

8-61 Steam expands in a turbine from a specified state to another specified state. The actual power output of the turbine is given. The reversible power output and the second-law efficiency are to be determined.

Assumptions 1 This is a steady-flow process since there is no change with time. **2** Potential energy change is negligible. **3** The temperature of the surroundings is given to be 25°C.

Properties From the steam tables (Tables A-4 through A-6)

$$\left. \begin{array}{l} P_1 = 6 \text{ MPa} \\ T_1 = 600^\circ\text{C} \end{array} \right\} \begin{array}{l} h_1 = 3658.8 \text{ kJ/kg} \\ s_1 = 7.1693 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left. \begin{array}{l} P_2 = 50 \text{ kPa} \\ T_2 = 100^\circ\text{C} \end{array} \right\} \begin{array}{l} h_2 = 2682.4 \text{ kJ/kg} \\ s_2 = 7.6953 \text{ kJ/kg} \cdot \text{K} \end{array}$$

Analysis (b) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{\text{system}}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}}^{\text{no (steady)}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

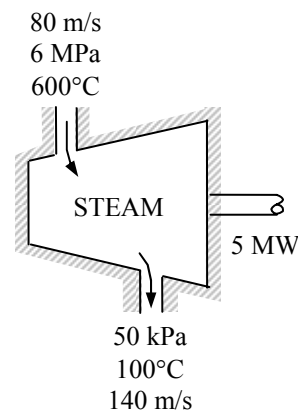
$$\dot{m}(h_1 + V_1^2/2) = \dot{W}_{\text{out}} + \dot{m}(h_2 + V_2^2/2)$$

$$\dot{W}_{\text{out}} = \dot{m} \left[h_1 - h_2 + \frac{V_1^2 - V_2^2}{2} \right]$$

Substituting,

$$5000 \text{ kJ/s} = \dot{m} \left(3658.8 - 2682.4 + \frac{(80 \text{ m/s})^2 - (140 \text{ m/s})^2}{2} \left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right) \right)$$

$$\dot{m} = 5.156 \text{ kg/s}$$



The reversible (or maximum) power output is determined from the rate form of the exergy balance applied on the turbine and setting the exergy destruction term equal to zero,

$$\underbrace{\dot{X}_{\text{in}} - \dot{X}_{\text{out}}}_{\text{Rate of net exergy transfer by heat, work, and mass}} - \underbrace{\dot{X}_{\text{destroyed}}}_{\text{Rate of exergy destruction}}^{\text{no (reversible)}} = \underbrace{\Delta \dot{X}_{\text{system}}}_{\text{Rate of change of exergy}}^{\text{no (steady)}} = 0$$

$$\dot{X}_{\text{in}} = \dot{X}_{\text{out}}$$

$$\dot{m}\psi_1 = \dot{W}_{\text{rev,out}} + \dot{m}\psi_2$$

$$\dot{W}_{\text{rev,out}} = \dot{m}(\psi_1 - \psi_2) = \dot{m}[(h_1 - h_2) - T_0(s_1 - s_2) - \Delta \text{ke} - \Delta \text{pe}]^{\text{no}}$$

Substituting,

$$\begin{aligned} \dot{W}_{\text{rev,out}} &= \dot{W}_{\text{out}} - \dot{m}T_0(s_1 - s_2) \\ &= 5000 \text{ kW} - (5.156 \text{ kg/s})(298 \text{ K})(7.1693 - 7.6953) \text{ kJ/kg} \cdot \text{K} = \mathbf{5808 \text{ kW}} \end{aligned}$$

(b) The second-law efficiency of a turbine is the ratio of the actual work output to the reversible work,

$$\eta_{\text{II}} = \frac{\dot{W}_{\text{out}}}{\dot{W}_{\text{rev,out}}} = \frac{5 \text{ MW}}{5.808 \text{ MW}} = \mathbf{86.1\%}$$

Discussion Note that 13.9% percent of the work potential of the steam is wasted as it flows through the turbine during this process.