6.3 Using the appropriate table, determine the change in specific entropy between the specified states, in kJ/kg·K.
(a) water, \( p_1 = 10 \text{ MPa}, T_1 = 400\, ^\circ\text{C}, p_2 = 10 \text{ MPa}, \ T_2 = 100\, ^\circ\text{C}. \)
(b) Refrigerant 134a, \( h_1 = 111.44 \text{ kJ/kg}, T_1 = -40\, ^\circ\text{C}, \) saturated vapor at \( p_2 = 5 \text{ bar} \)
(c) air as an ideal gas, \( T_1 = 7\, ^\circ\text{C}, p_1 = 2 \text{ bar}, \ T_2 = 327\, ^\circ\text{C}, \) \( p_2 = 1 \text{ bar}. \)
(d) hydrogen \((\text{H}_2)\) as an ideal gas, \( T_1 = 727\, ^\circ\text{C}, p_1 = 1 \text{ bar}, \ T_2 = 25\, ^\circ\text{C}, p_2 = 3 \text{ bar}. \)

6.4 Using the appropriate table, determine the change in specific entropy between the specified states, in Btu/lb·°R.
(a) water, \( p_1 = 1000 \text{ lbf/in}^2, T_1 = 800\, ^\circ\text{F}, p_2 = 1000 \text{ lbf/in}^2, \ T_2 = 100\, ^\circ\text{F}. \)
(b) Refrigerant 134a, \( h_1 = 47.91 \text{ Btu/lb}, T_1 = -40\, ^\circ\text{F}, \) saturated vapor at \( p_2 = 40 \text{ lbf/in}^2 \)
(c) air as an ideal gas, \( T_1 = 40\, ^\circ\text{F}, p_1 = 2 \text{ atm}, T_2 = 420\, ^\circ\text{F}, \) \( p_2 = 1 \text{ atm}. \)
(d) carbon dioxide as an ideal gas, \( T_1 = 820\, ^\circ\text{F}, p_1 = 1 \text{ atm}, \ T_2 = 77\, ^\circ\text{F}, p_2 = 3 \text{ atm}. \)

6.5 Using IT, determine the specific entropy of water at the indicated states. Compare with results obtained from the appropriate table.
(a) Specific entropy, in kJ/kg·K, for the cases of Problem 6.1.
(b) Specific entropy, in Btu/lb·°R, for the cases of Problem 6.2.

6.6 Using IT, determine the change in specific entropy between the specified states. Compare with results obtained from the appropriate table.
(a) Specific entropy change, in kJ/kg·K, for the cases of Problem 6.3.
(b) Specific entropy change, in Btu/lb·°R, for the cases of Problem 6.4.

6.7 Using steam table data, determine the indicated property data for a process in which there is no change in specific entropy between state 1 and state 2. In each case, locate the states on a sketch of the T-s diagram.
(a) \( T_1 = 40\, ^\circ\text{C}, x_1 = 100\%, p_2 = 150 \text{ kPa}. \) Find \( T_2, \) in °C, and \( \Delta h, \) in kJ/kg.
(b) \( T_1 = 10\, ^\circ\text{C}, x_1 = 75\%, p_2 = 1 \text{ MPa}. \) Find \( T_2, \) in °C, and \( \Delta u, \) in kJ/kg.

6.8 Using the appropriate table, determine the indicated property for a process in which there is no change in specific entropy between state 1 and state 2.
(a) water, \( p_1 = 14.7 \text{ lbf/in}^2, T_1 = 500\, ^\circ\text{F}, p_2 = 100 \text{ lbf/in}^2. \) Find \( T_2 \) in °F.
(b) water, \( T_1 = 10\, ^\circ\text{C}, x_1 = 0.75, \) saturated vapor at state 2. Find \( p_2 \) in bar.
(c) air as an ideal gas, \( T_1 = 27^\circ\text{C}, p_1 = 1.5 \text{ bar}, T_2 = 127^\circ\text{C}. \) Find \( p_2 \) in bar.
(d) air as an ideal gas, \( T_1 = 100^\circ\text{F}, p_1 = 3 \text{ atm}, p_2 = 2 \text{ atm}. \) Find \( T_2 \) in °F.
(e) Refrigerant 134a, \( T_1 = 20^\circ\text{C}, p_1 = 5 \text{ bar}, p_2 = 1 \text{ bar}. \) Find \( u_2 \) in m³/kg.

6.9 Using IT, obtain the property data requested in (a) Problem 6.7, (b) Problem 6.8, and compare with data obtained from the appropriate table.

6.10 Propane undergoes a process from state 1, where \( p_1 = 1.4 \text{ MPa}, T_1 = 60^\circ\text{C}, \) to state 2, where \( p_2 = 1.0 \text{ MPa}. \) during which the change in specific entropy is \( s_2 - s_1 = -0.055 \text{ kJ/kg·K}. \) At state 2, determine the temperature, in °C, and the specific enthalpy, in kJ/kg.

6.11 Air in a piston-cylinder assembly undergoes a process from state 1, where \( T_1 = 300\, ^\circ\text{K}, p_1 = 100 \text{ kPa}. \) to state 2, where \( T_2 = 500\, ^\circ\text{K}, p_2 = 650 \text{ kPa}. \) Using the ideal gas model for air, determine the change in specific entropy between these states, in kJ/kg·K, if the process occurs (a) without internal irreversibilities, (b) with internal irreversibilities.

6.12 Methane gas \((\text{CH}_4)\) enters a compressor at 298 K, 1 bar and exits at 2 bar and temperature \( T \). Employing the ideal gas model, determine \( T \) in K, if there is no change in specific entropy from inlet to exit.

6.13 One-quarter lbmol of nitrogen gas \((\text{N}_2)\) undergoes a process from \( p_1 = 20 \text{ lbf/in}^2, T_1 = 500^\circ\text{R}, \) to \( p_2 = 150 \text{ lbf/in}^2. \) For the process \( W = -500 \text{ Btu} \) and \( Q = -125.9 \text{ Btu}. \) Employing the ideal gas model, determine
(a) \( T_2, \) in °R.
(b) the change in entropy, in Btu/R.

