PROBLEM 3.70

KNOWN: Data are provided for water in a piston-cylinder assembly undergoing two processes in series: constant-pressure followed by constant-volume.

FIND: For the overall process find W and Q.

SCHEMATIC & GIVEN DATA:

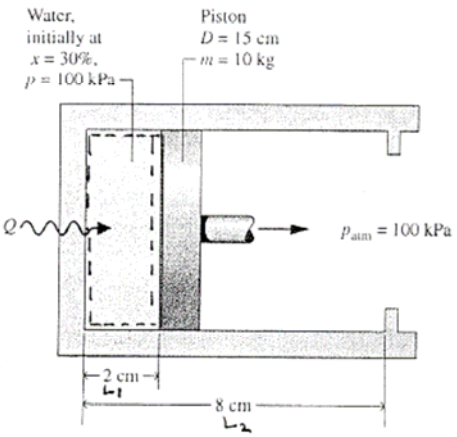
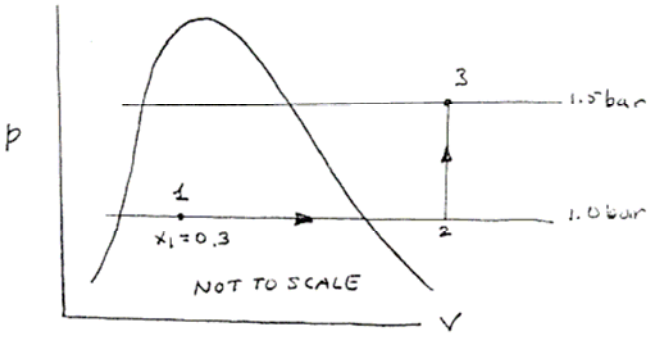


Fig. P3.70



ENGR. MODEL:

1. The water in the piston-cylinder assembly is the system.
2. Friction and kinetic and potential energy effects are absent. The piston is not accelerated during the process.
3. Volume change is the only work mode.

ANALYSIS:

Since volume change is the only work mode, work can be evaluated from Eq. 2.17. Thus

$$W_{12} = \int_1^2 p\,dV = p[V_2 - V_1] \qquad (1)$$

Note that $W_{23} = 0$ because there is no piston motion (volume is constant).

An energy balance for the overall process reads.

$$(U_3 - U_1) + \cancel{\Delta KE} + \cancel{\Delta PE} = Q_{13} - W_{13} \Rightarrow Q_{13} = m(u_3 - u_1) + \underbrace{W_{13}}_{=W_{12}} \qquad (2)$$

Need V_1, V_2, m, u_1, u_3

$$\Rightarrow V_1 = \frac{\pi D^2}{4} L_1 = \frac{\pi (0.15\text{m})^2}{4}(0.02\text{m}) = 3.53 \times 10^{-4}\,\text{m}^3$$

$$\Rightarrow V_2 = \frac{\pi D^2}{4} L_2 = \frac{\pi (0.15\text{m})^2}{4}(0.08\text{m}) = 1.414 \times 10^{-3}\,\text{m}^3$$

with data from Table A-3,

$$v_1 = v_f + x(v_g - v_f) = \frac{1.0432}{10^3} + 0.3\left[1.694 - \frac{1.0432}{10^3}\right] = 0.50893\ \text{m}^3/\text{kg}$$

$$\Rightarrow m = \frac{V_1}{v_1} = 6.94 \times 10^{-4}\,\text{kg}$$

$$u_1 = u_f + x(u_g - u_f) = 417.36 + 0.3(2506.1 - 417.36) = 1043.98\ \frac{\text{kJ}}{\text{kg}} \Leftarrow$$

$$v_3 = v_2 = \frac{V_2}{m} = \frac{1.414 \times 10^{-3}}{6.94 \times 10^{-4}} = 2.037\ \frac{\text{m}^3}{\text{kg}}.$$ Interpolating in Table A-4 at 1.5 bar, $u_3 = 2952.1\ \frac{\text{kJ}}{\text{kg}} \Leftarrow$

Using Eq. (1),

$$W_{12} = p[V_2 - V_1] = (1\text{ bar})\left|\frac{10^5\,\text{N/m}^2}{1\text{ bar}}\right|(14.14 - 3.53)\times 10^{-4}\,\text{m}^3\left|\frac{1\text{ kJ}}{10^3\,\text{N}\cdot\text{m}}\right| = 0.106\text{ kJ} \longleftarrow W$$

Using Eq. (2)

$$Q_{13} = m(u_3 - u_1) + W_{13} = (6.94 \times 10^{-4}\text{kg})(2952.1 - 1043.98)\frac{\text{kJ}}{\text{kg}} + 0.106\text{kJ} = 1.324 + 0.106 = 1.43\text{ kJ} \longleftarrow Q$$