6-7 Air is accelerated in a nozzle. The mass flow rate and the exit area of the nozzle are to be determined.

**Assumptions** Flow through the nozzle is steady.

**Properties** The density of air is given to be 2.21 kg/m³ at the inlet, and 0.762 kg/m³ at the exit.

**Analysis** (a) The mass flow rate of air is determined from the inlet conditions to be

\[ \dot{m} = \rho_1 A_1 V_1 = (2.21 \text{ kg/m}^3)(0.009 \text{ m}^2)(40 \text{ m/s}) = 0.796 \text{ kg/s} \]

(b) There is only one inlet and one exit, and thus \( \dot{m}_i = \dot{m}_2 = \dot{m} \). Then the exit area of the nozzle is determined to be

\[ \dot{m} = \rho_2 A_2 V_2 \implies A_2 = \frac{\dot{m}}{\rho_2 V_2} = \frac{0.796 \text{ kg/s}}{(0.762 \text{ kg/m}^3)(180 \text{ m/s})} = 0.0058 \text{ m}^2 = 58 \text{ cm}^2 \]

6-11 A rigid tank initially contains air at atmospheric conditions. The tank is connected to a supply line, and air is allowed to enter the tank until the density rises to a specified level. The mass of air that entered the tank is to be determined.

**Properties** The density of air is given to be 1.18 kg/m³ at the beginning, and 7.20 kg/m³ at the end.

**Analysis** We take the tank as the system, which is a control volume since mass crosses the boundary. The mass balance for this system can be expressed as

\[ \text{Mass balance:} \quad m_i - m_{out} = \Delta m_{\text{system}} \implies m_i = m_2 - m_1 = \rho_2 V - \rho_1 V \]

Substituting,

\[ m_i = (\rho_2 - \rho_1)V = [(7.20 - 1.18) \text{ kg/m}^3](1 \text{ m}^3) = 6.02 \text{ kg} \]

Therefore, 6.02 kg of mass entered the tank.
6-12 A smoking lounge that can accommodate 15 smokers is considered. The required minimum flow rate of air that needs to be supplied to the lounge and the diameter of the duct are to be determined.

**Assumptions** Infiltration of air into the smoking lounge is negligible.

**Properties** The minimum fresh air requirements for a smoking lounge is given to be 30 L/s per person.

**Analysis** The required minimum flow rate of air that needs to be supplied to the lounge is determined directly from

\[
\dot{V}_{\text{air}} = \dot{V}_{\text{air per person}} \times \text{(No. of persons)}
\]

\[
= (30 \text{ L/s} \cdot \text{person}) \times \text{(15 persons)} = 450 \text{ L/s} = 0.45 \text{ m}^3/\text{s}
\]

The volume flow rate of fresh air can be expressed as

\[
\dot{V} = VA = V彼 (\pi D^2 / 4)
\]

Solving for the diameter \(D\) and substituting,

\[
D = \sqrt{\frac{4V}{\pi V}} = \sqrt{\frac{4(0.45 \text{ m}^3/\text{s})}{\pi(8 \text{ m/s})}} = 0.268 \text{ m}
\]

Therefore, the diameter of the fresh air duct should be at least 26.8 cm if the velocity of air is not to exceed 8 m/s.

6-16 A spherical hot-air balloon is considered. The time it takes to inflate the balloon is to be determined.

**Assumptions** 1 Air is an ideal gas.

**Properties** The gas constant of air is \(R = 0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K} \) (Table A-1).

**Analysis** The specific volume of air entering the balloon is

\[
\nu = \frac{RT}{P} = \frac{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(35 + 273 \text{ K})}{120 \text{ kPa}} = 0.7366 \text{ m}^3/\text{kg}
\]

The mass flow rate at this entrance is

\[
\dot{m} = \frac{A \dot{V}}{\nu} = \frac{\pi D^2 \dot{V}}{4 \nu} = \frac{\pi(1 \text{ m})^2}{4} \frac{2 \text{ m/s}}{0.7366 \text{ m}^3/\text{kg}} = 2.132 \text{ kg/s}
\]

The initial mass of the air in the balloon is

\[
m_i = \frac{\nu_1}{\nu} \frac{\pi D^3}{6 \nu} = \frac{\pi(3 \text{ m})^3}{6(0.7366 \text{ m}^3/\text{kg})} = 19.19 \text{ kg}
\]

Similarly, the final mass of air in the balloon is

\[
m_f = \frac{\nu_1}{\nu} \frac{\pi D^3}{6 \nu} = \frac{\pi(15 \text{ m})^3}{6(0.7366 \text{ m}^3/\text{kg})} = 2399 \text{ kg}
\]

The time it takes to inflate the balloon is determined from

\[
\Delta t = \frac{m_f - m_i}{\dot{m}} = \frac{(2399 - 19.19) \text{ kg}}{2.132 \text{ kg/s}} = 1116 \text{ s} = 18.6 \text{ min}
\]
6-31 Air is accelerated in a nozzle from 30 m/s to 180 m/s. The mass flow rate, the exit temperature, and the exit area of the nozzle 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 constant 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 gas constant of air is 0.287 kPa·m³/kg·K (Table A-1). The specific heat of air at the anticipated average temperature of 450 K is \( c_p = 1.02 \text{ kJ/kg·°C} \) (Table A-2).