Show the initial and final states on a T-s diagram.

6.14 One kilogram of water contained in a piston-cylinder assembly, initially at 160°C, 150 kPa, undergoes an isothermal compression process to saturated liquid. For the process, \( W = -471.5 \text{ kJ}. \) Determine for the process,
(a) the heat transfer, in kJ.
(b) the change in entropy, in kJ/K.

Show the process on a sketch of the T-s diagram.

6.15 One-tenth kmol of carbon monoxide \((\text{CO})\) in a piston-cylinder assembly undergoes a process from \( p_1 = 150 \text{ kPa}, T_1 = 300 \text{ K}, \) to \( p_2 = 500 \text{ kPa}, T_2 = 370 \text{ K}. \) For the process, \( W = -300 \text{ kJ}. \) Employing the ideal gas model, determine
(a) the heat transfer, in kJ.
(b) the change in entropy, in kJ/K.

Show the process on a sketch of the T-s diagram.

6.16 Argon in a piston-cylinder assembly is compressed from state 1, where \( T_1 = 300 \text{ K}, V_1 = 1 \text{ m}^3, \) to state 2, where \( T_2 = 200 \text{ K}. \) If the change in specific entropy is \( s_2 - s_1 = -0.27 \text{ kJ/kg·K}. \) determine the final volume, in m³. Assume the ideal gas model with \( k = 1.67. \)

6.17 Steam enters a turbine operating at steady state at 1 MPa, 200°C and exits at 40°C with a quality of 83%. Stray heat transfer and kinetic and potential energy effects are negligible. Determine (a) the power developed by the turbine, in kJ per kg of steam flowing, (b) the change in specific entropy from inlet to exit, in kJ/K per kg of steam flowing.

6.18 Answer the following true or false. Explain.
(a) The change of entropy of a closed system is the same for every process between two specified states.
(b) The entropy of a fixed amount of an ideal gas increases in every isothermal compression.
(c) The specific internal energy and enthalpy of an ideal gas are each functions of temperature alone but its specific entropy depends on two independent intensive properties.
(d) One of the $T \, ds$ equations has the form $T \, ds = du - p \, dv$.
(e) The entropy of a fixed amount of an incompressible substance increases in every process in which temperature decreases.

6.19 A closed system consists of an ideal gas with constant specific heat ratio $k$.
(a) The gas undergoes a process in which temperature increases from $T_1$ to $T_2$. Show that the entropy change for the process is greater if the change in state occurs at constant pressure than if it occurs at constant volume.
Sketch the processes on $p-v$ and $T-s$ coordinates.
(b) Using the results of (a), show on $T-s$ coordinates that a line of constant specific volume passing through a state has a greater slope than a line of constant pressure passing through that state.
(c) The gas undergoes a process in which pressure increases from $p_1$ to $p_2$. Show that the ratio of the entropy change for an isothermal process to the entropy change for a constant-volume process is $(1 - k)$. Sketch the processes on $p-v$ and $T-s$ coordinates.

Analyzing Internally Reversible Processes

6.20 One kilogram of water in a piston-cylinder assembly undergoes the two internally reversible processes in series shown in Fig. P6.20. For each process, determine, in kJ, the heat transfer and the work.

![Fig. P6.20](image)

6.21 One kilogram of water in a piston-cylinder assembly undergoes the two internally reversible processes in series shown in Fig. P6.21. For each process, determine, in kJ, the heat transfer and the work.

![Fig. P6.21](image)

6.23 One pound mass of water initially a saturated liquid at 1 atm undergoes a constant-pressure, internally reversible expansion to $x = 90\%$. Determine the work and heat transfer, each in Btu. Sketch the process on $p-v$ and $T-s$ coordinates. Associate the work and heat transfer with areas on these diagrams.

6.24 A gas initially at 14 bar and $60^\circ$C expands to a final pressure of 2.8 bar in an isothermal, internally reversible process. Determine the heat transfer and the work, each in kJ per kg of gas, if the gas is (a) Refrigerant 134a, (b) air as an ideal gas. Sketch the processes on $p-v$ and $T-s$ coordinates.

6.25 Reconsider the data of Problem 6.24, but now suppose the gas expands to 2.8 bar isentropically. Determine the work, in kJ per kg of gas, if the gas is (a) Refrigerant 134a, (b) air as an ideal gas. Sketch the processes on $p-v$ and $T-s$ coordinates.

6.26 Nitrogen ($N_2$) initially occupying 0.5 m$^3$ at 1.0 bar, 20$^\circ$C undergoes an internally reversible compression during which $pV^{1.30} = \text{constant}$ to a final state where the temperature is 200$^\circ$C. Assuming the ideal gas model, determine
(a) the pressure at the final state, in bar.
(b) the work and heat transfer, each in kJ.
(c) the entropy change, in kJ/K.

6.27 Air in a piston-cylinder assembly and modeled as an ideal gas undergoes two internally reversible processes in series from state 1, where $T_1 = 290$ K, $p_1 = 1$ bar.

**Process 1-2:** Compression to $p_2 = 5$ bar during which $pV^{1.30} = \text{constant}$

**Process 2-3:** Isentropic expansion to $p_3 = 1$ bar.
(a) Sketch the two processes in series on $T-s$ coordinates.
(b) Determine the temperature at state 2, in K.
(c) Determine the net work, in kJ/kg.

6.28 Air in a piston-cylinder assembly undergoes a thermodynamic cycle consisting of three internally reversible processes in series.

