Example

A closed system contains 0.15 kg of water. Initially the water is a saturated vapor at 205°C. The water is cooked at constant volume until the temperature is 150°C and is then compressed at constant temperature until the volume is half the original value.

a) Sketch the P-v diagram for this two-step process.
b) Find the work in or out of the steam for each step.
c) Find the heat transfer in or out of the steam for each step.

\[ W_{12} = -\int_{1}^{2} P \, dv = 0 \]

\[ W_{23} = -\int_{2}^{3} P \, dv = -m \int_{2}^{3} P \, dv = -mP \int_{2}^{3} dv = -m (v_3 - v_2) \]

**Properties**

(1) \( T_1 = 205°C \)
\( u_1 = u_g (205°C) = 0.11521 \, \text{m}^3/\text{kg} \)
\( P_1 = P_{SAT} = 1.723 \, \text{MPa} \)

(2) \( T_2 = 150°C \)
\( P_2 = P_{SAT} = 0.4758 \, \text{MPa} \)
\( v_2 = u_1 = 0.11521 \)

(3) \( T_3 = 150°C \)
\( v_3 = v_2/2 = 0.05761 \, \text{m}^3/\text{kg} \)
\( u_1 < u_3 < u_g \Rightarrow \text{still a mixture} \)

\[ W_{23} = -(0.15 \, \text{kg})(475.8 \, \text{kPa})(0.05761 - 0.11521) \, \text{m}^3/\text{kg} \times \frac{\text{kPa} \cdot \text{m}^3}{\text{kJ}} \]

\[ = 4.11 \, \text{kJ} \]
(c) USE CONSERVATION OF ENERGY

CLOSED SYS., FINITE TIME

\[ E_2 - E_1 = Q_{12} + W_{12} \]

\[ U_2 - U_1 = Q_{12} \quad \text{(NO KE, PE)} \]

\[ m(u_2-u_1) = Q_{12} \quad (1) \]

TO FIND \( X_2 \):

\[ U_2 = (1 - X_2) U_f + X_2 U_g = (1 - X_2)(0.001009 \text{ M}^3) + X_2 (0.3928) \text{ M}^3/\text{kg} \]

\[ = 0.11521 \text{ M}^3/\text{kg} \]

\[ \Rightarrow X_2 = 0.2913 \]

\[ U_2 = (1 - 0.2913) 631.68 + (0.2913) (255.5) \]

\[ = 1193.3 \text{ KJ/kg} \]

(1) BECOMES

\[ Q_{12} = (0.15 \text{ kg}) (1193.3 - 2597.5) \text{ KJ} = -210.6 \text{ KJ/kg} \]

\[ = 210.6 \text{ KJ OUT} \]

CLOSED SYS., FINITE TIME

\[ E_3 - E_2 = Q_{23} + W_{23} \]

\[ U_3 - U_2 = Q_{23} + W_{23} \]

\[ m(u_3-u_2) = Q_{23} + W_{23} \]

\[ Q_{23} = m(u_3 - u_2) + W_{23} \]
EVEN MORE PROPERTIES

\[ U_3 = (1 - x_3) U_f + x_3 U_g \]

\[ 0.05261 = (1 - x_3) (0.001091) + x_3 (0.3928) \]

\[ \Rightarrow x_3 = 0.1443 \]

\[ U_3 = (1 - x_3) U_f + x_3 U_g = (1 - 0.1443) (631.68) + 0.1443 (25585) \]

\[ = 909.8 \text{ kJ/kg} \]

\[ Q_{23} = (0.15 \text{ kg})(909.8 - 1193.3) \frac{\text{kJ}}{\text{kg}} - 4.11 \text{ kJ} \]

\[ = -4.66 \text{ kJ} = \boxed{4.66 \text{ kJ OUT}} \]