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# ME 3322A: Thermodynamics: Fall 2014
## Homework Set # 4
## Due Date: September 18, 2014

| | Problem # in Textbook | | Answer |
|---|---|---|---|
| | 7th Ed. | 8th Ed. | |
| 1 | 3.50 | 3.49 | Q/m=-485.5 Btu/lb |
| 2 | 3.53 | 3.54 | $T_2$=50 C, $Q_{12}$/m= 72.91 kJ/kg |
| 3 | 3.59 | 3.60 | a) 79.17 °F; c) 2583 Btu. |
| 4 | 3.70 | 3.71 | Q/m=1704.93 kJ/kg |
| 5 | 3.78 | 3.79 | $Q_{12}$=710.44 Btu, $x_3$=0.103; $W_{34}$=-8.24 Btu; H=0.08 |
| | | | |

# PROBLEM 3.50

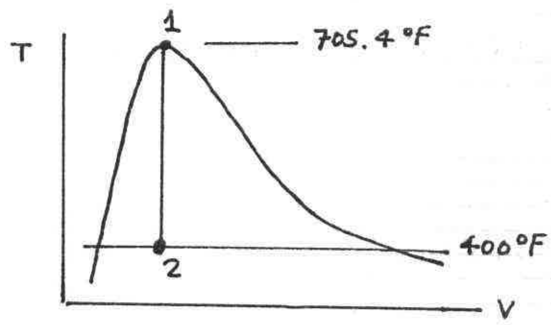
**KNOWN:** A closed, rigid tank is filled with water, initially at the critical point. The water is cooled to a given temperature.

**FIND:** For the water, show the process on a T-v diagram and determine the heat transfer, in Btu/lb.

**SCHEMATIC & GIVEN DATA:**


Initially at the critical point.

Finally at 400°F




**ENGINEERING MODEL**

1. The water in the tank is the closed system.
2. The only energy transfer is by heat.
3. Kinetic and potential energy effects can be ignored.

**ANALYSIS:**

Since the total mass and total volume remain constant, the water undergoes a constant-volume process, as shown in the T-v diagram.

With 2 and 3, the energy balance reduces as follows:

$$\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q - \cancel{W} \Rightarrow Q = \Delta U = m(u_2 - u_1), \text{ or}$$

$$\frac{Q}{m} = u_2 - u_1 \qquad (1)$$

From Table A-2E, $u_1 = 872.6$ Btu/lb

To find $u_2$, first evaluate $x_2$ using $v_2 = v_1 = 0.05053$ ft³/lb.

$$x_2 = \frac{v_2 - v_f}{v_g - v_f} = \frac{0.05053 - 0.01864}{1.866 - 0.01864} = 0.0173 \quad (1.73\%)$$

Table A-2 at 400°F

$$\Rightarrow u_2 = u_f + x_2(u_g - u_f) = 374.3 + (0.0173)(1116.6 - 374.3) = 387.1 \text{ Btu/lb},$$

where $u_f$ and $u_g$ are from Table A-2 at 400°F.

Substituting values into Eq. (1),

$$\frac{Q}{m} = (387.1 - 872.6)\frac{\text{Btu}}{\text{lb}} = -485.5 \text{ Btu/lb}$$

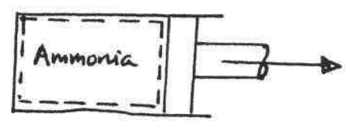
Energy transfer by heat from the water

## PROBLEM 3.53

**KNOWN:** Data are provided for a process of ammonia contained in a piston-cylinder assembly.

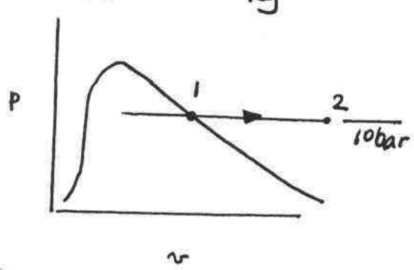
**FIND:** Determine the final temperature and $Q/m$ for the process.