**Process 1-2:** Constant-volume heating from $T_1 = 288$ K, $p_1 = 0.1$ MPa to $p_2 = 0.42$ MPa.

**Process 2-3:** Constant-pressure cooling.

**Process 3-1:** Isothermal heating to the initial state.
Employing the ideal gas model with $c_v = 1$ kJ/kg · K, evaluate the change in specific entropy, in kJ/kg · K, for each process. Sketch the cycle on $p-v$ and $T-s$ coordinates. For each process, associate work and heat transfer with areas on these diagrams, respectively.

6.29 One-tenth kilogram of a gas in a piston-cylinder assembly undergoes a Carnot power cycle for which the isothermal expansion occurs at 800 K. The change in specific entropy of the gas during the isothermal compression, which occurs at 400 K, is $-25$ kJ/kg · K. Determine (a) the net work developed per cycle, in kJ, and (b) the thermal efficiency.

6.30 One pound mass of air as an ideal gas contained within a piston-cylinder assembly undergoes a Carnot power cycle. At the beginning of the isothermal expansion, the temperature is 1600°F and the pressure is 1200 lb/in.$^2$. The isothermal
compression occurs at 500°F and the heat added per cycle is 40.0 Btu. Assuming the ideal gas model for the air, determine
(a) the pressures at the end of the isothermal expansion, the adiabatic expansion, and the isothermal compression, each in lbf/ft²;
(b) the net work developed per cycle, in Btu.
(c) the thermal efficiency.

6.31 Air in a piston–cylinder assembly undergoes a Carnot power cycle. The isothermal expansion and compression processes occur at 1400 K and 350 K, respectively. The pressures at the beginning and end of the isothermal compression are 100 kPa and 500 kPa, respectively. Assuming the ideal gas model with \( c_p = 1.005 \text{ kJ/kg} \cdot \text{K} \), determine
(a) the pressures at the beginning and end of the isothermal expansion, each in kPa.
(b) the heat transfer and work, in kJ/kg, for each process.
(c) the thermal efficiency.

6.32 Water in a piston–cylinder assembly undergoes a Carnot power cycle. At the beginning of the isothermal expansion, the temperature is 250°C and the quality is 80%. The isothermal expansion continues until the pressure is 2 MPa. The adiabatic expansion then occurs to a final temperature of 175°C.
(a) Sketch the cycle on T–s coordinates.
(b) Determine the heat transfer and work, in kJ/kg, for each process.
(c) Evaluate the thermal efficiency.

6.33 A Carnot power cycle operates at steady state as shown in Fig. 5.15 with water as the working fluid. The boiler pressure is 200 lbf/in², with saturated liquid entering and saturated vapor exiting. The condenser pressure is 20 lbf/in².
(a) Sketch the cycle on T–s coordinates.
(b) Determine the heat transfer and work for each process, in Btu per lb of water flowing.
(c) Evaluate the thermal efficiency.

6.34 Figure P6.34 shows a Carnot heat pump cycle operating at steady state with ammonia as the working fluid. The condenser temperature is 120°F, with saturated vapor entering and saturated liquid exiting. The evaporator temperature is 10°F.
(a) Determine the heat transfer and work for each process, in Btu per lb of ammonia flowing.
(b) Evaluate the coefficient of performance for the heat pump.
(c) Evaluate the coefficient of performance for a Carnot refrigeration cycle operating as shown in the figure.

6.35 Figure P6.35 gives the schematic of a vapor power plant in which water steadily circulates through the four components shown. The water flows through the boiler and condenser at constant pressure, and flows through the turbine and pump adiabatically.
(a) Sketch the cycle on T–s coordinates.
(b) Determine the thermal efficiency and compare with the thermal efficiency of a Carnot cycle operating between the same maximum and minimum temperatures.
Applying the Entropy Balance: Closed Systems

6.36 A closed system undergoes a process in which work is done on the system and the heat transfer $Q$ occurs only at temperature $T_a$. For each case, determine whether the entropy change of the system is positive, negative, zero, or indeterminate.

(a) internally reversible process, $Q > 0$.
(b) internally reversible process, $Q = 0$.
(c) internally reversible process, $Q < 0$.
(d) internal irreversibilities present, $Q > 0$.
(e) internal irreversibilities present, $Q = 0$.
(f) internal irreversibilities present, $Q < 0$.

6.37 Answer the following true or false. Explain.

(a) A process that violates the second law of thermodynamics violates the first law of thermodynamics.
(b) When a net amount of work is done on a closed system undergoing an internally reversible process, a net heat transfer of energy from the system also occurs.
(c) One corollary of the second law of thermodynamics states that the change in entropy of a closed system must be greater than or equal to zero.
(d) A closed system can experience an increase in entropy only when irreversibilities are present within the system during the process.
(e) Entropy is produced in every internally reversible process of a closed system.
(f) In an adiabatic and internally reversible process of a closed system, the entropy remains constant.
(g) The energy of an isolated system must remain constant, but the entropy can only decrease.

6.38 A fixed mass of water $m$, initially a saturated liquid, is brought to a saturated vapor condition while its pressure and temperature remain constant. Volume change is the only work mode.

(a) Derive expressions for the work and heat transfer in terms of the mass $m$ and properties that can be obtained directly from the steam tables.
(b) Demonstrate that this process is internally reversible.

6.39 Five kg of water contained in a piston-cylinder assembly expand from an initial state where $T_1 = 400$°C, $p_1 = 700$ kPa to a final state where $T_2 = 200$°C, $p_2 = 300$ kPa, with no significant effects of kinetic and potential energy. The accompanying table provides additional data at the two states. It is claimed that the water undergoes an adiabatic process between these states, while developing work. Evaluate this claim.

