

4-133 A cylinder is initially filled with helium gas at a specified state. Helium is compressed polytropically to a specified temperature and pressure. The heat transfer during the process is to be determined.

Assumptions 1 Helium is an ideal gas with constant specific heats. 2 The cylinder is stationary and thus the kinetic and potential energy changes are negligible. 3 The thermal energy stored in the cylinder itself is negligible. 4 The compression or expansion process is quasi-equilibrium.

Properties The gas constant of helium is $R = 2.0769 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}$ (Table A-1). Also, $c_v = 3.1156 \text{ kJ/kg}\cdot\text{K}$ (Table A-2).

Analysis The mass of helium and the exponent n are determined to be

$$m = \frac{P_1 V_1}{RT_1} = \frac{(150 \text{ kPa})(0.5 \text{ m}^3)}{(2.0769 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293 \text{ K})} = 0.123 \text{ kg}$$

$$\frac{P_1 V_1}{RT_1} = \frac{P_2 V_2}{RT_2} \longrightarrow V_2 = \frac{T_2 P_1}{T_1 P_2} V_1 = \frac{413 \text{ K}}{293 \text{ K}} \times \frac{150 \text{ kPa}}{400 \text{ kPa}} \times 0.5 \text{ m}^3 = 0.264 \text{ m}^3$$

$$P_2 V_2^n = P_1 V_1^n \longrightarrow \left(\frac{P_2}{P_1}\right) = \left(\frac{V_1}{V_2}\right)^n \longrightarrow \frac{400}{150} = \left(\frac{0.5}{0.264}\right)^n \longrightarrow n = 1.536$$

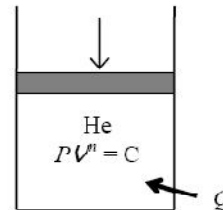
Then the boundary work for this polytropic process can be determined from

$$W_{b,\text{in}} = \int_1^2 P dV = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$$

$$= \frac{(0.123 \text{ kg})(2.0769 \text{ kJ/kg}\cdot\text{K})(413 - 293)\text{K}}{1 - 1.536} = 57.2 \text{ kJ}$$

We take the contents of the cylinder as the system. This is a closed system since no mass enters or leaves. Taking the direction of heat transfer to be to the cylinder, the energy balance for this stationary closed system can be expressed as

$$\begin{aligned} \underbrace{E_{\text{in}} - E_{\text{out}}}_{\text{Net energy transfer by heat, work, and mass}} &= \underbrace{\Delta E_{\text{system}}}_{\text{Change in internal, kinetic, potential, etc. energies}} \\ Q_{\text{in}} + W_{b,\text{in}} &= \Delta U = m(u_2 - u_1) \\ Q_{\text{in}} &= m(u_2 - u_1) - W_{b,\text{in}} \\ &= mc_v(T_2 - T_1) - W_{b,\text{in}} \end{aligned}$$



Substituting,

$$Q_{\text{in}} = (0.123 \text{ kg})(3.1156 \text{ kJ/kg}\cdot\text{K})(413 - 293)\text{K} - (57.2 \text{ kJ}) = -11.2 \text{ kJ}$$

The negative sign indicates that heat is lost from the system.

5-26C A steady-flow system involves no changes with time anywhere within the system or at the system boundaries

5-27C No.

5-38E Air is decelerated in a diffuser from 600 ft/s to a low velocity. The exit temperature and the exit velocity of air are to be determined.

Assumptions 1 This is a steady-flow process since there is no change with time. 2 Air is an ideal gas with variable specific heats. 3 Potential energy changes are negligible. 4 The device is adiabatic and thus heat transfer is negligible. 5 There are no work interactions.

Properties The enthalpy of air at the inlet temperature of 20°F is $h_1 = 114.69$ Btu/lbm (Table A-17E).

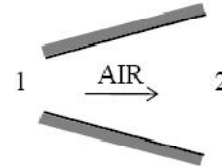
Analysis (a) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take diffuser as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

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

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

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

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



or,

$$h_2 = h_1 - \frac{V_2^2 - V_1^2}{2} = 114.69 \text{ Btu/lbm} - \frac{0 - (600 \text{ ft/s})^2}{2} \left(\frac{1 \text{ Btu/lbm}}{25,037 \text{ ft}^2/\text{s}^2} \right) = 121.88 \text{ Btu/lbm}$$

From Table A-17E,

$$T_2 = \mathbf{510.0 \text{ R}}$$

(b) The exit velocity of air is determined from the conservation of mass relation,

$$\frac{1}{\nu_2} A_2 V_2 = \frac{1}{\nu_1} A_1 V_1 \longrightarrow \frac{1}{RT_2/P_2} A_2 V_2 = \frac{1}{RT_1/P_1} A_1 V_1$$

Thus,

$$V_2 = \frac{A_1 T_2 P_1}{A_2 T_1 P_2} V_1 = \frac{1}{5} \frac{(510 \text{ R})(13 \text{ psia})}{(480 \text{ R})(14.5 \text{ psia})} (600 \text{ ft/s}) = \mathbf{114.3 \text{ ft/s}}$$

5-52 Steam expands in a turbine. The change in kinetic energy, the power output, and the turbine inlet area are to be determined.