**SCHEMATIC & GIVEN DATA:**




State 1: Sat. vapor at 10 bar.
State 2: $p_2 = 10$ bar

$$\frac{W_{12}}{m} = +16.5 \frac{kJ}{kg}$$




**ENGR. MODEL**

1. The ammonia in the piston-cylinder assembly is the closed system.
2. The expansion occurs at constant pressure.
3. Volume change is the only work mode.
4. Changes in kinetic and potential energy are negligible.

**ANALYSIS:** Two property values are required to fix state 2. One is the pressure and the other is specific volume found from $W_{12}/m$.

$$\frac{W_{12}}{m} = \int_1^2 p\,dv = p(v_2 - v_1)$$

$$\Rightarrow \quad v_2 = \frac{W_{12}/m}{p} + v_1$$

$$= \left(\frac{16.5\ kJ/kg}{10\times10^5\ N/m^2}\right)\left|\frac{10^3\ N\cdot m}{1\ kJ}\right| + 0.1285\ m^3/kg \quad \text{(Table A-15)}$$

$$= 0.1450\ m^3/kg$$

So, from Table A-15 at 10 bar, $v_2 = 0.1450\ m^3/kg$,

$$T_2 = 50°C \qquad \longleftarrow T_2$$

An energy balance reduces to $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q_{12} - W_{12}$, or

$$\frac{Q_{12}}{m} = u_2 - u_1 + \frac{W_{12}}{m}$$

$$= (1391.07 - 1334.66) + 16.5$$

$$= 72.91\ kJ/kg \qquad \longleftarrow Q_{12}/m$$

## PROBLEM 3.59

**KNOWN:** Data are provided for Refrigeration 134a in a closed, rigid tank exposed to solar radiation.

**FIND:** For the process of the refrigerant, determine the initial temperature, final pressure, and $Q$.

**SCHEMATIC & GIVEN DATA:**

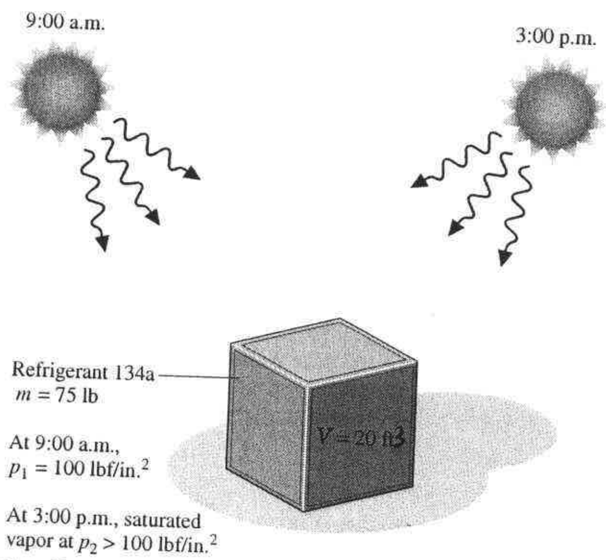
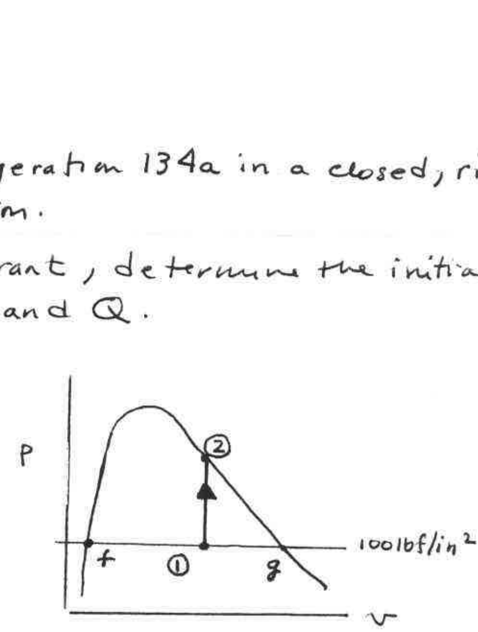



Fig. P3.59




**ENGR. MODEL**

1. The R134a in the tank is the closed system.
2. For the system, $W = 0$.
3. Kinetic and potential energy effects play no role.