<table>
<thead>
<tr>
<th>State</th>
<th>$T$ (°C)</th>
<th>$p$ (kPa)</th>
<th>$u$ (m$^3$/kg)</th>
<th>$u$(kJ/kg)</th>
<th>$h$(kJ/kg)</th>
<th>$s$ (kJ/kg·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400</td>
<td>700</td>
<td>0.4397</td>
<td>2960.9</td>
<td>3286.7</td>
<td>7.6530</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>300</td>
<td>0.7160</td>
<td>2630.7</td>
<td>2865.5</td>
<td>7.3115</td>
</tr>
</tbody>
</table>

6.40 Two m$^3$ of air in a rigid, insulated container fitted with a paddle wheel is initially at 293 K, 200 kPa. The air receives 710 kJ by work from the paddle wheel. Assuming the ideal gas model with $c_v = 0.72$ kJ/kg·K, determine for the air (a) the mass, in kg, (b) final temperature, in K, and (c) the amount of entropy produced, in kJ/K.

6.41 A rigid, insulated container fitted with a paddle wheel contains 5 lb of water, initially at 260°F and a quality of 60%.

The water is stirred until the temperature is 350°F. For the water, determine (a) the work, in Btu, and (b) the amount of entropy produced, in Btu°R.

6.42 One kilogram of air contained in a piston-cylinder assembly is initially at 1 bar and 450 K. Can a final state at 2 bar and 350 K be attained in an adiabatic process?

6.43 One pound mass of Refrigerant 134a contained within a piston-cylinder assembly undergoes a process from a state where the pressure is 120 lbf/in.$^2$ and the quality is 40% to a state where the temperature is 50°F and the refrigerant is saturated liquid. Determine the change in specific entropy of the refrigerant, in Btu/lb · °R. Can this process be accomplished adiabatically?

6.44 Refrigerant 134a contained in a piston-cylinder assembly rapidly expands from an initial state where $T_1 = 140$°F, $p_1 = 200$ lbf/in.$^2$ to a final state where $p_2 = 5$ lbf/in.$^2$ and the quality, $x_2$, is (a) 99%, (b) 95%. In each case, determine if the process can occur adiabatically. If yes, determine the work, in Btu/lb, for an adiabatic expansion between these states. If no, determine the direction of the heat transfer.

6.45 One kg of air contained in a piston-cylinder assembly undergoes a process from an initial state where $T_1 = 300$ K, $u_1 = 0.8$ m$^3$/kg to a final state where $T_2 = 420$ K, $v_2 = 0.2$ m$^3$/kg. Can this process occur adiabatically? If yes, determine the work, in kJ, for an adiabatic process between these states. If no, determine the direction of the heat transfer. Assume the ideal gas model for air.

6.46 Air as an ideal gas contained within a piston–cylinder assembly is compressed between two specified states. In each of the following cases, can the process occur adiabatically? If yes, determine the work in appropriate units for an adiabatic process between these states. If no, determine the direction of the heat transfer.

(a) State 1: $p_1 = 0.1$ MPa, $T_1 = 27$°C. State 2: $p_2 = 0.5$ MPa, $T_2 = 207$°C. Use Table A-22 data.
(b) State 1: $p_1 = 3$ atm, $T_1 = 80$°F. State 2: $p_2 = 10$ atm, $T_2 = 240$°F. Assume $c_p = 0.241$ Btu/lb°R.

6.47 A piston–cylinder assembly initially contains 0.04 m$^3$ of water at 1.0 MPa, 320°C. The water expands adiabatically to a final pressure of 0.1 MPa. Develop a plot of the work done by the water, in kJ, versus the amount of entropy produced, in kJ/K.

6.48 Two pounds mass of steam contained in a piston–cylinder assembly expands adiabatically from state 1, where $p_1 = 100$ lbf/in.$^2$, $T_1 = 500$°F, to a final pressure of 10 lbf/in.$^2$. Develop a plot of the work done by the water, in Btu, versus the amount of entropy produced, in Btu°R.

6.49 One-tenth kilogram of water, initially at 300 kPa, 200°C, is compressed in a piston–cylinder assembly to 1500 kPa, 210°C. If heat transfer from the water occurs at an average temperature of 205°C, determine the minimum theoretical work of compression, in kJ.

6.50 One-half kilogram of propane initially at 4 bar, 30°C undergoes a process to 14 bar, 100°C while being rapidly compressed in a piston–cylinder assembly. Heat transfer with the surroundings at 20°C occurs through a thin wall.
6.79 As shown in Fig. P6.79, a turbine is located between two tanks. Initially, the smaller tank contains steam at 3.0 MPa, 280°C and the larger tank is evacuated. Steam is allowed to flow from the smaller tank, through the turbine, and into the larger tank until equilibrium is attained. If heat transfer with the surroundings is negligible, determine the maximum theoretical work that can be developed, in kJ.

![Fig. P6.79](image)

Applying the Entropy Balance: Control Volumes

6.80 A gas flows through a one-inlet, one-exit control volume operating at steady state. Heat transfer at the rate \( Q_w \) takes place only at a location on the boundary where the temperature is \( T_b \). For each of the following cases, determine whether the specific entropy of the gas at the exit is greater than, equal to, or less than the specific entropy of the gas at the inlet:

(a) no internal irreversibilities, \( Q_w = 0 \).
(b) no internal irreversibilities, \( Q_w < 0 \).
(c) no internal irreversibilities, \( Q_w > 0 \).
(d) internal irreversibilities, \( Q_w \approx 0 \).

6.81 Steam at 10 bar, 600°C, 50 m/s enters an insulated turbine operating at steady state and exits at 0.35 bar, 100 m/s. The work developed per kg of steam flowing is claimed to be (a) 1000 kJ/kg, (b) 500 kJ/kg. Can either claim be correct? Explain.

6.82 Air enters an insulated turbine operating at steady state at 6.5 bar, 687°C and exits at 1 bar, 327°C. Neglecting kinetic and potential energy changes and assuming the ideal gas model, determine

(a) the work developed, in kJ per kg of air flowing through the turbine.
(b) whether the expansion is internally reversible, irreversible, or impossible.

6.83 Propane at 0.1 MPa, 20°C enters an insulated compressor operating at steady state and exits at 0.4 MPa, 90°C. Neglecting kinetic and potential energy effects, determine

(a) the power required by the compressor, in kJ per kg of propane flowing.
(b) the rate of entropy production within the compressor, in kJ/K per kg of propane flowing.