**Analysis**

(a) There is only one inlet and one exit, and thus \( \dot{m}_1 = \dot{m}_2 = \dot{m} \). Using the ideal gas relation, the specific volume and the mass flow rate of air are determined to be

\[
\nu_1 = \frac{RT_1}{P_1} = \frac{(0.287 \text{ kPa·m}^3/\text{kg·K}) \times (473 \text{ K})}{300 \text{ kPa}} = 0.4525 \text{ m}^3/\text{kg}
\]

\[
\dot{m} = \frac{1}{\nu_1} A_1 V_1 = \frac{1}{0.4525 \text{ m}^3/\text{kg}} (0.008 \text{ m}^2)(30 \text{ m/s}) = 0.5304 \text{ kg/s}
\]

(b) We take nozzle 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

\[
\dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \Delta \dot{E}_{\text{system}} = 0
\]

Rate of net energy transfer
Rate of change in internal, kinetic, by heat, work, and mass potential, etc. energies

\[
\dot{E}_{\text{in}} = \dot{E}_{\text{out}}
\]

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

\[
0 = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} \quad \Rightarrow \quad 0 = c_p,\text{ave}(T_2 - T_1) + \frac{V_2^2 - V_1^2}{2}
\]

Substituting,

\[
0 = (1.02 \text{ kJ/kg·K})(T_2 - 200\text{°C}) + \frac{(180 \text{ m/s})^2 - (30 \text{ m/s})^2}{2} \left( \frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2} \right)
\]

It yields \( T_2 = 184.6°\text{C} \)

(c) The specific volume of air at the nozzle exit is

\[
\nu_2 = \frac{RT_2}{P_2} = \frac{(0.287 \text{ kPa·m}^3/\text{kg·K})(184.6 + 273 \text{ K})}{100 \text{ kPa}} = 1.313 \text{ m}^3/\text{kg}
\]

\[
\dot{m} = \frac{1}{\nu_2} A_2 V_2 \rightarrow 0.5304 \text{ kg/s} = \frac{1}{1.313 \text{ m}^3/\text{kg}} A_2 (180 \text{ m/s}) \rightarrow A_2 = 0.00387 \text{ m}^2 = 38.7 \text{ cm}^2
\]
Steam is accelerated in a nozzle from a velocity of 80 m/s. The mass flow rate, the exit velocity, and the exit area of the nozzle 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. There are no work interactions.

**Properties**
From the steam tables (Table A-6)

\[
egin{align*}
P_1 &= 5 \text{ MPa} & \nu_1 &= 0.057838 \text{ m}^3/\text{kg} \\
T_1 &= 400\degree \text{C} & h_1 &= 3196.7 \text{ kJ/kg}
\end{align*}
\]

and

\[
egin{align*}
P_2 &= 2 \text{ MPa} & \nu_2 &= 0.12551 \text{ m}^3/\text{kg} \\
T_2 &= 300\degree \text{C} & h_2 &= 3024.2 \text{ kJ/kg}
\end{align*}
\]

**Analysis**
(a) There is only one inlet and one exit, and thus \( \dot{m}_1 = \dot{m}_2 = \dot{m} \). The mass flow rate of steam is

\[
\dot{m} = \frac{1}{\nu_1} V_1 A_1 = \frac{1}{0.057838} \text{ m}^3/\text{kg} \left( 80 \text{ m/s}(50 \times 10^{-4} \text{ m}^2) \right) = 6.92 \text{ kg/s}
\]

(b) We take nozzle 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

\[
\dot{E}_\text{in} - \dot{E}_\text{out} = \Delta \dot{E}_\text{system} = 0
\]

Rate of net energy transfer
by heat, work, and mass
Rate of change in internal, kinetic, potential, etc. energies

\[
\dot{E}_\text{in} = \dot{E}_\text{out}
\]

\[
\dot{m}(h_1 + \frac{V_1^2}{2}) = \dot{Q}_\text{out} + \dot{m}(h_2 + \frac{V_2^2}{2}) \quad \text{(since } \dot{W} \equiv \Delta p e \equiv 0) \\
- \dot{Q}_\text{out} = \dot{m} \left( h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} \right)
\]

