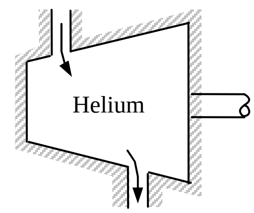
8-53 Heium expands in an adiabatic turbine from a specified inlet state to a specified exit state. The maximum work output is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** The device is adiabatic and thus heat transfer is negligible. **3** Helium is an ideal gas. **4** Kinetic and potential energy changes are negligible.

Properties The properties of helium are c_p = 5.1926 kJ/kg.K and R = 2.0769 kJ/kg.K (Table A-1).

Analysis The entropy change of helium is



$$\begin{aligned} s_2 - s_1 &= c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1} \\ &= (5.1926\ \text{kJ/kg}\cdot\text{K})\ln\frac{298\ \text{K}}{573\ \text{K}} - (2.0769\ \text{kJ/kg}\cdot\text{K})\ln\frac{100\ \text{kPa}}{1500\ \text{kPa}} \\ &= 2.2295\ \text{kJ/kg}\cdot\text{K} \end{aligned}$$

The maximum (reversible) work is the exergy difference between the inlet and exit states

$$\begin{aligned} w_{\text{rev,out}} &= h_1 - h_2 - T_0(s_1 - s_2) \\ &= c_p(T_1 - T_2) - T_0(s_1 - s_2) \\ &= (5.1926\ \text{kJ/kg}\cdot\text{K})(300-25)\text{K} - (298\ \text{K})(-2.2295\ \text{kJ/kg}\cdot\text{K}) \\ &= \mathbf{2092\ kJ/kg} \end{aligned}$$

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

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

$$\begin{aligned} \dot{E}_{\text{in}} &= \dot{E}_{\text{out}} \\ \dot{m}h_1 &= \dot{W}_{\text{out}} + \dot{Q}_{\text{out}} + \dot{m}h_2 \\ \dot{W}_{\text{out}} &= \dot{m}(h_1 - h_2) - \dot{Q}_{\text{out}} \\ w_{\text{out}} &= (h_1 - h_2) - q_{\text{out}} \end{aligned}$$

Inspection of this result reveals that any rejection of heat will decrease the work that will be produced by the turbine since inlet and exit states (i.e., enthalpies) are fixed.

If there is heat loss from the turbine, the maximum work output is determined from the rate form of the exergy balance applied on the turbine and setting the exergy destruction term equal to zero,

$$\underbrace{\dot{X}_{\text{in}} - \dot{X}_{\text{out}}}_{\substack{\text{Rate of net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{\dot{X}_{\text{destroyed}}^{\nearrow 0\ \text{(reversible)}}}_{\substack{\text{Rate of exergy}\\ \text{destruction}}} = \underbrace{\Delta \dot{X}_{\text{system}}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change}\\ \text{of exergy}}} = 0$$

$$\begin{aligned} \dot{X}_{\text{in}} &= \dot{X}_{\text{out}} \\ \dot{m}\psi_1 &= \dot{W}_{\text{rev,out}} + \dot{Q}_{\text{out}}\left(1 - \frac{T_0}{T}\right) + \dot{m}\psi_2 \\ w_{\text{rev,out}} &= (\psi_1 - \psi_2) - q_{\text{out}}\left(1 - \frac{T_0}{T}\right) \\ &= (h_1 - h_2) - T_0(s_1 - s_2) - q_{\text{out}}\left(1 - \frac{T_0}{T}\right) \end{aligned}$$

Inspection of this result reveals that any rejection of heat will decrease the maximum work that could be produced by the turbine. Therefore, for the maximum work, the turbine must be adiabatic.