

# Chapter 7

## ENTROPY

### Entropy and the Increase of Entropy Principle

**7-1C** Yes. Because we used the relation  $(Q_H/T_H) = (Q_L/T_L)$  in the proof, which is the defining relation of absolute temperature.

**7-2C** No. The  $\oint \delta Q$  represents the net heat transfer during a cycle, which could be positive.

**7-3C** Yes.

**7-4C** No. A system may reject more (or less) heat than it receives during a cycle. The steam in a steam power plant, for example, receives more heat than it rejects during a cycle.

**7-5C** No. A system may produce more (or less) work than it receives during a cycle. A steam power plant, for example, produces more work than it receives during a cycle, the difference being the net work output.

**7-6C** The entropy change will be the same for both cases since entropy is a property and it has a fixed value at a fixed state.

**7-7C** No. In general, that integral will have a different value for different processes. However, it will have the same value for all reversible processes.

**7-8C** Yes.

**7-9C** That integral should be performed along a reversible path to determine the entropy change.

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

**7-11C** The value of this integral is always larger for reversible processes.

**7-12C** No. Because the entropy of the surrounding air increases even more during that process, making the total entropy change positive.

**7-13C** It is possible to create entropy, but it is not possible to destroy it.

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7-14C Sometimes.

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7-15C Never.

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7-16C Always.

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7-17C Increase.

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7-18C Increases.

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7-19C Decreases.

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7-20C Sometimes.

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7-21C Yes. This will happen when the system is losing heat, and the decrease in entropy as a result of this heat loss is equal to the increase in entropy as a result of irreversibilities.

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7-22C They are heat transfer, irreversibilities, and entropy transport with mass.

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7-23C Greater than.

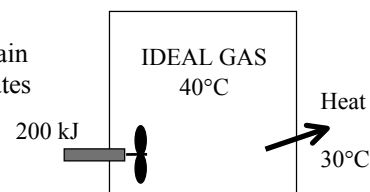
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7-24 A rigid tank contains an ideal gas that is being stirred by a paddle wheel. The temperature of the gas remains constant as a result of heat transfer out. The entropy change of the gas is to be determined.

**Assumptions** The gas in the tank is given to be an ideal gas.

**Analysis** The temperature and the specific volume of the gas remain constant during this process. Therefore, the initial and the final states of the gas are the same. Then  $s_2 = s_1$  since entropy is a property. Therefore,

$$\Delta S_{\text{sys}} = 0$$



**7-25** Air is compressed steadily by a compressor. The air temperature is maintained constant by heat rejection to the surroundings. The rate of entropy change of air 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** Air is an ideal gas. **4** The process involves no internal irreversibilities such as friction, and thus it is an isothermal, internally reversible process.

**Properties** Noting that  $h = h(T)$  for ideal gases, we have  $h_1 = h_2$  since  $T_1 = T_2 = 25^\circ\text{C}$ .

**Analysis** We take the compressor as the system. Noting that the enthalpy of air remains constant, the energy balance for this steady-flow system can be expressed in the rate form as

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

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

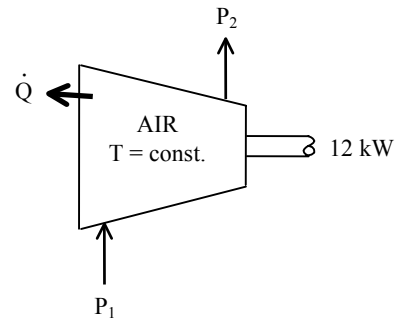
$$\dot{W}_{\text{in}} = \dot{Q}_{\text{out}}$$

Therefore,

$$\dot{Q}_{\text{out}} = \dot{W}_{\text{in}} = 12 \text{ kW}$$

Noting that the process is assumed to be an isothermal and internally reversible process, the rate of entropy change of air is determined to be

$$\Delta \dot{S}_{\text{air}} = -\frac{\dot{Q}_{\text{out,air}}}{T_{\text{sys}}} = -\frac{12 \text{ kW}}{298 \text{ K}} = \mathbf{-0.0403 \text{ kW/K}}$$



**7-26** Heat is transferred isothermally from a source to the working fluid of a Carnot engine. The entropy change of the working fluid, the entropy change of the source, and the total entropy change during this process are to be determined.

