2 - U_1 = m_{in} h_{in} + Q - W$

Heat transfer during the process:

$Q = m_2 u_2 - m_1 u_1 - m_{in} h_{in} + W$

Boundary work during the process:

$$W = \int_{V_1}^{V_2} P\,dV = (P_1 = P_2)(V_2 - V_1) = (10 \times 100)\,kPa * (0.2 - 0.1)\,m^3$$
$$= +100\ kJ$$

$$Q = 0.879\ kg * 2693.3\ \frac{kJ}{kg} - 0.6\ kg * 2322.3\ \frac{kJ}{kg}$$
$$- 0.279\ kg * 3446\ \frac{kJ}{kg} + 100\ kJ$$

$\boxed{Q = +112.6\ kJ}$ $\quad Q > 0 \Rightarrow$ heat transfer into the cylinder