**ANALYSIS:** At the initial state, $v_1 = \frac{V}{m} = \frac{20\ \text{ft}^3}{75\ \text{lb}} = 0.2667\ \frac{\text{ft}^3}{\text{lb}}$. Since $v_f < v_1 < v_g$, the initial state is in the two-phase, liquid-vapor region. Further, since mass and volume are each constant, there is no change in specific volume for the process: $v_2 = v_1$.

(a) Since the initial state is a two-phase, liquid-vapor mixture at 100 lbf/in², the initial temperature is the corresponding saturation temperature. From Table A-11E, $T_1 = 79.17°\text{F}$. ← $T_1$

(b) Interpolating in Table A-11E with $v_2 = v_g = 0.2667\ \text{ft}^3/\text{lb}$, we get $p_2 = 174.4\ \text{lbf/in}^2$ and $u_2 = 107.93\ \text{Btu/lb}$. ← $p_2$

(c) Reducing an energy balance $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q_{12} - \cancel{W_{12}}$, we get

$$Q_{12} = m(u_2 - u_1)$$

Finding $u_1$ requires the quality at state 1. That is, with $v_f$ and $v_g$ from Table A-11E at 100 lbf/in²,

$$x_1 = \frac{v_1 - v_f}{v_g - v_f} = \left(\frac{0.2667 - 0.01332}{0.4747 - 0.01332}\right) = 0.549$$

Then,

$$u_1 = u_f + x_1(u_g - u_f) = 36.75 + (0.549)(103.68 - 36.75) = 73.49\ \text{Btu/lb}$$

Finally,

$$Q_{12} = 75\ \text{lb}(107.93 - 73.49)\frac{\text{Btu}}{\text{lb}} = 2583\ \text{Btu}$$

← $Q_{12}$

## PROBLEM 3.70

**KNOWN:** Water contained in a piston-cylinder assembly, initially a two-phase liquid-vapor mixture undergoes two processes in series. State data is provided.

**FIND:** Show the two processes of the water in series on a T-v diagram. For the overall process of the water evaluate the work and heat transfer, each in kJ/kg.

**SCHEMATIC & GIVEN DATA:**

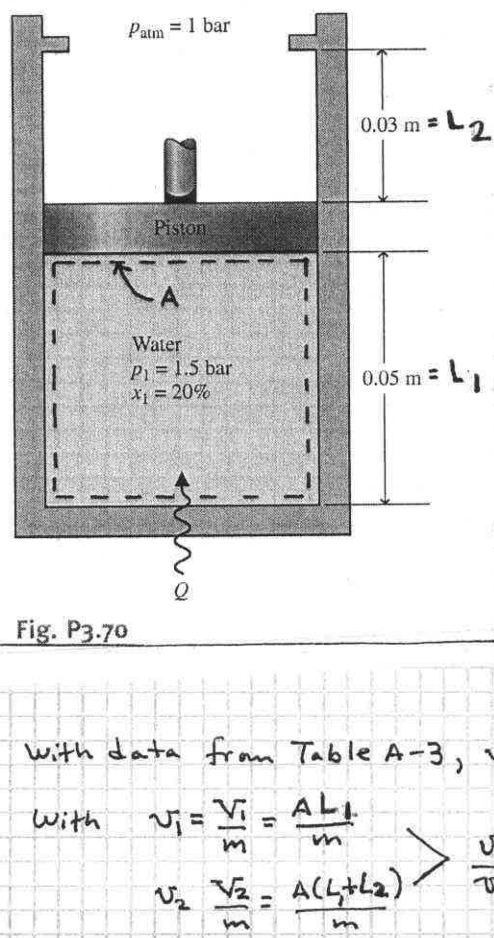
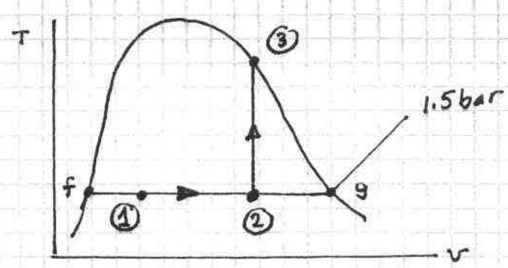



