(a) Propane, $T = 20^\circ C$, $x = 1$

$\Rightarrow$ $\boxed{\text{saturated vapor}}$

$P = P_{sat}(20^\circ C) \Rightarrow \boxed{P = 8.3654 \text{ bar}}$

$v = v_g(20^\circ C) \Rightarrow \boxed{v = 0.055317 \frac{m^3}{kg}}$

$u = u_g(20^\circ C) \Rightarrow \boxed{u = 445.25 \frac{kJ}{kg}}$

(b) Propane, $T = 20^\circ C$, $v = 0.033990 \frac{m^3}{kg}$

$v_f(20^\circ C) < v < v_g(20^\circ C) \Rightarrow$ $\boxed{\text{saturated liquid-vapor mixture}}$

$P = P_{sat}(20^\circ C) \Rightarrow \boxed{P = 8.3654 \text{ bar}}$

$$v = x\, v_g + (1-x)\, v_f$$

$$\Rightarrow x = \frac{v - v_f}{v_g - v_f} = \frac{0.033990 - 0.0019996}{0.055317 - 0.0019996}$$

$$\boxed{x = 0.6}$$

$$u = x\, u_g + (1-x)\, u_f$$

$$= 0.6 * 445.25 \frac{kJ}{kg} + (1-0.6) * 145.37 \frac{kJ}{kg}$$

$$\Rightarrow \boxed{u = 325.30 \frac{kJ}{kg}}$$

(c) Propane, $P = 1$ bar, $T = 40^\circ C$

$T_{sat}(1\,bar) = -42.41^\circ C \Rightarrow T > T_{sat}(1\,bar)$

or

$P_{sat}(40^\circ C) = 13.70$ bar $\Rightarrow P < P_{sat}(40^\circ C)$

$\Rightarrow$ $\boxed{\text{superheated vapor}}$

$\boxed{x = N/A}$

$\boxed{v = 0.58241 \frac{m^3}{kg}}$

$\boxed{u = 493.22 \frac{kJ}{kg}}$

(d) Propane, $P = 10$ bar, $u = 158.53 \frac{kJ}{kg}$

$u_f(10\,bar) = 163.82 \frac{kJ}{kg} \Rightarrow u < u_f(10\,bar)$

$\Rightarrow$ $\boxed{\text{compressed liquid}}$

$\boxed{x = N/A}$

$\boxed{T = 25^\circ C}$

$\boxed{v = 0.0020302 \frac{m^3}{kg}}$

Given

Saturated liquid-vapor mixture of water inside a closed, rigid tank

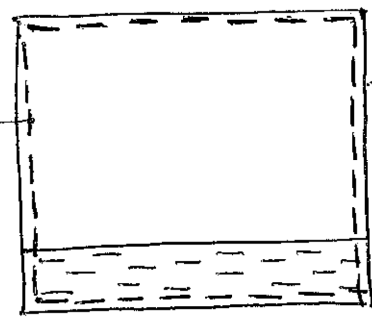
Find

(a) Quality of the mixture

(b) Mass of liquid (kg) and vapor (kg) in the mixture

(c) Volume of liquid (m^3) and vapor (m^3) in the mixture

System



Water substance in the tank is the system

$V = 1\ m^3$

$m = 150\ kg$

$T = 25^\circ C$

Assumptions

N/A

Basic Equations

N/A

Solution

(a) Specific volume of the mixture : $v = \frac{V}{m} = \frac{1\ m^3}{150\ kg}$

$v = 0.0066667\ \frac{m^3}{kg}$

$v_f(25^\circ C) < v < v_g(25^\circ) \Rightarrow$ saturated liquid-vapor mixture

$v = x\, v_g + (1 - x)\, v_f$

Quality of the mixture : $x = \frac{v - v_f}{v_g - v_f}$

$$x = \frac{0.0066667 - 0.0010030}{43.337 - 0.0010030}$$

$$\boxed{x = 0.000131}$$

(b) Mass of saturated liquid in the mixture:

$m_f = (1-x)\,m = (1-0.000131) * 150\ kg$

$$\boxed{m_f = 149.98\ kg}$$

Mass of saturated vapor in the mixture:

$m_g = x\,m = 0.000131 * 150\ kg = 0.0196\ kg$

$$\boxed{m_g \cong 0.02\ kg}$$

$m_f + m_g = 150\ kg = m$ ✓

(c) Volume of saturated liquid in the mixture:

$V_f = m_f\, v_f = 149.98\ kg * 0.0010030\ \frac{m^3}{kg}$

$$\boxed{V_f = 0.1506\ m^3}$$

Volume of saturated vapor in the mixture:

