A piston-cylinder assembly contains 2 lb of water, initially at 100 lbf/in.\(^2\) and 400\(^\circ\)F. The water undergoes two processes in series: a constant pressure process followed by a constant volume process. At the of the constant volume process, the temperature is 300\(^\circ\)F and the water is a two-phase liquid-vapor mixture with a quality of 60%. Neglect kinetic and potential energy effects.

(a) Sketch \(T\-v\) and \(p\-v\) diagrams showing the key states and the processes.
(b) Determine the work and heat transfer for each process, all in Btu.

**KNOWN:** Water contained in a piston-cylinder assembly undergoes two processes in series.

**FIND:** Sketch the \(T\-v\) and \(p\-v\) diagrams and for each process determine \(Q\) and \(W\).

**SCHEMATIC AND GIVEN DATA:**

![Diagram of the processes](image)

**ENGINEERING MODEL:**
1. The water is a closed system.
2. Volume change is the only work mode.
3. Process 1-2 occurs at constant pressure and Process 2-3 occurs at constant volume.
4. Kinetic and potential energy effects can be neglected.

**ANALYSIS:** First, we fix each state. State 1 is in the superheated vapor region. From Table A-4E; \(v_1 = 4.934\) ft\(^3\)/lb and \(u_1 = 1136.2\) Btu/lb.

With \(T_3 = 300\)\(^\circ\)F and \(x_3 = 0.6\), we can evaluate \(v_3\) and \(u_3\) using data from Table A-2E at 300\(^\circ\)F as follows.

\[
v_3 = v_{f3} + x_3(v_{g3} - v_{f3}) = 0.01745 + (0.6)(6.472 - 0.01745) = 3.89\ ft^3/lb
\]

\[
u_3 = u_{f3} + x_3(u_{g3} - u_{f3}) = 269.5 + (0.6)(1100.0 - 269.5) = 767.8\ \text{Btu/lb}
\]

Note that \(v_2 = v_3 = 3.89\ ft^3/lb\), and from Table A-3E we see that \(v_2 < v_g(100\ \text{lbf/in.}^2)\). Thus

\[
x_2 = \frac{v_2 - v_{f2}}{v_{g2} - v_{f2}} = \frac{3.89 - 0.01774}{4.434 - 0.01774} = 0.8768
\]
and 
\[ u_2 = u_{12} + x_2(u_{g2} - u_{t2}) = 298.3 + (0.8768)(1105.8 - 298.3) = 1006.3 \text{ Btu/lb} \]

Now, for Process 1-2 the pressure is constant. Thus

\[ W_{12} = \int_1^2 p\,dV = m p_1 (v_2 - v_1) = (2 \text{ lb}) \left( 100 \frac{\text{lbf}}{\text{in}^2} \right) (3.89 - 4.934) \frac{\text{ft}^3}{\text{lb}} \frac{144 \text{ in}^2}{1 \text{ ft}^2} \frac{1 \text{ Btu}}{778 \text{ ft-lbf}} \]
\[ = -38.65 \text{ Btu (in)} \]

An energy balance reduces to give

\[ Q_{12} = m(u_2 - u_1) + W_{12} = (2 \text{ lb})(1006.3 - 1136.2) \text{ Btu/lb} + (-38.65 \text{ Btu}) = -298.5 \text{ Btu (out)} \]

Now, for Process 2-3, the volume is constant, so \( W_{23} = 0 \)

And, the energy balance reduces to give

\[ Q_{23} = m(u_3 - u_2) = (2 \text{ lb})(767.8 - 1006.3) \text{ Btu/lb} = -477 \text{ Btu (out)} \]

REVISED 12-14
**PROBLEM 3.130**

**KNOWN:** Data are provided for air on one side of a rigid container. The other side of the container is initially evacuated.

**FIND:** For the air, determine the final temperature and Q.

**SCHEMATIC & GIVEN DATA:**

![Diagram of system with initial and final conditions](image)

Initially:
- \( V_1 = 0.2 \text{ m}^3 \)
- \( p_1 = 5 \text{ bar} \)
- \( T_1 = 500 \text{ K} \)

Finally:
- \( V_2 = 2V_1 \)
- \( p_2 = \frac{4}{3}p_1 \)

**ENERG. MODEL:**
1. The closed system is the region within the container, ignoring the partition.
2. The air is modeled as an ideal gas.
3. There are no overall changes in kinetic or potential energy.
4. \( W = 0 \).

**ANALYSIS:**

(a) Using the ideal gas model in an unchanging state, \( p_1 V_1 = mRT_1 \), \( p_2 V_2 = mRT_2 \). Thus,

\[
T_2 = T_1 \left( \frac{p_2 V_2}{p_1 V_1} \right) = \frac{500 \text{ K} \left[ \frac{4}{3} \right]^2}{2} = 250 \text{ K} \]

(b) An energy balance reduces to \( \Delta U + \Delta KE + \Delta PE = Q - W \), m

\[
Q = m \left( U(T_2) - U(T_1) \right)
\]

Where

\[
m = \frac{p_1 V_1}{RT_1} = \left( \frac{5 \times 10^5 \text{ Pa} \cdot \text{m}^3}{83.14 \text{ J} / \text{K} \cdot \text{mol}} \right) \left( 0.2 \text{ m}^3 \right) = 0.7 \text{ kg}
\]

So, with data from Table A-21

\[
Q = 0.7 \text{ kg} \cdot (178.28 - 335.49) \text{ J} / \text{kg}
\]

\[
= -126.8 \text{ kJ}
\]