Fig. P3.70




**ENGINEERING MODEL:**

1. The water is the closed system.
2. Volume change is the only work mode.
3. Kinetic and potential energy effects are negligible

**ANALYSIS:** With assumption 2,

$$W = \int_1^3 p\,dV = \int_1^2 p\,dV + \cancel{\int_2^3 p\,dV}^{\,0}$$

$$\Rightarrow \frac{W}{m} = \int_1^2 p\,dv = p(v_2 - v_1) \qquad (1)$$

With data from Table A-3, $v_1 = v_f + x_1(v_g - v_f) = \left(\frac{1.0528}{10^3}\right) + 0.2\left[1.159 - \left(\frac{1.0528}{10^3}\right)\right] = 0.2326\ \frac{m^3}{kg}$

With $v_1 = \frac{V_1}{m} = \frac{AL_1}{m}$, $v_2 = \frac{V_2}{m} = \frac{A(L_1+L_2)}{m}$ $\Big\rangle$ $\frac{v_2}{v_1} = \frac{L_1+L_2}{L_1} = \frac{0.08\text{m}}{0.05\text{m}} \Rightarrow v_2 = \left(\frac{0.08\text{m}}{0.05\text{m}}\right)v_1 = 0.3722\ \frac{m^3}{kg}$

Also, $v_3 = v_2$.

Thus, Eq. (1) gives $\frac{W}{m} = 1.5\text{ bar}\left|\frac{10^5\text{ N/m}^2}{1\text{ bar}}\right|(0.3722 - 0.2326)\frac{m^3}{kg}\left|\frac{1\text{ kJ}}{10^3\text{ N}\cdot\text{m}}\right| = 20.94\ \frac{kJ}{kg}$

Reducing an energy balance, $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = Q - W$, we get

$$Q = W + m(u_3 - u_1) \Rightarrow \frac{Q}{m} = \frac{W}{m} + (u_3 - u_1) \qquad (2)$$

With data from Table A-3, $u_1 = u_f + x_1(u_g - u_f) = 466.94 + 0.2[2519.7 - 466.94] = 877.49\ \frac{kJ}{kg}$

Interpolation in Table A-3 with $v_3 (= v_2) = v_g$, $u_3 = 2561.48$ kJ/kg.

Then, Eq (2) gives

$$\frac{Q}{m} = 20.94\ \frac{kJ}{kg} + (2561.48 - 877.49)\frac{kJ}{kg} = 1704.93\ \frac{kJ}{kg}$$

# PROBLEM 3.78

**KNOWN:** Water contained in a piston-cylinder undergoes a power cycle. State data are provided.

**FIND:** For each process of the cycle, evaluate work and heat transfer, in Btu; also evaluate the thermal efficiency.

**SCHEMATIC & GIVEN DATA:**

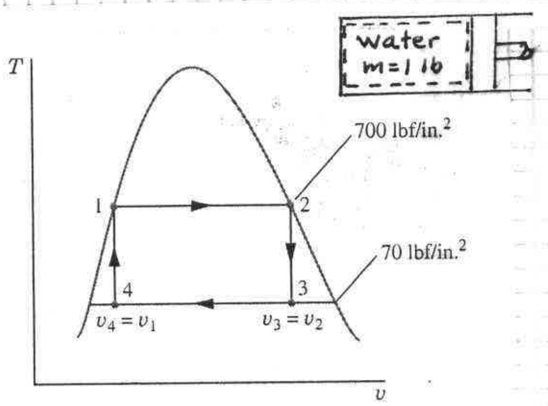



Fig. P3.78

**ENGINEERING MODEL**

1. The water is the closed system.
2. Kinetic and potential effects are ignored.

**ANALYSIS:**

The work for each process is evaluated using $W = \int p\,dV = m\int p\,dv$

**Process 1-2:**

$W_{12} = mp(v_2 - v_1)$. With data from Table A-3E

$$= (1\,lb)\left(700 \times 144 \frac{lbf}{in^2}\right)\underbrace{(0.656 - 0.02051)}_{= 0.63549}\frac{ft^3}{lb}\left|\frac{1\,Btu}{778\,ft\cdot lbf}\right|$$