$V_g = m_g\, v_g = 0.0196\ kg * 43.337\ \frac{m^3}{kg}$

$$\boxed{V_g = 0.8494\ m^3}$$

$V_f + V_g = 1\ m^3 = V$ ✓

Given

Cooling of R-134a inside a closed, rigid tank

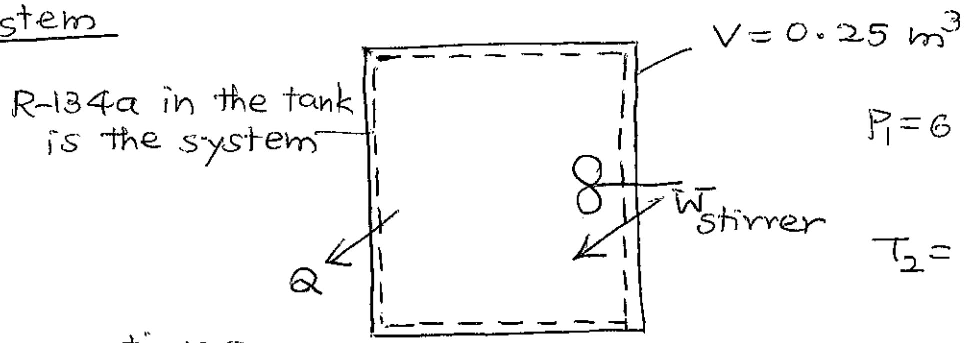
Find

(a) Absolute pressure (bar) at State 2

(b) Heat transfer (kJ) during the process

(c) P-v diagram

System



$P_1 = 6$ bar, $T_1 = 60°C$

$\downarrow$

$T_2 = 12°C$

Assumptions

- Closed system (m = constant)
- Quasi-equilibrium process
- Rigid tank (V = constant) $W_{boundary} = 0$
- Ignore change in KE and PE

Basic Equations

$$Q - W = \Delta E = \Delta U + \cancel{\Delta KE}^{\sim 0} + \cancel{\Delta PE}^{\sim 0}$$

$$W \rightarrow (\cancel{W_{boundary}}^{0} + W_{other})$$

Solution

(a) <u>State 1</u> $P_1 = 6$ bar, $T_1 = 60°C$

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

$$v_1 = 0.041389 \frac{m^3}{kg}$$

$$u_1 = 275.15 \frac{kJ}{kg}$$

For a closed, rigid tank: $v = \frac{V}{m}$ = constant

<u>State 2</u> $T_2 = 12°C$, $v_2 = v_1 = 0.041389 \frac{m^3}{kg}$

$v_f(T_2) < v_2 < v_g(T_2) \Rightarrow$ saturated liquid-vapor mixture

$$P_2 = P_{sat}(T_2) \Rightarrow \boxed{P_2 = 4.4301 \text{ bar}}$$

$$x_2 = \frac{v_2 - v_f(T_2)}{v_g(T_2) - v_f(T_2)} = \frac{0.041389 - 0.00079745}{0.046332 - 0.00079745} = 0.891$$

$$x_2 = \frac{u_2 - u_f(T_2)}{u_g(T_2) - u_f(T_2)} \Rightarrow 0.891 = \frac{u_2 - 67.832}{236.76 - 67.832}$$