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

$$\Delta S = \frac{Q}{T}$$

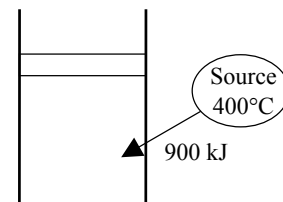
Noting that heat transferred from the source is equal to the heat transferred to the working fluid, the entropy changes of the fluid and of the source become

$$\Delta S_{\text{fluid}} = \frac{Q_{\text{fluid}}}{T_{\text{fluid}}} = \frac{Q_{\text{in,fluid}}}{T_{\text{fluid}}} = \frac{900 \text{ kJ}}{673 \text{ K}} = \mathbf{1.337 \text{ kJ/K}}$$

$$(b) \quad \Delta S_{\text{source}} = \frac{Q_{\text{source}}}{T_{\text{source}}} = -\frac{Q_{\text{out,source}}}{T_{\text{source}}} = -\frac{900 \text{ kJ}}{673 \text{ K}} = \mathbf{-1.337 \text{ kJ/K}}$$

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

$$S_{\text{gen}} = \Delta S_{\text{total}} = \Delta S_{\text{fluid}} + \Delta S_{\text{source}} = 1.337 - 1.337 = \mathbf{0}$$



7-27 EES Problem 7-26 is reconsidered. The effects of the varying the heat transferred to the working fluid and the source temperature on the entropy change of the working fluid, the entropy change of the source, and the total entropy change for the process as the source temperature varies from 100°C to 1000°C are to be investigated. The entropy changes of the source and of the working fluid are to be plotted against the source temperature for heat transfer amounts of 500 kJ, 900 kJ, and 1300 kJ.

**Analysis** The problem is solved using EES, and the results are tabulated and plotted below.

"Knowns:"

{T\_H = 400 [C]}

Q\_H = 1300 [kJ]

T\_Sys = T\_H

"Analysis:"

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

$\Delta S = Q/T$

"Noting that heat transferred from the source is equal to the heat transferred to the working fluid, the entropy changes of the fluid and of the source become "

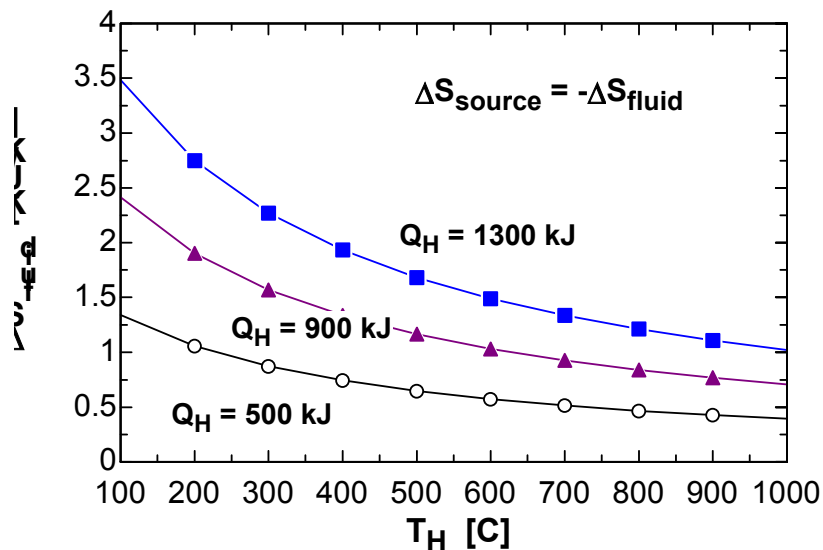
$\Delta S_{\text{source}} = -Q_H/(T_H+273)$

$\Delta S_{\text{fluid}} = +Q_H/(T_{\text{Sys}}+273)$

"(c) entropy generation for the process:"