Assumptions 1 This is a steady-flow process since there is no change with time. 2 Potential energy changes are negligible. 3 The device is adiabatic and thus heat transfer is negligible.

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

$$\left. \begin{array}{l} P_1 = 10 \text{ MPa} \\ T_1 = 450^\circ\text{C} \end{array} \right\} \begin{array}{l} v_1 = 0.029782 \text{ m}^3/\text{kg} \\ h_1 = 3242.4 \text{ kJ/kg} \end{array}$$

and

$$\left. \begin{array}{l} P_2 = 10 \text{ kPa} \\ x_2 = 0.92 \end{array} \right\} h_2 = h_f + x_2 h_{fg} = 191.81 + 0.92 \times 2392.1 = 2392.5 \text{ kJ/kg}$$

Analysis (a) The change in kinetic energy is determined from

$$\Delta ke = \frac{V_2^2 - V_1^2}{2} = \frac{(50 \text{ m/s})^2 - (80 \text{ m/s})^2}{2} \left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right) = -1.95 \text{ kJ/kg}$$

(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

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

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

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

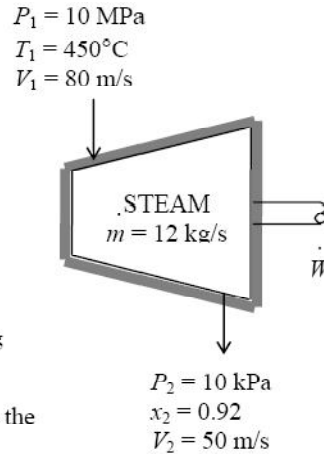
$$\dot{W}_{\text{out}} = -\dot{m} \left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} \right)$$

Then the power output of the turbine is determined by substitution to be

$$\dot{W}_{\text{out}} = -(12 \text{ kg/s})(2392.5 - 3242.4 - 1.95) \text{ kJ/kg} = \mathbf{10.2 \text{ MW}}$$

(c) The inlet area of the turbine is determined from the mass flow rate relation,

$$\dot{m} = \frac{1}{v_1} A_1 V_1 \longrightarrow A_1 = \frac{\dot{m} v_1}{V_1} = \frac{(12 \text{ kg/s})(0.029782 \text{ m}^3/\text{kg})}{80 \text{ m/s}} = \mathbf{0.00447 \text{ m}^2}$$



5-64C Yes.

5-74 Carbon dioxide flows through a throttling valve. The temperature change of CO₂ is to be determined if CO₂ is assumed an ideal gas and a real gas.

Assumptions 1 This is a steady-flow process since there is no change with time. 2 Kinetic and potential energy changes are negligible. 3 Heat transfer to or from the fluid is negligible. 4 There are no work interactions involved.

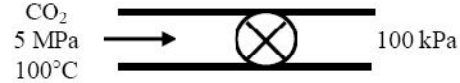
Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the throttling valve as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \Delta \dot{E}_{\text{system}} \stackrel{\text{no (steady)}}{=} 0$$

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

$$\dot{m}h_1 = \dot{m}h_2$$

$$h_1 = h_2$$



since $\dot{Q} \equiv \dot{W} = \Delta ke \equiv \Delta pe \equiv 0$.

(a) For an ideal gas, $h = h(T)$, and therefore,

$$T_2 = T_1 = 100^\circ\text{C} \longrightarrow \Delta T = T_1 - T_2 = \mathbf{0^\circ\text{C}}$$

(b) We obtain real gas properties of CO₂ from EES software as follows

$$\left. \begin{array}{l} P_1 = 5 \text{ MPa} \\ T_1 = 100^\circ\text{C} \end{array} \right\} h_1 = 34.77 \text{ kJ/kg}$$

$$\left. \begin{array}{l} P_2 = 100 \text{ kPa} \\ h_2 = h_1 = 34.77 \text{ kJ/kg} \end{array} \right\} T_2 = 66.0^\circ\text{C}$$

Note that EES uses a different reference state from the textbook for CO₂ properties. The temperature difference in this case becomes

$$\Delta T = T_1 - T_2 = 100 - 66.0 = \mathbf{34.0^\circ\text{C}}$$

That is, the temperature of CO₂ decreases by 34°C in a throttling process if its real gas properties are used.