7-10c No. An isothermal process can be irreversible. Example: A system that involves paddle-wheel work while losing an equivalent amount of heat.

7-30c Yes, because an internally reversible, adiabatic process involves no irreversibilities or heat transfer.

7-52c No, because entropy is not a conserved property.

7-63c The \( P_r \) and \( u_r \) are called relative pressure and relative specific volume, respectively. They are derived for isentropic processes of ideal gases, and thus their use is limited to isentropic processes only.

7-101c The ideal process for all three devices is the reversible adiabatic (i.e., isentropic) process. The adiabatic efficiencies of these devices are defined as

\[ \eta_r = \frac{\text{actual work output}}{\text{isentropic work output}}, \quad \eta_c = \frac{\text{isentropic work input}}{\text{actual work input}}, \quad \text{and} \quad \eta_v = \frac{\text{actual exit kinetic energy}}{\text{isentropic exit kinetic energy}} \]

7-28e Heat is transferred isothermally from the working fluid of a Carnot engine to a heat sink. The entropy change of the working fluid is given. The amount of heat transfer, the entropy change of the sink, and the total entropy change during the process are to be determined.

**Analysis** (a) This is a reversible isothermal process, and the entropy change during such a process is given by

\[ \Delta S = \frac{Q}{T} \]

Noting that heat transferred from the working fluid is equal to the heat transferred to the sink, the heat transfer becomes

\[ Q_{\text{fluid}} = T_{\text{fluid}} \Delta S_{\text{fluid}} = (555 \text{ R})(-0.7 \text{ Btu/R}) = -388.5 \text{ Btu} \rightarrow Q_{\text{fluid, out}} = 388.5 \text{ Btu} \]

(b) The entropy change of the sink is determined from

\[ \Delta S_{\text{sink}} = \frac{Q_{\text{sink, in}}}{T_{\text{sink}}} = \frac{388.5 \text{ Btu}}{555 \text{ R}} = 0.7 \text{ Btu/R} \]

(c) Thus the total entropy change of the process is

\[ S_{\text{gen}} = \Delta S_{\text{total}} = \Delta S_{\text{fluid}} + \Delta S_{\text{sink}} = -0.7 + 0.7 = 0 \]

This is expected since all processes of the Carnot cycle are reversible processes, and no entropy is generated during a reversible process.
7.34 An insulated rigid tank contains a saturated liquid-vapor mixture of water at a specified pressure. An electric heater inside is turned on and kept on until all the liquid vaporized. The entropy change of the water during this process is to be determined.

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

\[
\begin{align*}
R_1 &= 100 \text{ kPa } \quad \nu_1 = \nu_f + x_1 \nu_{fg} = 0.001 + (0.25)(1.6941 - 0.001) = 0.4243 \text{ m}^3/\text{kg} \\
x_1 &= 0.25 \quad s_1 = s_f + x_1 s_{fg} = 1.3028 + (0.25)(0.0562) = 2.8108 \text{ kJ/kg} \cdot \text{K} \\
\nu_2 - \nu_1 \quad \text{sat. vapor } \quad s_2 &= 6.8649 \text{ kJ/kg} \cdot \text{K} 
\end{align*}
\]

Then the entropy change of the steam becomes

\[
\Delta S = m(s_2 - s_1) = (2 \text{ kg})(6.8649 - 2.8108) \text{ kJ/kg} \cdot \text{K} = 8.10 \text{ kJ/K}
\]

7.49 A rigid tank contains saturated water vapor at a specified temperature. Steam is cooled to ambient temperature. The process is to be sketched and entropy changes for the steam and for the process are to be determined.

**Assumptions** 1. The kinetic and potential energy changes are negligible.

**Analysis** (b) From the steam tables (Tables A-4 through A-6).

**State 1**

\[
\begin{align*}
\nu_1 &= \nu_g = 1.6720 \text{ KJ/kg} \\
u_1 &= 2506.0 \text{ KJ/kg} \\
s_1 &= s_g = 7.3542 \text{ KJ/kg-K} \\
\nu_1 &= \nu_2 \\
\end{align*}
\]

**State 2**

\[
\begin{align*}
x_2 &= \nu_2 - \nu_g = 0.0386 \\
u_2 &= \nu_f + x_2 \nu_{fg} = 193.78 \text{ KJ/kg} \\
s_2 &= s_f + x_2 s_{fg} = 0.6833 \text{ KJ/kg-K} \\
\Delta S &= m(s_2 - s_1) = -33.36 \text{ KJ/kg-K} \\
\end{align*}
\]