$S_{\text{gen}} = \Delta S_{\text{source}} + \Delta S_{\text{fluid}}$

$\Delta S_{\text{fluid}}$ [kJ/K]	$\Delta S_{\text{source}}$ [kJ/K]	$S_{\text{gen}}$ [kJ/K]	$T_H$ [C]
3.485	-3.485	0	100
2.748	-2.748	0	200
2.269	-2.269	0	300
1.932	-1.932	0	400
1.682	-1.682	0	500
1.489	-1.489	0	600
1.336	-1.336	0	700
1.212	-1.212	0	800
1.108	-1.108	0	900
1.021	-1.021	0	1000



**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 become

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

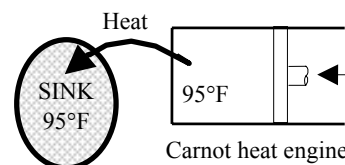
(b) The entropy change of the sink is determined from

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

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

$$S_{\text{gen}} = \Delta S_{\text{total}} = \Delta S_{\text{fluid}} + \Delta S_{\text{sink}} = -0.7 + 0.7 = \mathbf{0}$$

This is expected since all processes of the Carnot cycle are reversible processes, and no entropy is generated during a reversible process.



**7-29** R-134a enters an evaporator as a saturated liquid-vapor at a specified pressure. Heat is transferred to the refrigerant from the cooled space, and the liquid is vaporized. The entropy change of the refrigerant, the entropy change of the cooled space, and the total entropy change for this process are to be determined.

**Assumptions** **1** Both the refrigerant and the cooled space involve no internal irreversibilities such as friction. **2** Any temperature change occurs within the wall of the tube, and thus both the refrigerant and the cooled space remain isothermal during this process. Thus it is an isothermal, internally reversible process.

**Analysis** Noting that both the refrigerant and the cooled space undergo reversible isothermal processes, the entropy change for them can be determined from

$$\Delta S = \frac{Q}{T}$$

(a) The pressure of the refrigerant is maintained constant. Therefore, the temperature of the refrigerant also remains constant at the saturation value,

$$T = T_{\text{sat}@160 \text{ kPa}} = -15.6^\circ\text{C} = 257.4 \text{ K} \quad (\text{Table A-12})$$

Then,

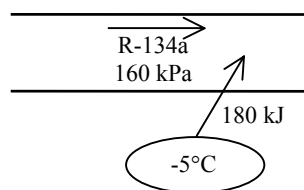
$$\Delta S_{\text{refrigerant}} = \frac{Q_{\text{refrigerant,in}}}{T_{\text{refrigerant}}} = \frac{180 \text{ kJ}}{257.4 \text{ K}} = \mathbf{0.699 \text{ kJ/K}}$$

(b) Similarly,

$$\Delta S_{\text{space}} = -\frac{Q_{\text{space,out}}}{T_{\text{space}}} = -\frac{180 \text{ kJ}}{268 \text{ K}} = \mathbf{-0.672 \text{ kJ/K}}$$

(c) The total entropy change of the process is

$$S_{\text{gen}} = S_{\text{total}} = \Delta S_{\text{refrigerant}} + \Delta S_{\text{space}} = 0.699 - 0.672 = \mathbf{0.027 \text{ kJ/K}}$$



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**Entropy Changes of Pure Substances**


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

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**7-31** The radiator of a steam heating system is initially filled with superheated steam. The valves are closed, and steam is allowed to cool until the temperature drops to a specified value by transferring heat to the room. The entropy change of the steam during this process is to be determined.

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

$$\left. \begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = 150^\circ\text{C} \end{array} \right\} \begin{array}{l} \nu_1 = 0.95986 \text{ m}^3/\text{kg} \\ s_1 = 7.2810 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left. \begin{array}{l} T_2 = 40^\circ\text{C} \\ \nu_2 = \nu_1 \end{array} \right\} x_2 = \frac{\nu_2 - \nu_f}{\nu_{fg}} = \frac{0.95986 - 0.001008}{19.515 - 0.001008} = 0.04914$$

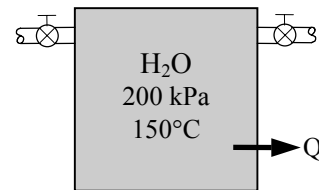
$$s_2 = s_f + x_2 s_{fg} = 0.5724 + (0.04914)(7.6832) = 0.9499 \text{ kJ/kg} \cdot \text{K}$$