6.84 By injecting liquid water into superheated steam, the desuperheater shown in Fig. P6.84 has a saturated vapor stream at its exit. Steady-state operating data are provided in the accompanying table. Stray heat transfer and all kinetic and potential energy effects are negligible. (a) Locate states 1, 2, and 3 on a sketch of the T-s diagram. (b) Determine the rate of entropy production within the desuperheater, in kW/K.

<table>
<thead>
<tr>
<th>State</th>
<th>( p ) (MPa)</th>
<th>( T ) (°C)</th>
<th>( v \times 10^5 ) (m³/kg)</th>
<th>( u ) (kJ/kg)</th>
<th>( h ) (kJ/kg)</th>
<th>( s ) (kJ/kg·K)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>167.2</td>
<td>169.9</td>
<td>0.5714</td>
</tr>
<tr>
<td>2</td>
<td>2.7</td>
<td>300</td>
<td>91.01</td>
<td>2757.0</td>
<td>3002.8</td>
<td>6.6001</td>
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<tr>
<td>3</td>
<td>2.5</td>
<td>sat. vap.</td>
<td>79.98</td>
<td>2603.1</td>
<td>2803.1</td>
<td>6.2575</td>
</tr>
</tbody>
</table>

![Fig. P6.84](image)

6.85 An inventor claims that at steady state the device shown in Fig. P6.85 develops power from entering and exiting streams of water at a rate of 1174.9 kW. The accompanying table provides data for inlet 1 and exits 3 and 4. The pressure at inlet 2 is 1 bar. Stray heat transfer and kinetic and potential energy effects are negligible. Evaluate the inventor’s claim.

<table>
<thead>
<tr>
<th>State</th>
<th>( m ) (kg/s)</th>
<th>( p ) (bar)</th>
<th>( T ) (°C)</th>
<th>( v ) (m³/kg)</th>
<th>( u ) (kJ/kg)</th>
<th>( h ) (kJ/kg)</th>
<th>( s ) (kJ/kg·K)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
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<td>3.334</td>
<td>3049.0</td>
<td>3382.4</td>
<td>8.6926</td>
</tr>
<tr>
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<td>4</td>
<td>3</td>
<td>200</td>
<td>1.080</td>
<td>2654.4</td>
<td>2870.5</td>
<td>7.5066</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>4</td>
<td>200</td>
<td>0.773</td>
<td>2964.4</td>
<td>3273.4</td>
<td>7.8985</td>
</tr>
</tbody>
</table>

![Fig. P6.85](image)

6.86 Figure P6.86 provides steady-state operating data for a well-insulated device having steam entering at one location and exiting at another. Neglecting kinetic and potential energy effects, determine (a) the direction of flow and (b) the
power output or input, as appropriate, in kJ per kg of steam flowing.

Fig. P6.86

6.87 Steam enters a well-insulated nozzle operating at steady state at 1000°F, 500 lbf/in.² and a velocity of 10 ft/s. At the nozzle exit, the pressure is 14.7 lbf/in.² and the velocity is 4055 ft/s. Determine the rate of entropy production, in Btu/°R per lb of steam flowing.

6.88 Air at 400 kPa, 970 K enters a turbine operating at steady state and exits at 100 kPa, 670 K. Heat transfer from the turbine occurs at an average outer surface temperature of 315 K at the rate of 30 kJ per kg of air flowing. Kinetic and potential energy effects are negligible. For air as an ideal gas with \( c_p = 1.1 \text{ kJ/kg} \cdot \text{K} \), determine (a) the rate power is developed, in kJ per kg of air flowing, and (b) the rate of entropy production within the turbine, in kJ/K per kg of air flowing.

6.89 Steam at 240°C, 700 kPa enters an open feedwater heater operating at steady state with a mass flow rate of 0.5 kg/s. A separate stream of liquid water enters at 45°C, 700 kPa with a mass flow rate of 4 kg/s. A single mixed stream exits at 700 kPa and temperature \( T \). Stray heat transfer and kinetic and potential energy effects can be ignored. Determine (a) \( T \), in °C, and (b) the rate of entropy production within the feedwater heater, in kW/K. (c) Locate the three principal states on a sketch of the \( T-s \) diagram.

6.90 By injecting liquid water into superheated vapor, the desuperheater shown in Fig. P6.90 has a saturated vapor stream at its exit. Steady-state operating data are shown on the figure. Ignoring stray heat transfer and kinetic and potential energy effects, determine (a) the mass flow rate of the superheated vapor stream, in kg/min, and (b) the rate of entropy production within the desuperheater, in kW/K.

6.91 Air at 600 kPa, 330 K enters a well-insulated, horizontal pipe having a diameter of 1.2 cm and exits at 120 kPa, 300 K. Applying the ideal gas model for air, determine at steady state (a) the inlet and exit velocities, each in m/s, (b) the mass flow rate, in kg/s, and (c) the rate of entropy production, in kW/K.

6.92 At steady state, air at 200 kPa, 52°C and a mass flow rate of 0.5 kg/s enters an insulated duct having differing inlet and exit cross-sectional areas. At the duct exit, the pressure of the air is 100 kPa, the velocity is 255 m/s, and the cross-sectional area is \( 2 \times 10^{-3} \) m². Assuming the ideal gas model, determine

(a) the temperature of the air at the exit, in °C.
(b) the velocity of the air at the inlet, in m/s.
(c) the inlet cross-sectional area, in m².
(d) the rate of entropy production within the duct, in kW/K.

6.93 For the computer of Example 4.8, determine the rate of entropy production, in W/K, when air exits at 32°C. Ignore the change in pressure between the inlet and exit.

6.94 For the computer of Problem 4.86, determine the rate of entropy production, in kW/K, ignoring the change in pressure between the inlet and exit.