Substituting, the exit velocity of the steam is determined to be

\[
-120 \text{ kJ/s} = \left( 6.916 \text{ kg/s} \left( 3024.2 - 3196.7 + \frac{V_2^2 - (80 \text{ m/s})^2}{2} \right) \left( 1 \text{ kJ/kg} \frac{1000 \text{ m}^2/\text{s}^2}{\text{kJ/s}} \right) \right)
\]

It yields

\[
V_2 = 562.7 \text{ m/s}
\]

(c) The exit area of the nozzle is determined from

\[
\dot{m} = \frac{1}{\nu_2} V_2 A_2 \quad \text{or} \quad A_2 = \frac{\dot{m} \nu_2}{V_2} = \frac{(6.916 \text{ kg/s})(0.12551 \text{ m}^3/\text{kg})}{562.7 \text{ m/s}} = 15.42 \times 10^{-4} \text{ m}^2
\]
\[ \dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \Delta \dot{E}_{\text{system}} = 0 \]

Rate of net energy transfer by heat, work, and mass

Rate of change in internal, kinetic, potential, etc. energies

\[ \dot{E}_{\text{in}} = \dot{E}_{\text{out}} \]

\[ \dot{W}_{\text{in}} + \dot{m} h_1 = \dot{m} h_2 \quad (\text{since } \Delta ke \approx \Delta pe \approx 0) \]

\[ \dot{W}_{\text{in}} = \dot{m}(h_2 - h_1) = \dot{m} c_p(T_2 - T_1) \]

Thus,

\[ w_{\text{in}} = c_p(T_2 - T_1) = (1.018 \text{ kJ/kg \cdot K})(300 - 20) \text{K} = 285.0 \text{ kJ/kg} \]

(b) The specific volume of air at the inlet and the mass flow rate are

\[ \nu_1 = \frac{RT_1}{P_1} = \frac{(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(20 + 273 \text{K})}{120 \text{ kPa}} = 0.7008 \text{ m}^3/\text{kg} \]

\[ \dot{m} = \frac{\dot{V}_1}{\nu_1} = \frac{0.010 \text{ m}^3/\text{s}}{0.7008 \text{ m}^3/\text{kg}} = 0.01427 \text{ kg/s} \]

Then the power input is determined from the energy balance equation to be

\[ \dot{W}_{\text{in}} = \dot{m} c_p(T_2 - T_1) = (0.01427 \text{ kg/s})(1.018 \text{ kJ/kg \cdot K})(300 - 20) \text{K} = 4.068 \text{ kW} \]
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)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_1$</td>
<td>10 MPa</td>
</tr>
<tr>
<td>$v_1$</td>
<td>0.029782 m³/kg</td>
</tr>
<tr>
<td>$T_1$</td>
<td>450°C</td>
</tr>
<tr>
<td>$h_1$</td>
<td>3242.4 kJ/kg</td>
</tr>
</tbody>
</table>

and

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_2$</td>
<td>10 kPa</td>
</tr>
<tr>
<td>$x_2$</td>
<td>0.92</td>
</tr>
<tr>
<td>$T_2$</td>
<td>200°C</td>
</tr>
<tr>
<td>$h_2$</td>
<td>3292.1 kJ/kg</td>
</tr>
</tbody>
</table>

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

$$\dot{E}_\text{in} - \dot{E}_\text{out} = \Delta \dot{E}_\text{system} = 0$$

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

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

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

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

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

$$\dot{E}_\text{in} - \dot{E}_\text{out} = \Delta \dot{E}_\text{system} = 0$$

since $\dot{Q} = \dot{W} = \Delta ke = \Delta pe = 0$.
(a) For an ideal gas, \( h = h(T) \), and therefore,
\[
T_2 = T_1 = 100^\circ C \quad \rightarrow \quad \Delta T = T_1 - T_2 = 0^\circ C
\]

(b) We obtain real gas properties of CO\(_2\) from EES software as follows
\[
\begin{align*}
P_1 &= 5 \text{ MPa } \quad & h_1 &= 34.77 \text{ kJ/kg } \\
T_1 &= 100^\circ C & & \\

P_2 &= 100 \text{ kPa } \quad & h_2 &= h_1 = 34.77 \text{ kJ/kg } \\
T_2 &= 66.0^\circ C
\end{align*}
\]

Note that EES uses a different reference state from the textbook for CO\(_2\) properties. The temperature difference in this case becomes
\[
\Delta T = T_1 - T_2 = 100 - 66.0 = 34^\circ C
\]

That is, the temperature of CO\(_2\) decreases by 34\(^\circ\) in a throttling process if its real gas properties are used.