The mass of the steam is

$$m = \frac{\nu}{\nu_1} = \frac{0.020 \text{ m}^3}{0.95986 \text{ m}^3/\text{kg}} = 0.02084 \text{ kg}$$

Then the entropy change of the steam during this process becomes

$$\Delta S = m(s_2 - s_1) = (0.02084 \text{ kg})(0.9499 - 7.2810) \text{ kJ/kg} \cdot \text{K} = \mathbf{-0.132 \text{ kJ/K}}$$



**7-32** A rigid tank is initially filled with a saturated mixture of R-134a. Heat is transferred to the tank from a source until the pressure inside rises to a specified value. The entropy change of the refrigerant, entropy change of the source, and the total entropy change for this process are to be determined.  $\checkmark$

**Assumptions** **1** The tank is stationary and thus the kinetic and potential energy changes are zero. **2** There are no work interactions.

**Analysis** (a) From the refrigerant tables (Tables A-11 through A-13),

$$\begin{aligned}
 \left. \begin{array}{l} P_1 = 200 \text{ kPa} \\ x_1 = 0.4 \end{array} \right\} & \begin{array}{l} u_1 = u_f + x_1 u_{fg} = 38.28 + (0.4)(186.21) = 112.76 \text{ kJ/kg} \\ s_1 = s_f + x_1 s_{fg} = 0.15457 + (0.4)(0.78316) = 0.4678 \text{ kJ/kg} \cdot \text{K} \\ \nu_1 = \nu_f + x_1 \nu_{fg} = 0.0007533 + (0.4)(0.099867 - 0.0007533) = 0.04040 \text{ m}^3/\text{kg} \end{array} \\
 \\
 \left. \begin{array}{l} P_2 = 400 \text{ kPa} \\ \nu_2 = \nu_1 \end{array} \right\} & \begin{array}{l} x_2 = \frac{\nu_2 - \nu_f}{\nu_{fg}} = \frac{0.04040 - 0.0007907}{0.051201 - 0.0007907} = 0.7857 \\ u_2 = u_f + x_2 u_{fg} = 63.62 + (0.7857)(171.45) = 198.34 \text{ kJ/kg} \\ s_2 = s_f + x_2 s_{fg} = 0.24761 + (0.7857)(0.67929) = 0.7813 \text{ kJ/kg} \cdot \text{K} \end{array}
 \end{aligned}$$

The mass of the refrigerant is

$$m = \frac{\nu}{\nu_1} = \frac{0.5 \text{ m}^3}{0.04040 \text{ m}^3/\text{kg}} = 12.38 \text{ kg}$$

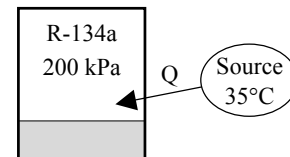
Then the entropy change of the refrigerant becomes

$$\Delta S_{\text{system}} = m(s_2 - s_1) = (12.38 \text{ kg})(0.7813 - 0.4678) \text{ kJ/kg} \cdot \text{K} = \mathbf{3.880 \text{ kJ/K}}$$

(b) We take the tank as the system. This is a closed system since no mass enters or leaves. Noting that the volume of the system is constant and thus there is no boundary work, the energy balance for this stationary closed system can be expressed as

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

$$Q_{\text{in}} = \Delta U = m(u_2 - u_1)$$



Substituting,

$$Q_{\text{in}} = m(u_2 - u_1) = (12.38 \text{ kg})(198.34 - 112.76) = 1059 \text{ kJ}$$

The heat transfer for the source is equal in magnitude but opposite in direction. Therefore,

$$Q_{\text{source, out}} = -Q_{\text{tank, in}} = -1059 \text{ kJ}$$

and

$$\Delta S_{\text{source}} = -\frac{Q_{\text{source, out}}}{T_{\text{source}}} = -\frac{1059 \text{ kJ}}{308 \text{ K}} = \mathbf{-3.439 \text{ kJ/K}}$$

(c) The total entropy change for this process is

$$\Delta S_{\text{total}} = \Delta S_{\text{system}} + \Delta S_{\text{source}} = 3.880 + (-3.439) = \mathbf{0.442 \text{ kJ/K}}$$

**7-33 EES** Problem 7-32 is reconsidered. The effects of the source temperature and final pressure on the total entropy change for the process as the source temperature varies from 30°C to 210°C, and the final pressure varies from 250 kPa to 500 kPa are to be investigated. The total entropy change for the process is to be plotted as a function of the source temperature for final pressures of 250 kPa, 400 kPa, and 500 kPa.

