Given:

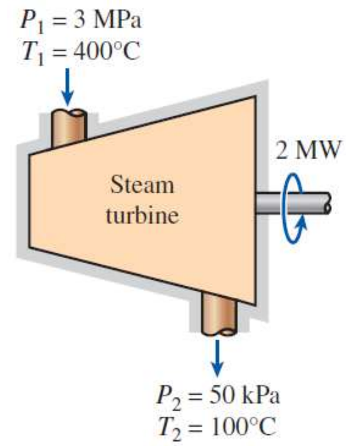
Steam enters an adiabatic turbine steadily at 3 MPa and 400°C and leaves at 50 kPa and 100°C.

$P_1 := 3\ \text{MPa} \qquad T_1 := 400\ °\text{C} = 673.15\ \text{K} \qquad P_2 := 50\ \text{kPa} \qquad T_2 := 100\ °\text{C} = 373.15\ \text{K}$

Required:

If the power output of the turbine is 2 MW, determine the isentropic efficiency and the mass flow rate of the steam.

Solution:



The power output of the turbine is defined as

$$W'_{out} := 2\ \text{MW}$$

The isentropic efficiency is given by

$$\eta_T = \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

Going to Table A-5 @ $P_1 = 3000\ \text{kPa}$ shows

$$T_{sat} := 233.85\ °\text{C}$$

Since $T_1 > T_{sat}$ the state is superheated. Going to Table A-6 @ $P_1 = 3.000\ \text{MPa}$ and $T_1 = 400.0\ °\text{C}$ shows

$$h_1 := 3231.7\ \frac{\text{kJ}}{\text{kg}} \qquad s_1 := 6.9235\ \frac{\text{kJ}}{\text{kg K}}$$

Going to Table A-4 @ $T_2 = 100.0\ °\text{C}$ shows

$$P_{sat} := 101.42\ \text{kPa}$$

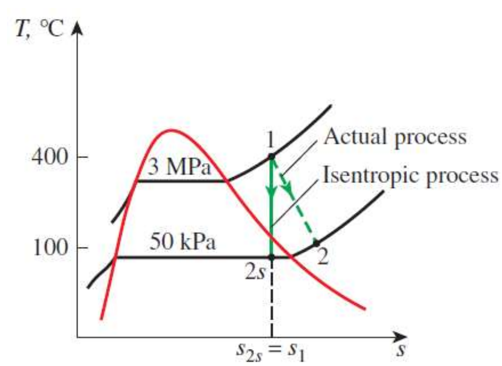
Since $P_2 < P_{sat}$ the stae is superheated. Going to Table A-6 @ $T_2 = 100.0\ °\text{C}$ and $P_2 = 0.05\ \text{MPa}$ shows

$$h_{2a} := 2682.4\ \frac{\text{kJ}}{\text{kg}}$$

The enthalpy h_{2s} is the final state of an isentropic process. Thus

$$s_{2s} := s_1 = 6.924\ \frac{\text{kJ}}{\text{kg K}}$$

Going to Table A-5 @ $P_2 = 50.00\ \text{kPa}$ and $s_{2s} = 6.924\ \frac{\text{kJ}}{\text{kg K}}$ shows



$$s_f := 1.0912\ \frac{\text{kJ}}{\text{kg K}} \qquad s_g := 7.5931\ \frac{\text{kJ}}{\text{kg K}}$$

$$h_f := 340.54\ \frac{\text{kJ}}{\text{kg}} \qquad h_g := 2645.2\ \frac{\text{kJ}}{\text{kg}}$$

$$x_{2s} := \frac{s_{2s} - s_f}{s_g - s_f} = 0.897$$

$$h_{2s} := h_f + x_{2s} \cdot \left(h_g - h_f\right) = 2408\ \frac{\text{kJ}}{\text{kg}}$$

Thus the isentropic efficiency is

$$\boxed{\eta_T := \frac{h_1 - h_{2a}}{h_1 - h_{2s}} = 66.68\ \%}$$

Solution (contd.):
1st Law for a steady state adiabatic turbine with negligible changes in KE and PE shows

$$\frac{d}{d\,t} E_{sys} = \Sigma E'_{in} - \Sigma E'_{out}$$

$$0 = m'_{in} \cdot \left(h_{in} + \frac{V_{in}^{\;2}}{2} + g_e \cdot z_{in} \right) - m'_{out} \cdot \left(h_{out} + \frac{V_{out}^{\;2}}{2} + g_e \cdot z_{out} \right) - W'_{out}$$

$$0 = m'_{in} \cdot h_{in} - m'_{out} \cdot h_{out} - W'_{out}$$

Since the turbine has a single inlet and outlet mass stream, the mass flow rates are the same. Thus

$$0 = m' \cdot \left(h_{in} - h_{out} \right) - W'_{out}$$

$$\boxed{m' := \frac{W'_{out}}{h_1 - h_{2a}} = 3.641\ \frac{\mathrm{kg}}{\mathrm{s}}}$$