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

\[
\begin{align*}
\frac{F_{in} - F_{out}}{\text{Net energy transfer by heat, work, and mass}} = -\Delta F_{\text{system}} \\
- Q_{\text{ex}} = \Delta U = m(\nu_2 - \nu_1) \\
\end{align*}
\]

That is,

\[
Q_{\text{ex}} = m(\nu_2 - \nu_1) = (5 \text{ kg})(2506.0 - 193.78) \text{ kJ/kg} = 11,511 \text{ kJ}
\]

The total entropy change for the process is
\[ S_{gen} = \Delta S + \frac{Q_{sw}}{T_{sw}} = -33.36 + \frac{11,511}{298K} = 5.42 \text{kJ/K} \]

7-5A An insulated rigid can initially contains R-134a at a specified state. A crack develops, and refrigerant escapes slowly. The final mass in the can is to be determined when the pressure inside drops to a specified value.

**Assumptions**
1. The can is well-insulated and thus heat transfer is negligible. 2. The refrigerant that remains in the can underwent a reversible adiabatic process.

**Analysis**
Noting that for a reversible adiabatic (i.e., isentropic) process, \( s_1 = s_2 \), the properties of the refrigerant in the can are (Tables A-11E through A-13E)

\[ P_1 = 140 \text{ psia} \quad T_1 = 70^\circ \text{F} \]
\[ s_1 \approx s_{f (70^\circ F)} - 0.07306 \text{ Btu/lbm R} \]

\[ x_2 = \frac{s_2 - s_f}{s_F} - \frac{0.07306 - 0.02605}{0.19962} = 0.2355 \]

Thus the final mass of the refrigerant in the can is

\[ m = \frac{\nu}{\nu_2} = \frac{1.2 \text{ ft}^3}{0.5453 \text{ ft}^3/\text{lbm}} = 2.201 \text{ lbm} \]
An aluminum block is brought into contact with an iron block in an insulated enclosure. The final equilibrium temperature and the total entropy change for this process are to be determined.

**Assumptions**
1. Both the aluminum and the iron block are incompressible substances with constant specific heats.
2. The system is stationary and thus the kinetic and potential energies are negligible.
3. The system is well-insulated and thus there is no heat transfer.

**Properties**
The specific heat of aluminum at the anticipated average temperature of 450 K is \( c_p = 0.973 \text{ kJ/kg·°C} \). The specific heat of iron at room temperature (the only value available in the tables) is \( c_p = 0.45 \text{ kJ/kg·°C} \) (Table A-3).

**Analysis**
We take the iron–aluminum blocks as the system, which is a closed system. The energy balance for this system can be expressed as

\[
\frac{E_{in} - E_{out}}{\text{Net energy transfer by heat, work, and mass}} = \frac{\Delta E_{\text{system}}}{\text{Change in internal, kinetic, potential, etc. energies}}
\]

\[
0 = \Delta U
\]

or,

\[
\Delta U_{\text{alum}} + \Delta U_{\text{iron}} = 0
\]

\[
[ mc(T_2 - T_1) ]_{\text{alum}} + [ mc(T_2 - T_1) ]_{\text{iron}} = 0
\]

Substituting,

\[
(20 \text{ kg})(0.45 \text{ kJ/kg·°C})(T_2 - 100\degree \text{C}) + (20 \text{ kg})(0.973 \text{ kJ/kg·°C})(T_2 - 200\degree \text{C}) = 0
\]

\[
T_2 = 168.4\degree \text{C} = 441.4 \text{ K}
\]

The total entropy change for this process is determined from

\[
\Delta S_{\text{iron}} = m c_{\text{avg}} \ln \left( \frac{T_2}{T_1} \right) = \frac{[ 20 \text{ kg} ](0.45 \text{ kJ/kg·°C})}{\text{K}} \ln \left( \frac{441.4 \text{ K}}{373 \text{ K}} \right) = 1.515 \text{ kJ/K}
\]

\[
\Delta S_{\text{alum}} = m c_{\text{avg}} \ln \left( \frac{T_2}{T_1} \right) = \frac{[ 20 \text{ kg} ](0.973 \text{ kJ/kg·°C})}{\text{K}} \ln \left( \frac{441.4 \text{ K}}{473 \text{ K}} \right) = -1.346 \text{ kJ/K}
\]

Thus,

\[
\Delta S_{\text{total}} = \Delta S_{\text{iron}} + \Delta S_{\text{alum}} = 1.515 - 1.346 = 0.169 \text{ kJ/K}
\]
7-73 Air is compressed steadily by a 5-kW compressor from one specified state to another specified state. The rate of entropy change of air is to be determined.