**Analysis** The problem is solved using EES, and the results are tabulated and plotted below.

"Knowns:"

$$P_1 = 200 \text{ [kPa]}$$

$$x_1 = 0.4$$

$$V_{\text{sys}} = 0.5 \text{ [m}^3\text{]}$$

$$P_2 = 400 \text{ [kPa]}$$

$$\{T_{\text{source}} = 35 \text{ [C]}\}$$

"Analysis: "

" Treat the rigid tank as a closed system, with no work in, neglect changes in KE and PE of the R134a."

$$E_{\text{in}} - E_{\text{out}} = \text{DELTA}E_{\text{sys}}$$

$$E_{\text{out}} = 0 \text{ [kJ]}$$

$$E_{\text{in}} = Q$$

$$\text{DELTA}E_{\text{sys}} = m_{\text{sys}}(u_2 - u_1)$$

$$u_1 = \text{INTENERGY}(\text{R134a}, P=P_1, x=x_1)$$

$$v_1 = \text{volume}(\text{R134a}, P=P_1, x=x_1)$$

$$V_{\text{sys}} = m_{\text{sys}}v_1$$

"Rigid Tank: The process is constant volume. Then  $P_2$  and  $v_2$  specify state 2."

$$v_2 = v_1$$

$$u_2 = \text{INTENERGY}(\text{R134a}, P=P_2, v=v_2)$$

"Entropy calculations:"

$$s_1 = \text{entropy}(\text{R134a}, P=P_1, x=x_1)$$

$$s_2 = \text{entropy}(\text{R134a}, P=P_2, v=v_2)$$

$$\text{DELTA}S_{\text{sys}} = m_{\text{sys}}(s_2 - s_1)$$

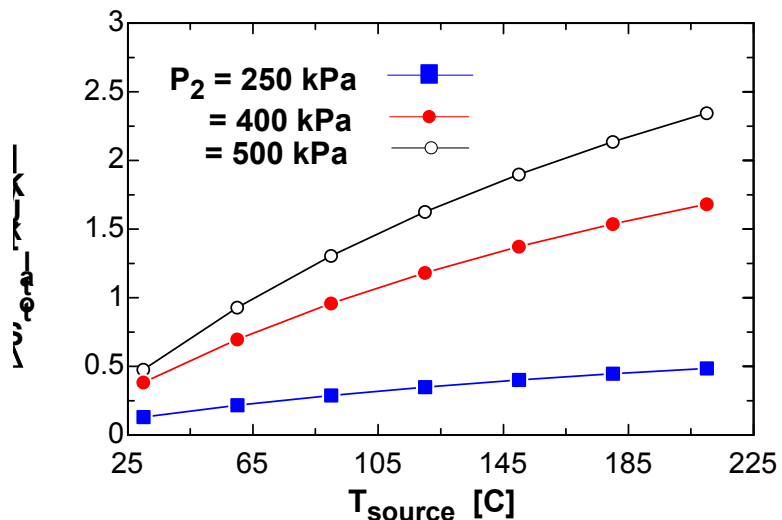
"Heat is leaving the source, thus:"

$$\text{DELTA}S_{\text{source}} = -Q/(T_{\text{source}} + 273)$$

"Total Entropy Change:"

$$\text{DELTA}S_{\text{total}} = \text{DELTA}S_{\text{source}} + \text{DELTA}S_{\text{sys}}$$

$\Delta S_{\text{total}}$ [kJ/K]	$T_{\text{source}}$ [C]
0.3848	30
0.6997	60
0.9626	90
1.185	120
1.376	150
1.542	180
1.687	210