$$u_2 = 218.35 \frac{kJ}{kg}$$

(b) Considering energy balance: $Q = W_{other} + \Delta U$

$$Q = W_{other} + (U_2 - U_1) = W_{other} + m_2 u_2 - m_1 u_1$$

$$Q = W_{other} + (m_1 = m_2)(u_2 - u_1)$$

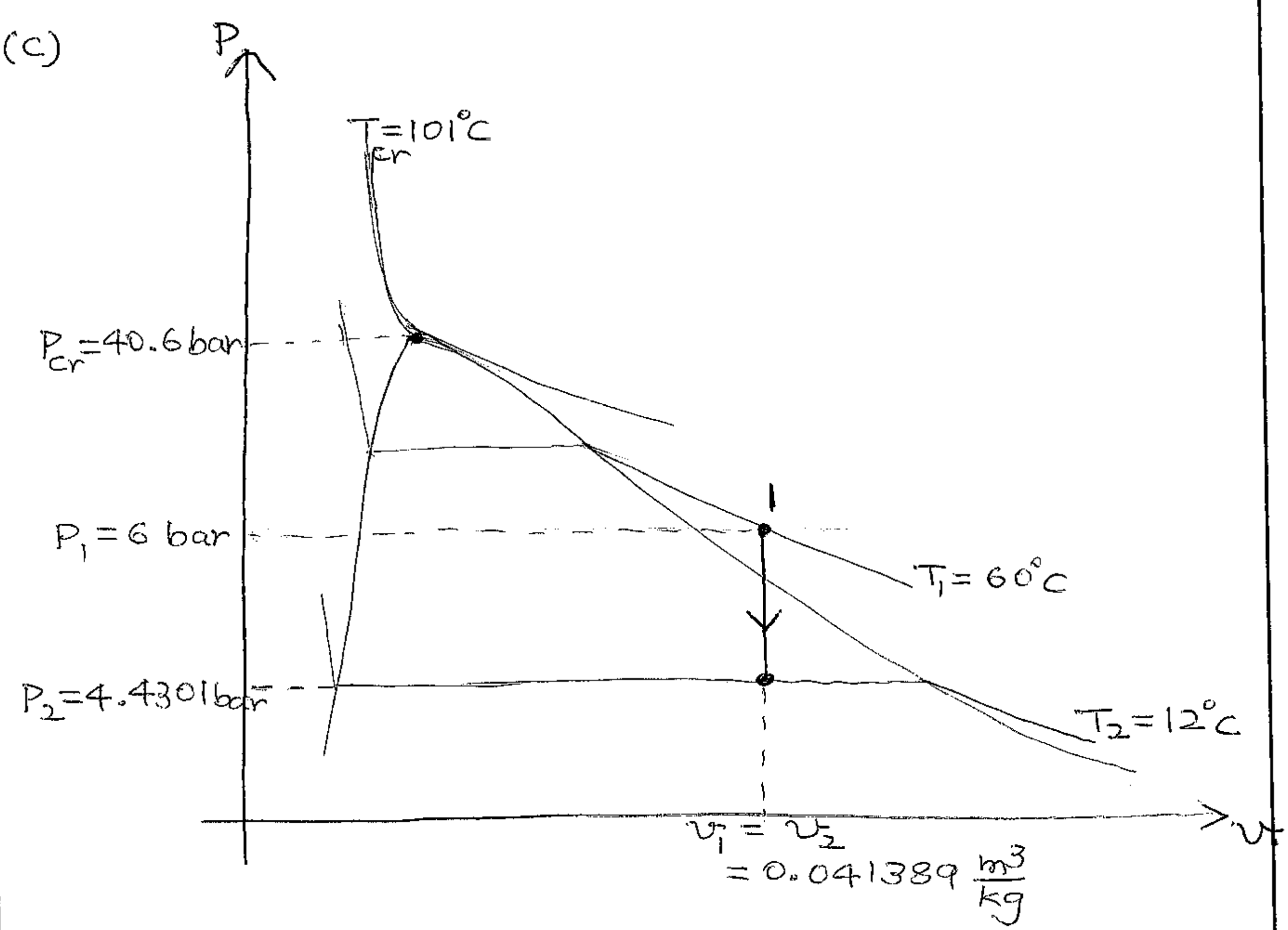
Mass of R-134a in the tank: $m_1 = m_2 = \frac{V}{v_1 = v_2}$

$$m_1 = m_2 = \frac{0.25\ m^3}{0.041389\ \frac{m^3}{kg}} = 6.04\ kg$$

$$Q = -10\ kJ + 6.04\ kg * (218.35 - 275.15)\frac{kJ}{kg}$$

$\Rightarrow \boxed{Q = -353.1\ kJ}$ $Q < 0$ heat transfer out of the system

(c)



Given

Ammonia inside a closed piston-cylinder device undergoing three processes

Find

(a) Polytropic exponent(n) for constant temperature process

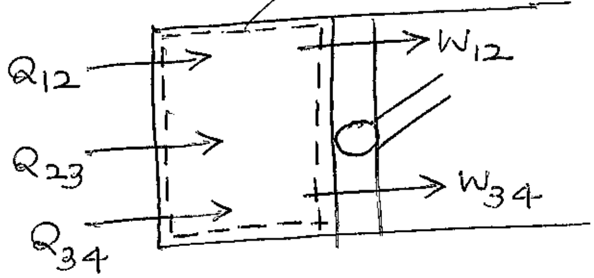
(b) Work (kJ) for each process

(c) Heat transfer (kJ) during each process

(d) T-v diagram

System

~~Water~~ Ammonia substance inside the cylinder is the system



Assumptions

- Closed system (m = constant)
- Quasi-equilibrium process
- Neglect friction between piston and cylinder wall
- Ignore change in KE and PE