**Assumptions** At specified conditions, air can be treated as an ideal gas. 2 Air has variable specific heats.

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

**Analysis** From the air table (Table A-17),

\[
\begin{align*}
T_1 &= 290 \text{ K} \\
P_1 &= 100 \text{ kPa} \\
T_2 &= 440 \text{ K} \\
P_2 &= 600 \text{ kPa}
\end{align*}
\]

\[
\begin{align*}
S_1 &= 1.66802 \text{ kJ/kg} \cdot \text{K} \\
S_2 &= 2.0887 \text{ kJ/kg} \cdot \text{K}
\end{align*}
\]

Then the rate of entropy change of air becomes

\[
\Delta S_{sys} = \left| \frac{S_2 - S_1 - R \ln \frac{P_2}{P_1}}{T_1} \right|
\]

\[
= \left| \frac{2.0887 - 1.66802 - (0.287 \text{ kJ/kg} \cdot \text{K}) \ln \left( \frac{600 \text{ kPa}}{100 \text{ kPa}} \right)}{290 \text{ K}} \right|
\]

\[
= -0.00250 \text{ kW/K}
\]

7-76 Air contained in a constant-volume tank is cooled to ambient temperature. The entropy changes of the air and the universe due to this process are to be determined and the process is to be sketched on a T-s diagram.

**Assumptions** 1 Air is an ideal gas with constant specific heats.

**Properties** The specific heat of air at room temperature is \( c_v = 0.718 \text{ kJ/kg} \cdot \text{K} \) (Table A-2a).

**Analysis (a)** The entropy change of air is determined from

\[
\Delta S_{air} = mc_v \ln \frac{T_2}{T_1}
\]

\[
= (5 \text{ kg})(0.718 \text{ kJ/kg} \cdot \text{K}) \ln \frac{(273 + 27)}{(327 + 273)} \text{K}
\]

\[
= -2.488 \text{ kJ/K}
\]

(b) An energy balance on the system gives

\[
Q_{out} = mc_v(T_2 - T_1)
\]

\[
= (5 \text{ kg})(0.718 \text{ kJ/kg} \cdot \text{K})(327 - 27) \]

\[
= 1077 \text{ kJ}
\]

The entropy change of the surroundings is

\[
\Delta S_{sur} = \frac{Q_{out}}{T_{sur}} = \frac{1077 \text{ kJ}}{300 \text{ K}} = 3.59 \text{ kJ/K}
\]

The entropy change of universe due to this process is

\[
S_{univ} = \Delta S_{total} = \Delta S_{air} + \Delta S_{sur} = -2.488 + 3.59 = 1.10 \text{ kJ/K}
\]
7.91 Liquid water is to be pumped by a 25-kW pump at a specified rate. The highest pressure the water can be pumped to is to be determined.

Assumptions 1 Liquid water is an incompressible substance. 2 Kinetic and potential energy changes are negligible. 3 The process is assumed to be reversible since we will determine the limiting case.

Properties The specific volume of liquid water is given to be \( v_s = 0.001 \text{ m}^3/\text{kg} \).

Analysis The highest pressure the liquid can have at the pump exit can be determined from the reversible steady-flow work relation for a liquid,

\[
\dot{W}_{\text{rev}} = \dot{m} \left( \int_{1}^{2} \left( \omega P - \Delta \dot{v} P - \Delta \dot{v} \phi \right) \right) = \dot{m} v_1 (P_2 - P)
\]

Thus,

\[
25 \text{ kJ/s} = (5 \text{ kg/s})(0.001 \text{ m}^3/\text{kg})(P_2 - 100) \text{kPa} \left( \frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3} \right)
\]

It yields \( P_2 = 5100 \text{ kPa} \)
A steam power plant operates between the pressure limits of 10 MPa and 20 kPa. The ratio of the turbine work to the pump work is to be determined.

**Assumptions** 1 Liquid water is an incompressible substance. 2 Kinetic and potential energy changes are negligible. 3 The process is reversible. 4 The pump and the turbine are adiabatic.

**Properties** The specific volume of saturated liquid water at 20 kPa is \(v_L = \gamma @ 20 \text{ kPa} = 0.001017 \text{ m}^3/\text{kg} \) (Table A-5).