**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.

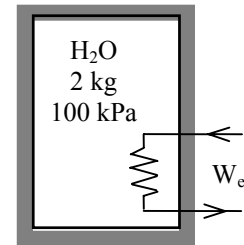
**Analysis** From the steam tables (Tables A-4 through A-6)

$$\left. \begin{array}{l} P_1 = 100 \text{ kPa} \\ x_1 = 0.25 \end{array} \right\} \begin{array}{l} \nu_1 = \nu_f + x_1 \nu_{fg} = 0.001 + (0.25)(1.6941 - 0.001) = 0.4243 \text{ m}^3/\text{kg} \\ s_1 = s_f + x_1 s_{fg} = 1.3028 + (0.25)(6.0562) = 2.8168 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left. \begin{array}{l} \nu_2 = \nu_1 \\ \text{sat. vapor} \end{array} \right\} s_2 = 6.8649 \text{ kJ/kg} \cdot \text{K}$$

Then the entropy change of the steam becomes

$$\Delta S = m(s_2 - s_1) = (2 \text{ kg})(6.8649 - 2.8168) \text{ kJ/kg} \cdot \text{K} = \mathbf{8.10 \text{ kJ/K}}$$



**7-35** [Also solved by EES on enclosed CD] A rigid tank is divided into two equal parts by a partition. One part is filled with compressed liquid water while the other side is evacuated. The partition is removed and water expands into the entire tank. The entropy change of the water during this process is to be determined.

**Analysis** The properties of the water are (Table A-4)

$$\left. \begin{array}{l} P_1 = 300 \text{ kPa} \\ T_1 = 60^\circ\text{C} \end{array} \right\} \begin{array}{l} \nu_1 \cong \nu_{f@60^\circ\text{C}} = 0.001017 \text{ m}^3/\text{kg} \\ s_1 = s_{f@60^\circ\text{C}} = 0.8313 \text{ kJ/kg} \cdot \text{K} \end{array}$$

1.5 kg compressed liquid	Vacuum
300 kPa 60°C	

Noting that  $\nu_2 = 2\nu_1 = (2)(0.001017) = 0.002034 \text{ m}^3/\text{kg}$

$$\left. \begin{array}{l} P_2 = 15 \text{ kPa} \\ \nu_2 = 0.002034 \text{ m}^3/\text{kg} \end{array} \right\} \begin{array}{l} x_2 = \frac{\nu_2 - \nu_f}{\nu_{fg}} = \frac{0.002034 - 0.001014}{10.02 - 0.001014} = 0.0001018 \\ s_2 = s_f + x_2 s_{fg} = 0.7549 + (0.0001018)(7.2522) = 0.7556 \text{ kJ/kg} \cdot \text{K} \end{array}$$

Then the entropy change of the water becomes

$$\Delta S = m(s_2 - s_1) = (1.5 \text{ kg})(0.7556 - 0.8313) \text{ kJ/kg} \cdot \text{K} = \mathbf{-0.114 \text{ kJ/K}}$$

**7-36 EES** Problem 7-35 is reconsidered. The entropy generated is to be evaluated and plotted as a function of surroundings temperature, and the values of the surroundings temperatures that are valid for this problem are to be determined. The surrounding temperature is to vary from 0°C to 100°C.

**Analysis** The problem is solved using EES, and the results are tabulated and plotted below.

#### "Input Data"

P[1]=300 [kPa]

T[1]=60 [C]

m=1.5 [kg]

P[2]=15 [kPa]

Fluid\$='Steam\_IAPWS'

V[1]=m\*spv[1]

spv[1]=volume(Fluid\$,T=T[1], P=P[1]) "specific volume of steam at state 1, m<sup>3</sup>/kg"

s[1]=entropy(Fluid\$,T=T[1],P=P[1]) "entropy of steam at state 1, kJ/kgK"

V[2]=2\*V[1] "Steam expands to fill entire volume at state 2"

"State 2 is identified by P[2] and spv[2]"

spv[2]=V[2]/m "specific volume of steam at state 2, m<sup>3</sup>/kg"

s[2]=entropy(Fluid\$,P=P[2],v=spv[2]) "entropy of steam at state 2, kJ/kgK"

T[2]=temperature(Fluid\$,P=P[2],v=spv[2])

DELTAS\_sys=m\*(s[2]-s[1]) "Total entropy change of steam, kJ/K"

"What does the first law tell us about this problem?"