6.95 For the water-jacketed electronics housing of Problem 4.87, determine the rate of entropy production, in kW/K, when water exits at 26°C.

6.96 Electronic components are mounted on the inner surface of a horizontal cylindrical duct whose inner diameter is 0.2 m, as shown in Fig. P6.96. To prevent overheating of the electronics, the cylinder is cooled by a stream of air flowing through it and by convection from its outer surface. Air enters the duct at 25°C, 1 bar and a velocity of 0.3 m/s and exits at 40°C with negligible changes in kinetic energy and heat transfer. If it is desired to keep the temperature of the air at the exit to be 40°C, determine (a) the rate of entropy production, in kW/K, (b) the mass flow rate of the air, in kg/s, and (c) the rate of entropy generation in the coil, in kW/K.

Fig. P6.90
pressure. Convective cooling occurs on the outer surface to the surroundings, which are at 25°C, in accord with hA = 3.4 W/K, where h is the heat transfer coefficient and A is the surface area. The electronic components require 0.20 kW of electric power. For a control volume enclosing the cylinder, determine at steady state (a) the mass flow rate of the air, in kg/s, (b) the temperature on the outer surface of the duct, in °C, and (c) the rate of entropy production, in W/K. Assume the ideal gas model for air.

6.97 Air enters a turbine operating at steady state at 500 kPa, 860 K and exits at 100 kPa. A temperature sensor indicates that the exit air temperature is 460 K. Stray heat transfer and kinetic and potential energy effects are negligible, and the air can be modeled as an ideal gas. Determine if the exit temperature reading can be correct. It yes, determine the power developed by the turbine for an expansion between these states, in kJ per kg of air flowing. If no, provide an explanation with supporting calculations.

6.98 Figure P6.98 provides steady-state test data for a control volume in which two entering streams of air mixed to form a single exiting stream. Stray heat transfer and kinetic and potential energy effects are negligible. A hard-to-read photocopy of the data sheet indicates that the pressure of the exiting stream is either 1.0 MPa or 1.8 MPa. Assuming the ideal gas model for air with cp = 1.02 kJ/kg · K, determine if either or both of these pressure values can be correct.

\[
\begin{align*}
T_1 &= 800 \text{ K} \\
p_1 &= 1.8 \text{ MPa} \\
m_1 &= 1 \text{ kg/s} \\
\dot{Q}_c &= 0, \dot{W}_c = 0 \\
T_2 &= 600 \text{ K} \\
p_2 &= 1.0 \text{ MPa} \\
m_2 &= 2 \text{ kg/s} \\
\frac{p_3}{p_2} &= ?
\end{align*}
\]

**Fig. P6.98**

6.99 Hydrogen gas (H₂) at 35°C and pressure p enters an insulated control volume operating at steady state for which \( \dot{W}_c = 0 \). Half of the hydrogen exits the device at 2 bar and 90°C and the other half exits at 2 bar and -20°C. The effects of kinetic and potential energy are negligible. Employing the ideal gas model with constant \( cp = 14.3 \text{ kJ/kg · K} \), determine the minimum possible value for the inlet pressure \( p \), in bar.

6.100 According to test data, a new type of engine takes in streams of water at 200°C, 3 bar and 100°C, 3 bar. The mass flow rate of the higher temperature stream is twice that of the other. A single stream exits at 3.0 bar with a mass flow rate of 5400 kg/h. There is no significant heat transfer between the engine and its surroundings, and kinetic and potential energy effects are negligible. For operation at steady state, determine the maximum theoretical rate that power can be developed, in kW.

6.101 A patent application describes a device for chilling water. At steady state, the device receives energy by heat transfer at a location on its surface where the temperature is 540°F and discharges energy by heat transfer to the surroundings at another location on its surface where the temperature is 100°F. A warm liquid water stream enters at 100°F, 1 atm and a cool stream exits at temperature \( T \) and 1 atm. The device requires no power input to operate, there are no significant effects of kinetic and potential energy, and the water can be modeled as incompressible. Plot the minimum theoretical heat addition required, in Btu per lb of cool water exiting the device, versus \( T \) ranging from 60 to 100°F.

6.102 Steam at 550 lbf/in.², 700°F enters an insulated turbine operating at steady state with a mass flow rate of 1 lb/s. A two-phase liquid–vapor mixture exits the turbine at 14.7 lbf/in.² with quality \( x \). Plot the power developed, in Btu/s, and the rate of entropy production, in Btu/°R·s, each versus \( x \).

6.103 Refrigerant 134a at 20 lbf/in.², 0°F enters a compressor operating at steady state with a mass flow rate of 250 lb/h and exits at 140 lbf/in.², 220°F. Heat transfer occurs from the compressor to its surroundings, which are at 70°F. Changes in kinetic and potential energy can be ignored. The power input is claimed to be 2 horsepower. Determine whether this claim can be correct.

6.104 Steam enters a horizontal 15-cm-diameter pipe as a saturated vapor at 5 bar with a velocity of 10 m/s and exits at 4.5 bar with a quality of 95%. Heat transfer from the pipe to the surroundings at 300 K takes place at an average outer surface temperature of 315 K. For operation at steady state, determine

(a) the velocity at the exit, in m/s.
(b) the rate of heat transfer from the pipe, in kW.
(c) the rate of entropy production, in kW/K, for a control volume comprising only the pipe and its contents.
(d) the rate of entropy production, in kW/K, for an enlarged control volume that includes the pipe and enough of its immediate surroundings so that heat transfer from the control volume occurs at 300 K.

Why do the answers of parts (c) and (d) differ?

6.105 Air at 500 kPa, 500 K and a mass flow of 600 kg/h enters a pipe passing overhead in a factory space. At the pipe exit, the pressure and temperature of the air are 475 kPa and 450 K, respectively. Air can be modeled as an ideal gas with \( k = 1.39 \). Kinetic and potential energy effects can be ignored. Determine at steady state, (a) the rate of heat transfer, in kW, for a control volume comprising the pipe and its contents, and (b) the rate of entropy production, in kW/K, for an enlarged control volume that includes the pipe and enough of its surroundings that heat transfer occurs at the ambient temperature, 300 K.