**Analysis** Both the compression and expansion processes are reversible and adiabatic, and thus isentropic, \(s_1 = s_2 \) and \(s_3 = s_4\). Then the properties of the steam are

\[
\begin{align*}
P_2 &= 20 \text{ kPa} \quad h_4 = h_L @ 20 \text{ kPa} = 2608.9 \text{ kJ/kg} \\
&\text{sat.
sup\text{vapor}} \quad s_4 = s_L @ 20 \text{ kPa} = 7.9073 \text{ kJ/kg} \cdot \text{K} \\
P_1 &= 10 \text{ MPa} \quad h_3 = 4707.2 \text{ kJ/kg} \\
&\text{sat.} \\
\end{align*}
\]

Also, \(v_1 = \gamma @ 20 \text{ kPa} = 0.001017 \text{ m}^3/\text{kg} \).

The work output to this isentropic turbine is determined from the steady-flow energy balance to be

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

where the rate of change in internal, kinetic, potential, and entropic energies is

\[
\dot{E}_{\text{in}} = \dot{E}_{\text{out}} \\
\dot{m}h_1 = \dot{m}h_3 + \dot{W}_{\text{out}} \\
\dot{W}_{\text{out}} = \dot{m}(h_3 - h_4)
\]

Substituting,

\[
w_{\text{turb, out}} = h_3 - h_4 = 4707.2 - 2608.9 = 2098.3 \text{ kJ/kg}
\]

The pump work input is determined from the steady-flow work relation to be

\[
w_{\text{pump, in}} = \int_1^2 \dot{u}dP + \Delta \dot{E}_{\text{system}} = \dot{u}_1(P_2 - P_1)
\]

\[
= (0.001017 \text{ m}^3/\text{kg})(10,000 - 20) \text{kPa}(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3})
\]

\[
= -10.15 \text{ kJ/kg}
\]

Thus,

\[
\frac{w_{\text{turb, out}}}{w_{\text{pump, in}}} = \frac{2098.3}{10.15} = 206.7
\]
7-104 Steam enters an adiabatic turbine with an isentropic efficiency of 0.90 at a specified state with a specified mass flow rate, and leaves at a specified pressure. The turbine exit temperature and power output of the turbine are to be determined.

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

**Analysis** (a) From the steam tables (Tables A-4 through A-6),

\[
P_1 = 8 \text{ MPa} \\
T_1 = 500^\circ \text{C} \\
\dot{h}_1 = 3399.5 \text{ kJ/kg}
\]

From the isentropic efficiency relation,

\[
\eta_s = \frac{\dot{h}_1 - \dot{h}_{2s}}{\dot{h}_1 - \dot{h}_{2s}} \Rightarrow \dot{h}_{2s} = \dot{h}_1 - \eta_s (\dot{h}_1 - \dot{h}_{2s}) = 3399.5 - (0.9)(3399.5 - 2268.3) = 2381.4 \text{ kJ/kg}
\]

Thus,

\[
P_{2s} = 30 \text{ kPa} \\
\dot{h}_{2s} = 2381.4 \text{ kJ/kg} \]

\[
T_{2s} = T_{sat@30 \text{ kPa}} = 69.09^\circ \text{C}
\]

(b) There is only one inlet and one exit, and thus \( \dot{m}_1 = \dot{m}_2 = \dot{m} \). We take the actual 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

\[
\dot{E}_{in} - \dot{E}_{out} = \dot{E}_{syst} = 0
\]

\[
\dot{m}_1 \dot{h}_1 = \dot{m}_2 \dot{h}_2 + \dot{m} \dot{h}_{2s} \quad \text{(since } \dot{Q} = \Delta \text{ke} = \Delta \text{pe} = 0) \]

\[
\dot{W}_{s,\text{out}} = \dot{m}(\dot{h}_1 - \dot{h}_2)
\]

Substituting,

\[
\dot{W}_{s,\text{out}} = (3 \text{ kg/s})(3399.5 - 2381.4) \text{ kJ/kg} = 3054 \text{ kW}
\]
Combustion gases enter an adiabatic gas turbine with an isentropic efficiency of 82% at a specified state, and leave at a specified pressure. The work output of the turbine is to be determined.

**Assumptions**

1. This is a steady-flow process since there is no change with time.
2. Kinetic and potential energy changes are negligible.
3. The device is adiabatic and thus heat transfer is negligible.
4. Combustion gases can be treated as air that is an ideal gas with variable specific heats.