"Conservation of Energy for the entire, closed system"

E\_in - E\_out = DELTAE\_sys

"neglecting changes in KE and PE for the system:"

DELTAE\_sys=m\*(intenergy(Fluid\$, P=P[2], v=spv[2]) - intenergy(Fluid\$,T=T[1],P=P[1]))

E\_in = 0

"How do you interpret the energy leaving the system, E\_out? Recall this is a constant volume system."

Q\_out = E\_out

"What is the maximum value of the Surroundings temperature?"

"The maximum possible value for the surroundings temperature occurs when we set

S\_gen = 0=Delta S\_sys+sum(DeltaS\_surr)"

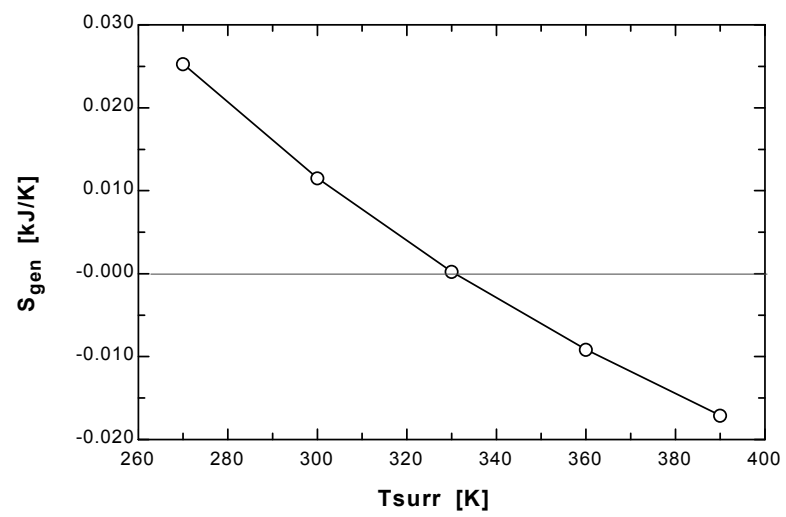
Q\_net\_surr=Q\_out

S\_gen = 0

S\_gen = DELTAS\_sys+Q\_net\_surr/Tsurr

"Establish a parametric table for the variables S\_gen, Q\_net\_surr, T\_surr, and DELTAS\_sys. In the Parametric Table window select T\_surr and insert a range of values. Then place '{' and '}' about the S\_gen = 0 line; press F3 to solve the table. The results are shown in Plot Window 1. What values of T\_surr are valid for this problem?"

S <sub>gen</sub> [kJ/K]	Q <sub>net,surr</sub> [kJ]	T <sub>surr</sub> [K]	ΔS <sub>sys</sub> [kJ/K]
0.02533	37.44	270	-0.1133
0.01146	37.44	300	-0.1133
0.0001205	37.44	330	-0.1133
-0.009333	37.44	360	-0.1133
-0.01733	37.44	390	-0.1133



**7-37E** A cylinder is initially filled with R-134a at a specified state. The refrigerant is cooled and condensed at constant pressure. The entropy change of refrigerant during this process is to be determined

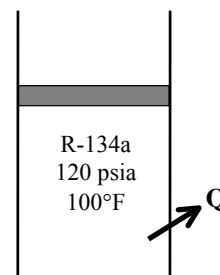
**Analysis** From the refrigerant tables (Tables A-11E through A-13E),

$$\left. \begin{array}{l} P_1 = 120 \text{ psia} \\ T_1 = 100^\circ\text{F} \end{array} \right\} s_1 = 0.22361 \text{ Btu/lbm} \cdot \text{R}$$

$$\left. \begin{array}{l} T_2 = 50^\circ\text{F} \\ P_2 = 120 \text{ psia} \end{array} \right\} s_2 \cong s_{f@90^\circ\text{F}} = 0.06039 \text{ Btu/lbm} \cdot \text{R}$$

Then the entropy change of the refrigerant becomes

$$\Delta S = m(s_2 - s_1) = (2 \text{ lbm})(0.06039 - 0.22361) \text{ Btu/lbm} \cdot \text{R} = \mathbf{-0.3264 \text{ Btu/R}}$$



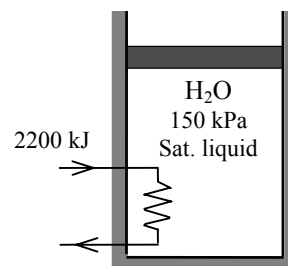
**7-38** An insulated cylinder is initially filled with saturated liquid water at a specified pressure. The water is heated electrically at constant pressure. The entropy change of the water during this process is to be determined.

