8-77 Steam is accelerated in an adiabatic nozzle. The exit velocity of the steam, the isentropic efficiency, and the exergy destroyed within the nozzle are to be determined.

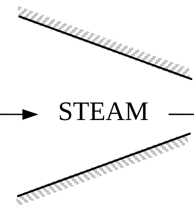
Assumptions **1** The nozzle operates steadily. **2** The changes in potential energies are negligible.

Properties The properties of steam at the inlet and the exit of the nozzle are (Tables A-4 through A-6)

$$\left.\begin{array}{l} P_1 = 7\text{ MPa} \\ T_1 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 3411.4\text{ kJ/kg} \\ s_1 = 6.8000\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 5\text{ MPa} \\ T_2 = 450°\text{C} \end{array}\right\} \begin{array}{l} h_2 = 3317.2\text{ kJ/kg} \\ s_2 = 6.8210\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_{2s} = 5\text{ MPa} \\ s_{2s} = s_1 \end{array}\right\} h_{2s} = 3302.0\text{ kJ/kg}$$



Analysis (*a*) We take the nozzle to be the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

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

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2) \quad (\text{since } \dot{W} = \dot{Q} \cong \Delta\text{pe} \cong 0)$$

$$0 = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}$$

Then the exit velocity becomes

$$V_2 = \sqrt{2(h_1 - h_2) + \mathbf{V}_1^2} = \sqrt{2(3411.4 - 3317.2)\text{ kJ/kg}\left(\frac{1000\text{ m}^2/\text{s}^2}{1\text{ kJ/kg}}\right) + (70\text{ m/s})^2} = \mathbf{439.6\ m/s}$$

(*b*) The exit velocity for the isentropic case is determined from

$$V_{2s} = \sqrt{2(h_1 - h_{2s}) + \mathbf{V}_1^2} = \sqrt{2(3411.4 - 3302.0)\text{ kJ/kg}\left(\frac{1000\text{ m}^2/\text{s}^2}{1\text{ kJ/kg}}\right) + (70\text{ m/s})^2} = 472.9\text{ m/s}$$

Thus,

$$\eta_N = \frac{V_2^2/2}{V_{2s}^2/2} = \frac{(439.6\text{ m/s})^2/2}{(472.9\text{ m/s})^2/2} = \mathbf{86.4\%}$$

(*c*) The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{gen}$ where the entropy generation S_{gen} is determined from an entropy balance on the actual nozzle. It gives

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy}\\ \text{generation}}} = \underbrace{\Delta \dot{S}_{\text{system}}^{\nearrow 0}}_{\substack{\text{Rate of change}\\ \text{of entropy}}} = 0$$

$$\dot{m}s_1 - \dot{m}s_2 + \dot{S}_{\text{gen}} = 0 \rightarrow \dot{S}_{\text{gen}} = \dot{m}(s_2 - s_1) \text{ or } \quad s_{\text{gen}} = s_2 - s_1$$

Substituting, the exergy destruction in the nozzle on a unit mass basis is determined to be

$$x_{\text{destroyed}} = T_0 s_{\text{gen}} = T_0(s_2 - s_1) = (298\text{ K})(6.8210 - 6.8000)\text{kJ/kg}\cdot\text{K} = \mathbf{6.28\ kJ/kg}$$