Given and Required: $\mathrm{kJ} := 1000\mathrm{J}$

Determine the work input required to compress steam isentropically from 100 kPa to 1 MPa, assuming that the steam exists as

(a) saturated liquid and

(b) as saturated vapor.

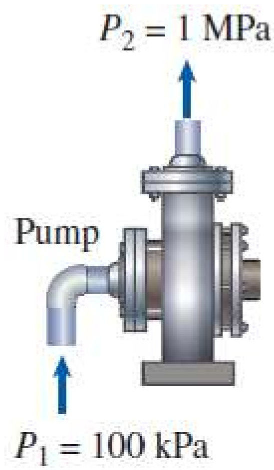
$P_1 := 100\mathrm{kPa} \qquad P_2 := 1\mathrm{MPa}$

Solution:

For the saturated liquid, the required work will be given by

$$w_{rev,in} = \int_1^2 \nu\, dP = \nu \cdot (P_2 - P_1)$$

Note: This assumes the liquid is incompressible.



Going to Table A-5 @ $P_1 = 100 \cdot \mathrm{kPa}$ shows

$$\nu_1 := 0.001043 \frac{m^3}{kg}$$

The required work is then found by

$$\boxed{w_{rev,in} := \nu_1 \cdot (P_2 - P_1) = 0.9387 \cdot \frac{kJ}{kg}} \quad \text{(a)}$$

For the saturated vapor, the required work is still given by

$$w_{rev,in} = \int_1^2 \nu\, dP$$

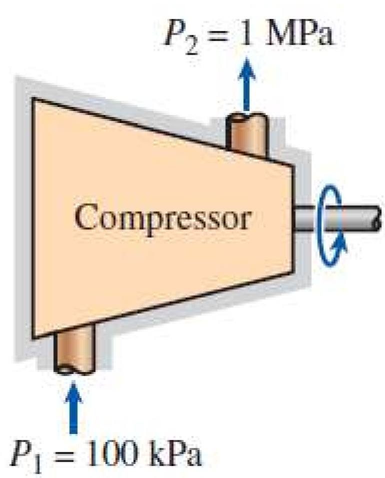
However, this time the specific volume is does not remain constant. If the Tds relation below is inspected, it may be seen that the following is true when dealing with an isentropic process (i.e. ds=0).

$$T \cdot ds = dh - \nu \cdot dP$$

$$dh = \nu \cdot dP$$

The required work may now be defined as

$$w_{rev,in} = \int_1^2 \nu\, dP = \int_1^2 1\, dh = h_2 - h_1$$



Going to Table A-5 @ $P_1 = 100 \cdot \mathrm{kPa}$ shows

$$h_1 := 2675.0 \frac{kJ}{kg} \qquad s_1 := 7.3589 \frac{kJ}{kg \cdot K}$$

Since the process is isentropic, the following is true.

$$s_2 := s_1 = 7.359 \cdot \frac{kJ}{kg \cdot K}$$

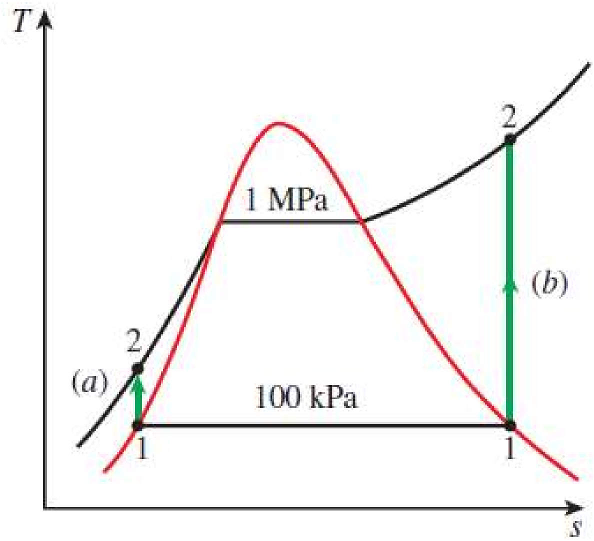
Solution (contd.):

Going to Table A-6 @ $P_2 = 1 \cdot MPa$ & $s_2 = 7.359 \frac{kJ}{kg \cdot K}$ shows interpolation is needed. This is shown below.

$s_a := 7.3029 \cdot \frac{kJ}{kg \cdot K}$ $\quad$ $s_b := 7.4670 \frac{kJ}{kg \cdot K}$

$h_a := 3158.2 \frac{kJ}{kg}$ $\quad$ $h_b := 3264.5 \frac{kJ}{kg}$

$$h_2 := \frac{s_2 - s_a}{s_b - s_a} \cdot (h_b - h_a) + h_a = 3194.5 \cdot \frac{kJ}{kg}$$



The required work may then be found by

$$\boxed{w_{rev,in} := h_2 - h_1 = 519.5 \cdot \frac{kJ}{kg}} \quad \text{(b)}$$

__Notes about the solution__

Notice that it takes approximately 500 times more energy to compress a gas (vapor) than a liquid.

This is why it is important to condense steam into a liquid during a heat engine process. Not only do gas bubbles damage the pump, but liquids require less power to compress (or pressurize).

The opposite is true for turbines. The expansion of gas in a turbine yields more energy than liquid flowing through a turbine.

This is why a steam power plant can generate as much electricity as a hydroelectric power plant. The hydroelectric dam requires much more water to generate the same amount of power. The one drawback for steam power plants is that you need a heat source to generate steam.