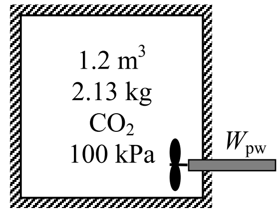
8-41 An insulated tank contains CO_2 gas at a specified pressure and volume. A paddle-wheel in the tank stirs the gas, and the pressure and temperature of CO_2 rises. The actual paddle-wheel work and the minimum paddle-wheel work by which this process can be accomplished are to be determined.

Assumptions **1** At specified conditions, CO_2 can be treated as an ideal gas with constant specific heats at the average temperature. **2** The surroundings temperature is 298 K.

Properties The gas constant of CO_2 is 0.1889 kJ/kg·K (Table A-1)



Analysis (a) The initial and final temperature of CO_2 are

$$T_1 = \frac{P_1\boldsymbol{V}_1}{mR} = \frac{(100\,\text{kPa})(1.2\,\text{m}^3)}{(2.13\,\text{kg})(0.1889\,\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})} = 298.2\,\text{K}$$

$$T_2 = \frac{P_2\boldsymbol{V}_2}{mR} = \frac{(120\,\text{kPa})(1.2\,\text{m}^3)}{(2.13\,\text{kg})(0.1889\,\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})} = 357.9\,\text{K}$$

$$T_{avg} = (T_1+T_2)/2 = (298.2+357.9)/2 = 328\,\text{K} \longrightarrow c_{\boldsymbol{v},avg} = 0.684\,\text{kJ/kg}\cdot\text{K} \text{ (Table A-2}b\text{)}$$

The actual paddle-wheel work done is determined from the energy balance on the CO gas in the tank,

We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. The energy balance for this stationary closed system can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}}$$

$$W_{pw,in} = \Delta U = mc_{\boldsymbol{v}}(T_2 - T_1)$$

or

$$W_{pw,in} = (2.13\,\text{kg})(0.684\,\text{kJ/kg}\cdot\text{K})(357.9-298.2)\text{K} = \mathbf{87.0\,kJ}$$

(b) The minimum paddle-wheel work with which this process can be accomplished is the reversible work,

which can be determined from the exergy balance by setting the exergy destruction equal to zero,

$$\underbrace{X_{in} - X_{out}}_{\substack{\text{Net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{X_{destroyed}^{\nearrow 0\text{ (reversible)}}}_{\substack{\text{Exergy}\\ \text{destruction}}} = \underbrace{\Delta X_{system}}_{\substack{\text{Change}\\ \text{in exergy}}} \rightarrow W_{rev,in} = X_2 - X_1$$

Substituting the closed system exergy relation, the reversible work input for this process is determined to be

$$\begin{aligned} W_{rev,in} &= m\left[(u_2-u_1) - T_0(s_2-s_1) + P_0(\boldsymbol{v}_2^{\nearrow 0} - \boldsymbol{v}_1)\right] \\ &= m\left[c_{\boldsymbol{v},avg}(T_2-T_1) - T_0(s_2-s_1)\right] \\ &= (2.13\,\text{kg})\left[(0.684\,\text{kJ/kg}\cdot\text{K})(357.9-298.2)\text{K} - (298.2)(0.1253\,\text{kJ/kg}\cdot\text{K})\right] \\ &= \mathbf{7.74\ kJ} \end{aligned}$$

since

$$s_2 - s_1 = c_{\boldsymbol{v},avg}\ln\frac{T_2}{T_1} + R\ln\frac{\boldsymbol{v}_2}{\boldsymbol{v}_1}^{\nearrow 0} = (0.684\,\text{kJ/kg}\cdot\text{K})\ln\left(\frac{357.9\,\text{K}}{298.2\,\text{K}}\right) = 0.1253\,\text{kJ/kg}\cdot\text{K}$$