6.106 Steam enters a turbine operating at steady state at 6 MPa, 600°C with a mass flow rate of 125 kg/min and exits as saturated vapor at 20 kPa, producing power at a rate of 2 MW. Kinetic and potential energy effects can be ignored. Determine (a) the rate of heat transfer, in kW, for a control volume including the turbine and its contents, and (b) the rate of entropy production, in kW/K, for an enlarged control volume that includes the turbine and enough of its surroundings that heat transfer occurs at the ambient temperature, 27°C.

6.107 Air enters a compressor operating at steady state at 1 bar, 22°C with a volumetric flow rate of 1 m³/min and is compressed to 4 bar, 177°C. The power input is 3.5 kW. Employing the ideal gas model and ignoring kinetic and potential energy effects, obtain the following results:
6.118 For the control volume of Example 4.12, determine the amount of entropy produced during filling, in kJ/K. Repeat for the case where no work is developed by the turbine.

6.119 Steam is contained in a large vessel at 100 lbf/in.², 450°F. Connected to the vessel by a valve is an initially evacuated tank having a volume of 1 ft³. The valve is opened until the tank is filled with steam at pressure p. The filling is adiabatic, kinetic and potential energy effects are negligible, and the state of the large vessel remains constant.

(a) If \( p = 100 \text{ lbf/in.}^2 \), determine the final temperature of the steam within the tank, in °F, and the amount of entropy produced within the tank, in Btu/R.

(b) Plot the quantities of part (a) versus pressure \( p \) ranging from 10 to 100 lbf/in.².

6.120 A well-insulated rigid tank of volume 10 m³ is connected by a valve to a large-diameter supply line carrying air at 227°C and 10 bar. The tank is initially evacuated. Air is allowed to flow into the tank until the tank pressure is \( p \). Using the ideal gas model with constant specific heat ratio \( k \), plot tank temperature, in K, the mass of air in the tank, in kg, and the amount of entropy produced, in kJ/K, versus \( p \) in bar.

6.121 A 180-ft³ tank initially filled with air at 1 atm and 70°F is evacuated by a device known as a vacuum pump, while the tank contents are maintained at 70°F by heat transfer through the tank walls. The vacuum pump discharges air to the surroundings at the temperature and pressure of the surroundings, which are 1 atm and 70°F, respectively. Determine the minimum theoretical work required, in Btu.

Using Isentropic Processes/Efficiencies

6.122 Air in a piston–cylinder assembly is compressed isentropically from state 1, where \( T_1 = 35°C \), to state 2, where the specific volume is one-tenth of the specific volume at state 1. Applying the ideal gas model with \( k = 1.4 \), determine (a) \( T_2 \), in °C and (b) the work, in kJ/kg.

6.123 Air in a piston–cylinder assembly is compressed isentropically from \( T_1 = 60°F \), \( p_1 = 20 \text{ lbf/in.}^2 \) to \( p_2 = 2000 \text{ lbf/in.}^2 \). Assuming the ideal gas model, determine the temperature at state 2, in °R, using (a) data from Table A-22E, and (b) a constant specific heat ratio, \( k = 1.4 \). Compare the values obtained in parts (a) and (b) and comment.

6.124 Propane undergoes an isentropic expansion from an initial state where \( T_1 = 40°C \), \( p_1 = 1 \text{ MPa} \) to a final state where the temperature and pressure are \( T_2, p_2 \), respectively. Determine

(a) \( p_2 \), in kPa, when \( T_2 = -40°C \)

(b) \( T_2 \), in °C, when \( p_2 = 0.8 \text{ MPa} \)

6.125 Argon in a piston–cylinder assembly is compressed isentropically from state 1, where \( p_1 = 150 \text{ kPa} \), \( T_1 = 35°C \), to state 2, where \( p_2 = 300 \text{ kPa} \). Assuming the ideal gas model with \( k = 1.67 \), determine (a) \( T_2 \), in °C, and (b) the work, in kJ per kg of argon.

6.126 Air enters a turbine operating at steady state at 6 bar and 1100 K and expands isentropically to a state where the temperature is 700 K. Employing the ideal gas model with data from Table A-22, and ignoring kinetic and potential energy changes, determine the pressure at the exit, in bar, and the work, in kJ per kg of air flowing.

6.127 A rigid well-insulated tank having a volume of 0.2 m³ is filled initially with Refrigerant 134a vapor at a pressure of 10 bar and a temperature of 40°C. A leak develops and refrigerant slowly escapes until the pressure within the tank becomes 1 bar. Determine

(a) the final temperature of the refrigerant within the tank, in °C.

(b) the amount of mass that exits the tank, in kg.

6.128 Air in a piston–cylinder assembly is compressed isentropically from an initial state where \( T_1 = 340 \text{ K} \) to a final state where the pressure is 90% greater than at state 1. Assuming the ideal gas model, determine (a) \( T_2 \), in K, and (b) the work, in kJ/kg.

6.129 An ideal gas with constant specific heat ratio \( k \) enters a nozzle operating at steady state at pressure \( p_1 \), temperature \( T_1 \), and velocity \( V_1 \). The air expands isentropically to a pressure of \( p_2 \).

(a) Develop an expression for the velocity at the exit, \( V_2 \), in terms of \( k, R, V_1, T_1, p_1 \), and \( p_2 \), only.

(b) For \( V_1 = 0, T_1 = 1000 \text{ K}, p_2/p_1 = 0.1 \) and \( k = 1.4 \), find \( V_2 \), in m/s.