Basic Equations

$$W_{boundary} = \int P dV$$

$$Q - W = \Delta E = \Delta U + \overset{no}{\cancel{\Delta KE}} + \overset{no}{\cancel{\Delta PE}}$$

$$\hookrightarrow (W_{boundary} + \overset{0}{\cancel{W_{other}}})$$

Solution

State 1 $\quad P_1 = 20 \text{ bar}, \; T_1 = 40°C$

$T_1 < T_{sat}(P_1) \Rightarrow$ sub-cooled (compressed) liquid

$$v_1 = 0.0017242 \frac{m^3}{kg}$$

$$u_1 = 368.1 \frac{kJ}{kg}$$

State 2 $\quad P_2 = 20 \text{ bar}, \; v_2 = \frac{V_2}{m_2} = 0.042174 \frac{m^3}{kg}$

$v_f(P_2) < v_2 < v_g(P_2) \Rightarrow$ saturated liquid-vapor mixture

$T_2 = T_{sat}(P_2) = 49.351°C$

$$x_2 = \frac{v_2 - v_f(P_2)}{v_g(P_2) - v_f(P_2)} = \frac{0.042174 - 0.0017732}{0.064453 - 0.0017732} = 0.645$$

$$x_2 = \frac{u_2 - u_f(P_2)}{u_g(P_2) - u_f(P_2)} \Rightarrow 0.645 = \frac{u_2 - 414.62}{1343.0 - 414.62}$$

$$u_2 = 1013.4 \ \frac{kJ}{kg}$$

<u>State 3</u> $v_3 = v_2 = 0.042174 \ \frac{m^3}{kg}$, sat. vapor

$P_3 = 30$ bar

$u_3 = u_g(P_3) = 1341.0 \ \frac{kJ}{kg}$

$T_3 = T_{sat}(P_3) = 65.725°C$

<u>State 4</u> $P_4 = 20$ bar, $T_4 = T_3 = 65.725°C$

$T_4 > T_{sat}(P_4) \Rightarrow$ superheated vapor

Interpolating:

$$\frac{v_4 - 0.068754}{0.075952 - 0.068754} = \frac{u_4 - 1372.6}{1421.5 - 1372.6} = \frac{65.725 - 60}{80 - 60}$$

$v_4 = 0.070814 \ \frac{m^3}{kg}$

$u_4 = 1386.6 \ \frac{kJ}{kg}$

(a) For the polytropic constant temperature process:

$$P_3 v_3^n = P_4 v_4^n$$

$$\Rightarrow 30 \text{ bar} * (0.042174)^n = 20 \text{ bar} * (0.070814)^n$$

Solving : $\boxed{n = 0.782}$

(b) Boundary work for each process:

$$W_{12} = \int_{V_1}^{V_2} P \, dV = (P_1 = P_2)(V_2 - V_1) = (m_1 = m_2)(P_1 = P_2)(v_2 - v_1)$$

$$= 10 \text{ kg} * (20 \times 100) \text{ kPa} * (0.042174 - 0.0017242) \ \frac{m^3}{kg}$$

$\boxed{W_{12} = +809\text{ kJ}}$ $W > 0$ work done by the system

$$W_{23} = \int_{V_2}^{V_3} P\,d\cancel{V}^{\,0} \Rightarrow \boxed{W_{23} = 0}$$

$$W_{34} = \int_{V_3}^{V_4} P\,dV = \int_{V_3}^{V_4} \frac{\text{constant}}{V^{0.782}}\,dV = \frac{P_3 V_3 - P_4 V_4}{n-1}$$

n

$$= \frac{(m_3 = m_4)(P_3 v_3 - P_4 v_4)}{n-1}$$

$$= \frac{10\text{ kg}}{(0.782-1)}\left[(30\times100)\text{kPa} * 0.042174\,\frac{m^3}{kg} - (20\times100)\text{kPa} * 0.070814\,\frac{m^3}{kg}\right]$$

$\boxed{W_{34} = +692.9\text{ kJ}}$ $W > 0$ work done by the system

(c) Considering energy balance, heat transfer during the process: $Q = W + \Delta U$

