

Given:

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

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

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

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

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

$$T_{sat} := 233.85 \text{ }^{\circ}\text{C}$$

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

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

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

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

Since $P_2 < P_{sat}$ the state is superheated. Going to Table A-6 @ $T_2 = 100.0 \text{ }^{\circ}\text{C}$ 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

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

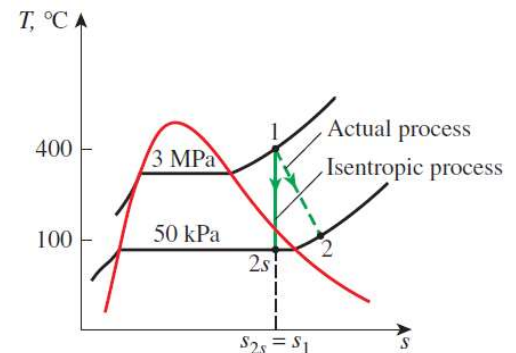
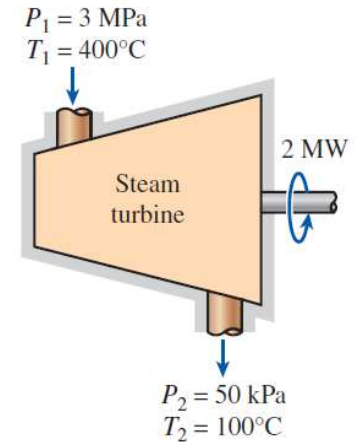
$$h_f := 340.54 \frac{\text{kJ}}{\text{kg}} \quad h_g := 2645.2 \frac{\text{kJ}}{\text{kg}}$$

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

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

Thus the isentropic efficiency is

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



Solution (contd.):

1st Law for a steady state adiabatic turbine with negligible changes in KE and PE shows

$$\frac{d}{dt} E_{sys} = \Sigma E'_{in} - \Sigma E'_{out}$$

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

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

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

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

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