6.130 Air modeled as an ideal gas enters a turbine operating at steady state at 1040 K, 278 kPa and exits at 120 kPa. The mass flow rate is 5.5 kg/s, and the power developed is 1120 kW. Stray heat transfer and kinetic and potential energy effects are negligible. Determine (a) the temperature of the air at the turbine exit, in K, and (b) the isentropic turbine efficiency.

6.131 Water vapor at 1000°F, 140 lbf/in.² enters a turbine operating at steady state and expands to 2 lbf/in.². The mass flow rate is 4 lb/s and the power developed is 1600 Btu/s. Stray heat transfer and kinetic and potential energy effects are negligible. Determine the isentropic turbine efficiency.

6.132 Water vapor at 6 MPa, 600°C enters a turbine operating at steady state and expands to 10 kPa. The mass flow rate is 2 kg/s, and the power developed is 2626 kW. Stray heat transfer and kinetic and potential energy effects are negligible. Determine (a) the isentropic turbine efficiency and (b) the rate of entropy production within the turbine, in kW/K.

6.133 Water vapor at 800 lbf/in.², 1000°F enters a turbine operating at steady state and expands to 2 lbf/in.². The mass flow rate is 5.56 lb/s, and the isentropic turbine efficiency is 92%. Stray heat transfer and kinetic and potential energy effects are negligible. Determine the power developed by the turbine, in hp.

6.134 Air enters the compressor of a gas turbine power plant operating at steady state at 290 K, 100 kPa and exits at 420 K, 330 kPa. Stray heat transfer and kinetic and potential energy effects are negligible. Using the ideal gas model for air, determine the isentropic compressor efficiency.

6.135 Air at 25°C, 100 kPa enters a compressor operating at steady state and exits at 260°C, 650 kPa. Stray heat transfer and kinetic and potential energy effects are negligible. Modeling air as an ideal gas with \( k = 1.4 \), determine the isentropic compressor efficiency.
6.136 Air enters an insulated compressor operating at steady state at 1 bar, 350 K with a mass flow rate of 1 kg/s and exits at 4 bar. The isentropic compressor efficiency is 82%. Determine the power input, in kW, and the rate of entropy production, in kW/K, using the ideal gas model with data from Table A-22.

6.137 Refrigerant 134a enters a compressor operating at steady state as saturated vapor at 20°F and exits at a pressure of 120 psig. There is no significant heat transfer with the surroundings, and kinetic and potential energy effects can be ignored.

(a) Determine the minimum theoretical work input required, in Btu per lb of refrigerant flowing through the compressor, and the corresponding exit temperature, in °F.

(b) If the refrigerant exits at a temperature of 120°F, determine the isentropic compressor efficiency.

6.138 Air enters an insulated compressor operating at steady state at 0.95 bar, 27°C with a mass flow rate of 4000 kg/h and exits at 8.7 bar. Kinetic and potential energy effects are negligible.

(a) Determine the minimum theoretical power input required, in kW, and the corresponding exit temperature, in °C.

(b) If the exit temperature is 347°C, determine the power input, in kW, and the isentropic compressor efficiency.

6.139 Water vapor enters an insulated nozzle operating at steady state at 0.7 MPa, 320°C, 35 m/s and expands to 0.15 MPa. If the isentropic nozzle efficiency is 94%, determine the velocity at the exit, in m/s.

6.140 Helium gas at 810°K, 45 lb/in.² and a velocity of 10 ft/s enters an insulated nozzle operating at steady state and exits at 670°R, 25 lb/in.². Modeling helium as an ideal gas with k = 1.67, determine (a) the velocity at the nozzle exit, in ft/s, (b) the isentropic nozzle efficiency, and (c) the rate of entropy production within the nozzle, in Btu/R per lb of helium flowing.

6.141 Air modeled as an ideal gas enters a one-inlet, one-exit control volume operating at steady state at 100 lb/in.², 900°R and expands adiabatically to 25 lb/in.². Kinetic and potential energy effects are negligible. Determine the rate of entropy production, in Btu/R per lb of air flowing.

(a) if the control volume encloses a turbine having an isentropic turbine efficiency of 89.1%.

(b) if the control volume encloses a throttling valve.

6.142 Ammonia enters a valve as a saturated liquid at 7 bar with a mass flow rate of 0.06 kg/min and undergoes a throttling process to a pressure of 1 bar. Determine the rate of entropy production, in kW/K. If the valve were replaced by a power-recovery turbine operating at steady state, determine the maximum theoretical power that could be developed, in kW. Would you recommend using such a turbine? In each case, ignore heat transfer with the surroundings and changes in kinetic and potential energy.

6.143 Figure P6.143 provides the schematic of a heat pump using Refrigerant 134a as the working fluid, together with steady-state data at key points. The mass flow rate of the refrigerant is 7 kg/min, and the power input to the compressor is 5.17 kW. (a) Determine the coefficient of performance for the heat pump. (b) If the valve were replaced by a turbine, power could be produced, reducing thereby the power requirement of the heat pump system. Would you recommend this power-saving measure? Explain.

![Fig. P6.143](image)

6.144 Air enters an insulated diffuser operating at steady state at 1 bar, −3°C, and 260 m/s and exits with a velocity of 130 m/s. Employing the ideal gas model and ignoring potential energy, determine

(a) the temperature of the air at the exit, in °C.

(b) The maximum attainable exit pressure, in bar.

6.145 As shown in Fig. P6.145, air enters the diffuser of a jet engine at 18 kPa, 216 K with a velocity of 265 m/s, all data corresponding to high-altitude flight. The air flows adiabatically through the diffuser, decelerating to a velocity of 50 m/s at the diffuser exit. Assume steady-state operation, the ideal gas model for air, and negligible potential energy effects.

(a) Determine the temperature of the air at the exit of the diffuser, in K.

(b) If the air would undergo an isentropic process as it flows through the diffuser, determine the pressure of the air at the diffuser exit, in kPa.

(c) If friction were present, would the pressure of the air at the diffuser exit be greater than, less than, or equal to the value found in part (b)? Explain.

![Fig. P6.145](image)