**Analysis**

From the air table and isentropic relations,

\[
T_1 = 2000 \text{ R} \quad \Rightarrow \quad h_1 = 504.71 \text{ Btu/lbm} \quad P_1 = 174.0
\]

\[
P_2 = \left(\frac{P_1}{P_1}\right) P_1 = \left(\frac{60 \text{ psia}}{120 \text{ psia}}\right) (174.0) = 87.0 \quad \Rightarrow \quad h_{2c} = 417.3 \text{ Btu/lbm}
\]

There is only one inlet and one exit, and thus \( \dot{m}_1 = \dot{m}_2 = \dot{m} \). We take the actual 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 as

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

\[
\dot{m} (h_1 - h_2) = \dot{m} (h_{1a} - h_{2a}) \quad \text{(since } \dot{Q} = \Delta ke = \Delta pe = 0)\]

Noting that \( w_e = \eta \dot{w}_e \), the work output of the turbine per unit mass is determined from

\[
\dot{w}_e = (0.82)(504.71 - 417.3) \text{ Btu/lbm} = 71.7 \text{ Btu/lbm}
\]

**7.112** Air is compressed by an adiabatic compressor from a specified state to another specified state. The isentropic efficiency of the compressor and the exit temperature of air for the isentropic case are to be determined.

**Assumptions**

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

**Analysis**

(a) From the air table (Table A-17),

\[
T_1 = 300 \text{ K} \quad \Rightarrow \quad h_1 = 300.19 \text{ kJ/kg} \quad P_1 = 1386
\]

\[
T_2 = 550 \text{ K} \quad \Rightarrow \quad h_{2a} = 554.74 \text{ kJ/kg}
\]

From the isentropic relation,

\[
P_2 = \left(\frac{P_1}{P_1}\right) P_1 = \left(\frac{600 \text{ kPa}}{95 \text{ kPa}}\right) (1386) = 8754 \quad \Rightarrow \quad h_{2s} = 508.72 \text{ kJ/kg}
\]

Then the isentropic efficiency becomes

\[
\eta_c = \frac{h_{2a} - h_1}{h_{2s} - h_1} = \frac{508.72 - 300.19}{554.74 - 300.19} = 0.819 = 81.9\%
\]

(b) If the process were isentropic, the exit temperature would be

\[
h_{2s} = 508.72 \text{ kJ/kg} \quad \Rightarrow \quad T_{2s} = 508.5 \text{ K}
\]
The pressure in a hot water tank rises to 2 MPa, and the tank explodes. The explosion energy of the water is to be determined, and expressed in terms of its TNT equivalence.

**Assumptions**
1. The expansion process during explosion is isentropic.
2. Kinetic and potential energy changes are negligible.
3. Heat transfer with the surroundings during explosion is negligible.

**Properties**
The explosion energy of TNT is 3250 kJ/kg. From the steam tables (Tables A-4 through 6)

\[
\begin{align*}
R_1 &= 2 \text{ MPa} \\
& (\text{sat. liquid}) \quad u_1 = u_f(2 \text{ MPa}) = 906.12 \text{ kJ/kg} \\
\rho_1 &= \frac{u_1}{R_1} = 0.001177 \text{ m}^3/\text{kg} \\
\beta_1 &= s_f(2 \text{ MPa}) - 2.4467 \text{ kJ/kg.K} \\
\beta_2 &= 100 \text{ kPa} \\
\frac{u_f}{s_f} &= 417.40, \quad u_{fe} = 2088.2 \text{ kJ/kg} \\
\frac{s_2 - s_1}{s_{fe}} &= 1.3028, \quad s_{fe} = 6.0562 \text{ kJ/kg.K} \\
\chi_2 &= \frac{s_2 - s_1}{s_{fe}} = \frac{2.4467 - 1.3028}{6.0562} = 0.1889 \\
\end{align*}
\]

\[
\begin{align*}
\nu_2 &= \frac{u_f + 0.1889(2088.2)}{417.40} = 811.83 \text{ kJ/kg} \\
\end{align*}
\]

**Analysis**
We idealize the water tank as a closed system that undergoes a reversible adiabatic process with negligible changes in kinetic and potential energies. The work done during this idealized process represents the explosive energy of the tank, and is determined from the closed system energy balance to be

\[
E_{in} - E_{out} = \Delta E_{system}
\]

\[
-W_{b,out} = \Delta U = m(u_2 - u_1)
\]

\[
E_{exp} = W_{b,out} = m(u_1 - u_2)
\]

where

\[
m = \frac{\nu}{\nu_1} = \frac{0.080 \text{ m}^3}{0.001177 \text{ m}^3/\text{kg}} = 67.99 \text{ kg}
\]

Substituting,

\[
E_{exp} = (67.99 \text{ kg})[906.12 - 811.83] \text{ kJ/kg} - 6410 \text{ kJ}
\]

which is equivalent to

\[
m_{TNT} = \frac{6410 \text{ kJ}}{3250 \text{ kJ/kg}} = 1.972 \text{ kg TNT}
\]