$$Q_{12} = W_{12} + (U_2 - U_1) = W_{12} + (m_1 = m_2)(u_2 - u_1)$$

$$= 809\text{ kJ} + 10\text{ kg} * (1013.4 - 368.1)\,\frac{kJ}{kg}$$

$\boxed{Q_{12} = +7262\text{ kJ}}$ $Q > 0$ heat transfer into the system

$$Q_{23} = \cancel{W_{23}}^{\,0} + (U_3 - U_2) = (m_2 = m_3)(u_3 - u_2)$$

$$= 10\text{ kg} * (1341.0 - 1013.4)\,\frac{kJ}{kg}$$

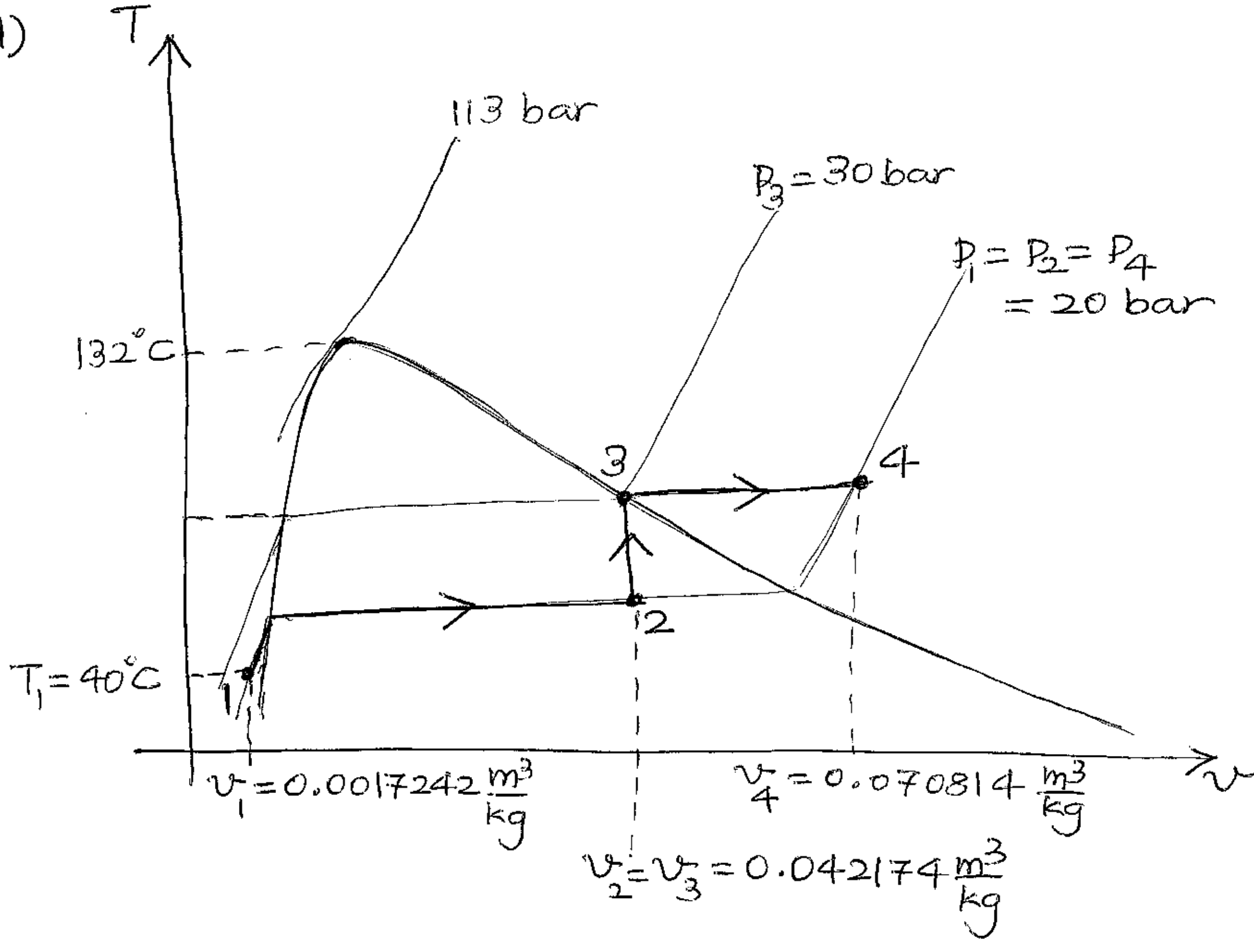
$\boxed{Q_{23} = +3276\text{ kJ}}$ $Q > 0$ heat transfer into the system

$$Q_{34} = W_{34} + (U_4 - U_3) = W_{34} + (m_3 = m_4)(u_4 - u_3)$$

$$= 692.9\text{ kJ} + 10\text{ kg} * (1386.6 - 1341.0)\,\frac{kJ}{kg}$$

$\boxed{Q_{34} = +1148.9\text{ kJ}}$ $Q > 0$ heat transfer into the system

(d)


T
113 bar
P3 = 30 bar
P1 = P2 = P4
= 20 bar
132°C
3
4
2
T1 = 40°C
1
v1 = 0.0017242 m3/kg
v4 = 0.070814 m3/kg
v2 = v3 = 0.042174 m3/kg
v