$$= 82.34\ Btu$$

An energy balance reduces to give

$$Q_{12} = \Delta U + W_{12} = m(u_2 - u_1) + W_{12}$$

$$= 1\,lb(1117 - 488.9)\frac{Btu}{lb} + 82.34\ Btu$$

$$= 710.44\ Btu$$

**Process 2-3:** $W_{23} = 0$. An energy balance reduces to give $Q_{23} = m(u_3 - u_2)$

With $v_3 = v_2$, $x_3 = \dfrac{v_3 - v_f}{v_g - v_f} = \dfrac{0.656 - 0.01748}{6.209 - 0.01748} = 0.1031 \Rightarrow u_3 = u_f + x_3(u_g - u_f)$

$$= 272.6 + 0.1031(1100.6 - 272.6)$$

$$= 357.97\ Btu/lb$$

$$\Rightarrow Q_{23} = (1\,lb)(357.97 - 1117)\frac{Btu}{lb} = -759.03\ Btu$$

**Process 3-4:** $W_{34} = mp(v_4 - v_3)$. With $v_4 = v_1$, $x_4 = \dfrac{v_4 - v_f}{v_g - v_f} = \dfrac{0.02051 - 0.01748}{6.209 - 0.01748}$

$$= 4.89 \times 10^{-4}$$

Noting that $(v_4 - v_3) = [v_f + x_4(v_g - v_f)] - [v_f + x_3(v_g - v_f)]$

$$= (x_4 - x_3)(v_g - v_f)$$

$$W_{34} = mp(x_4 - x_3)(v_g - v_f)$$

$$= (1\,lb)\left(70 \times 144 \frac{lbf}{in^2}\right)(4.89\times10^{-4} - 0.1031)\left(6.1952\frac{ft^3}{lb}\right)\left|\frac{1\,Btu}{778\,ft\cdot lbf}\right| = -8.24\ Btu$$

From an energy balance, $Q_{34} = m(u_4 - u_3) + W_{34}$, $u_4 = u_f + x_4(u_g - u_f) = 273\ Btu$
$(= 272.6 + 4.89\times10^{-4}(828\ Btu/lb))$

Thus, $Q_{34} = (1\,lb)(273 - 357.97)\frac{Btu}{lb} - 8.24\ Btu = -93.21\ Btu$

**PROCESS 4-1:** $W_{41} = 0$. $Q_{41} = m(u_1 - u_4) = 1\,lb\,(488.9 - 273)\frac{Btu}{lb} = 215.9\ Btu$

(1) $$\eta = \frac{\text{Net Work Developed}}{\text{Total Heat Transfer to the system}} = \frac{W_{12} + W_{23} + W_{34} + W_{41}}{Q_{12} + Q_{41}} = \frac{82.34 + (0) + (-8.24) + (0)}{(710.44 + 215.9)} = 0.08\ (8\%)$$

1. For every thermodynamic cycle, Net Work = Net Heat Transfer.

Thus, Net Work $= W_{12} + W_{23} + W_{34} + W_{41} = 74.1\ Btu$

Net Heat Transfer $= Q_{12} + Q_{23} + Q_{34} + Q_{41} = 710.44 + (-759.03) + (-93.21) + 215.9$
$= 74.1\ Btu$ (checks)

Also, note that the net work = Area (1-2-3-4). That is,

$$\text{Net work} = m[p_{12} - p_{34}](v_2 - v_1)$$

$$= (1\,lb)\left[(700 - 70)(144)\frac{lbf}{ft^2}\right]\left[0.63549\frac{ft^3}{lb}\right]\left|\frac{1\,Btu}{778\,ft\cdot lbf}\right| = 74.1\ Btu$$