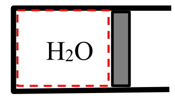
One kilogram of water contained in a piston-cylinder assembly, initially at 160 °C, 150 kPa (abs), undergoes an isothermal compression process to saturated liquid. For the process, the work done by the water is -471.5 kJ. Determine for the process:

a. the heat transfer into the water, and
b. the change in entropy of the water.

SOLUTION:

The heat transfer into the water may be found from the 1st Law:



$$\Delta E_{sys} = Q_{\underset{sys}{into}} - W_{\underset{sys}{by}} \Rightarrow Q_{\underset{sys}{into}} = \Delta E_{sys} + W_{\underset{sys}{by}}, \quad (1)$$

where $\Delta E_{sys} = \Delta U$ (neglected changes in kinetic and potential energy) and $W_{by\ sys}$ = -471.5 kJ. The change in internal energy is,

$$\Delta U = m(u_2 - u_1), \quad (2)$$

where,

m = 1 kg

u_1 = 2595.2 kJ/kg (@ 160 °C, 150 kPa = 1.5 bar ⇒ superheated vapor; found from Table A-4 in Moran et al., 7th ed.)

u_2 = 674.86 kJ/kg (saturated liquid at 160 °C; from Table A-2 in Moran et al., 7th ed.)

Thus,

ΔU = -1920.34 kJ,

$\boxed{Q_{into} = -2390 \text{ kJ}}$ (heat leaves the water).

The change in the water's entropy may be found using the thermodynamic tables.

s_1 = 7.4665 kJ/(kg.K) (@160 °C, 150 kPa = 1.5 bar ⇒ superheated vapor; found from Table A-4 in Moran et al., 7th ed.)

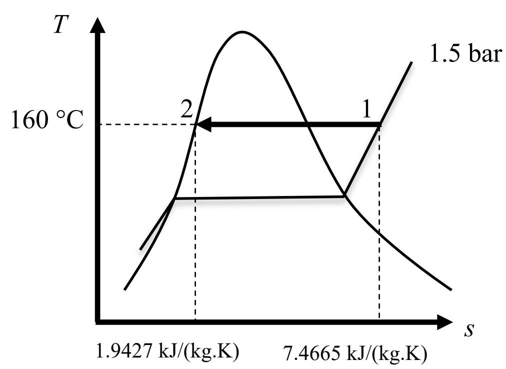
s_2 = 1.9427 kJ/(kg.K) (saturated liquid at 160 °C; from Table A-2 in Moran et al., 7th ed.)

Thus,

$S_2 - S_1 = m(s_2 - s_1)$,

$\Rightarrow \boxed{S_2 - S_1 = -5.5238 \text{ kJ/K}}$.

A plot of the process on a *T*-*s* diagram is shown in the following figure.



Although not specifically asked for, we can check to see if this process is internally reversible by checking to see if the entropy production term is zero,

$$S_2 - S_1 = \int_{1,b}^{2} \frac{\delta Q_{\text{into}}}{T} + \sigma_{12} \Rightarrow \sigma_{12} = S_2 - S_1 - \int_{1,b}^{2} \frac{\delta Q_{\text{into}}}{T}, \tag{3}$$

Since the process is isothermal, T remains constant so that we can write the previous equation as,

$$\sigma_{12} = S_2 - S_1 - \frac{Q_{\text{into},12}}{T}. \tag{4}$$

Substituting the values,

$S_2 - S_1 =$ -5.5238 kJ/K,
$Q_{\text{into},12}$ = -2392 kJ,
T = 160 °C = 433 K,
=> $\sigma_{12} = 4.5 * 10^{-4}$ kJ/K,

which is close enough to zero (within numerical error) for the process to be considered internally reversible.