Five kg of water is contained in a piston-cylinder assembly, initially at 5 bar (abs) and 240 °C. The water is slowly heated at constant pressure to a final state. If the heat transfer into the water for the process is 2960 kJ, determine the temperature at the final state, in °C, and the work done by the water on the piston, in kJ. Kinetic and potential energy effects are negligible.

SOLUTION:

Apply the First Law to the water in the piston,

$$\Delta E_{\text{H2O}} = Q_{\substack{\text{into}\\ \text{H2O}}} - W_{\substack{\text{by}\\ \text{H20}}}\,, \tag{1}$$

where

$$\Delta E_{\text{H2O}} = \Delta U_{\text{H2O}} = m(u_2 - u_1). \tag{2}$$

The specific internal energy at the initial state (state 1) may be found from the thermodynamic tables for water at p_1 = 5 bar (abs) and T_1 = 240 °C. Note that saturation temperature for liquid water at 5 bar (abs) is 151.83 °C; hence, the water must be in the superheated vapor region since T_1 is greater than the saturation temperature. Using the SHV table,

u_1 = 2707.9 kJ/kg,
v_1 = 0.46467 m^3/kg,
h_1 = 2940.2 kJ/kg.

The work done by the water on the piston is,

$$W_{\text{by H2O}} = \int_{V_1}^{V_2} p\,dV = p(V_2 - V_1) = pm(v_2 - v_1)\,, \tag{3}$$

where the pressure is constant ($p_1 = p_2$ = 5 bar (abs)) throughout the process. Substituting into Eq. (1),

$$m(u_2 - u_1) = Q_{\substack{\text{into}\\ \text{H2O}}} - pm(v_2 - v_1)\,, \tag{4}$$

$$m(u_2 + p_2 v_2 - u_1 - p_1 v_1) = Q_{\substack{\text{into}\\ \text{H2O}}}\,, \tag{5}$$

$$m(h_2 - h_1) = Q_{\substack{\text{into}\\ \text{H2O}}}\,, \tag{6}$$

$$h_2 = h_1 + \frac{Q_{\substack{\text{into}\\ \text{H2O}}}}{m}\,, \tag{7}$$

where h is the specific enthalpy of the water. Substituting values,

h_1 = 2940.2 kJ/kg
Q_{into} = 2960 kJ
m = 5 kg
$\Rightarrow h_2$ = 3532.2 kJ/kg

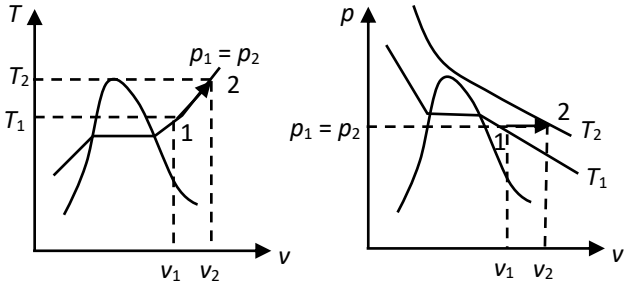
From the thermodynamic two-phase liquid-vapor table for water at p_2 = 5 bar (abs), the saturated vapor specific enthalpy is 2748.1 kJ/kg, which is smaller than h_2. Hence, the water at state 2 will be in the superheated vapor state. Using the thermodynamic superheated vapor table with h_2 and p_2, and interpolating,

$\boxed{T_2 = 522\ ^\circ\text{C}}$
v_2 = 0.7313 m^3/kg

Using Eq. (3) and the values for v_1, v_2, m, and p,

$\boxed{W_{\text{by H2O}} = 667\ \text{kJ}}$

Sketches of the process on T-v and p-v plots are shown.



SLVM Table for H2O

		Liquid				Vapor			
Press. (bar)	Temp. (C)	Volume (v_f, m^3/kg)	Internal Energy (u_f, kJ/kg)	Enthalpy (h_f, kJ/kg)	Entropy (s_f, kJ/kg/K)	Volume (v_g, m^3/kg)	Internal Energy (u_g, kJ/kg)	Enthalpy (h_g, kJ/kg)	Entropy (s_g, kJ/kg/K)
5	151.83	0.0010925	639.54	640.09	1.8604	0.37481	2560.7	2748.1	6.8207

SHV Table for H2O

Temp. (C)	Volume (m^3/kg)	Internal Energy (kJ/kg)	Enthalpy (kJ/kg)	Entropy (kJ/kg/K)
	p = 5.0 bar = 0.50 MPa, T_{sat} = 151.83°C			
Sat.	0.37481	2560.7	2748.1	6.8207
180	0.40466	2610.1	2812.4	6.9673
200	0.42503	2643.3	2855.8	7.0610
240	0.46467	2707.9	2940.2	7.2322
280	0.50344	2771.5	3023.2	7.3880
320	0.54169	2835.1	3105.9	7.5323
360	0.57961	2899.1	3188.9	7.6677
400	0.61730	2963.7	3272.3	7.7955
440	0.65484	3029.1	3356.6	7.9170
500	0.71094	3129.0	3484.5	8.0892
600	0.80409	3300.4	3702.5	8.3543
700	0.89696	3478.5	3927.0	8.5977