**Assumptions** **1** The kinetic and potential energy changes are negligible. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The compression or expansion process is quasi-equilibrium.

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

$$\left. \begin{array}{l} P_1 = 150 \text{ kPa} \\ \text{sat. liquid} \end{array} \right\} \begin{array}{l} v_1 = v_{f@150 \text{ kPa}} = 0.001053 \text{ m}^3/\text{kg} \\ h_1 = h_{f@150 \text{ kPa}} = 467.13 \text{ kJ/kg} \\ s_1 = s_{f@150 \text{ kPa}} = 1.4337 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\text{Also, } m = \frac{V}{v_1} = \frac{0.005 \text{ m}^3}{0.001053 \text{ m}^3/\text{kg}} = 4.75 \text{ kg}$$



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

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

$$W_{e,\text{in}} - W_{b,\text{out}} = \Delta U$$

$$W_{e,\text{in}} = m(h_2 - h_1)$$

since  $\Delta U + W_b = \Delta H$  during a constant pressure quasi-equilibrium process. Solving for  $h_2$ ,

$$h_2 = h_1 + \frac{W_{e,\text{in}}}{m} = 467.13 + \frac{2200 \text{ kJ}}{4.75 \text{ kg}} = 930.33 \text{ kJ/kg}$$

Thus,

$$\left. \begin{array}{l} P_2 = 150 \text{ kPa} \\ h_2 = 930.33 \text{ kJ/kg} \end{array} \right\} \begin{array}{l} x_2 = \frac{h_2 - h_f}{h_{fg}} = \frac{930.33 - 467.13}{2226.0} = 0.2081 \\ s_2 = s_f + x_2 s_{fg} = 1.4337 + (0.2081)(5.7894) = 2.6384 \text{ kJ/kg} \cdot \text{K} \end{array}$$

Then the entropy change of the water becomes

$$\Delta S = m(s_2 - s_1) = (4.75 \text{ kg})(2.6384 - 1.4337) \text{ kJ/kg} \cdot \text{K} = \mathbf{5.72 \text{ kJ/K}}$$

**7-39** An insulated cylinder is initially filled with saturated R-134a vapor at a specified pressure. The refrigerant expands in a reversible manner until the pressure drops to a specified value. The final temperature in the cylinder and the work done by the refrigerant are to be determined.

**Assumptions** **1** The kinetic and potential energy changes are negligible. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The process is stated to be reversible.

**Analysis** (a) This is a reversible adiabatic (i.e., isentropic) process, and thus  $s_2 = s_1$ . From the refrigerant tables (Tables A-11 through A-13),

$$P_1 = 0.8 \text{ MPa} \left. \begin{array}{l} \nu_1 = \nu_{g@0.8 \text{ MPa}} = 0.025621 \text{ m}^3/\text{kg} \\ u_1 = u_{g@0.8 \text{ MPa}} = 246.79 \text{ kJ/kg} \\ s_1 = s_{g@0.8 \text{ MPa}} = 0.91835 \text{ kJ/kg} \cdot \text{K} \end{array} \right\} \text{ sat. vapor}$$

Also,

$$m = \frac{\nu}{\nu_1} = \frac{0.05 \text{ m}^3}{0.025621 \text{ m}^3/\text{kg}} = 1.952 \text{ kg}$$

and

$$P_2 = 0.4 \text{ MPa} \left. \begin{array}{l} x_2 = \frac{s_2 - s_f}{s_{fg}} = \frac{0.91835 - 0.24761}{0.67929} = 0.9874 \\ u_2 = u_f + x_2 u_{fg} = 63.62 + (0.9874)(171.45) = 232.91 \text{ kJ/kg} \end{array} \right\} s_2 = s_1$$

$$T_2 = T_{\text{sat}@0.4 \text{ MPa}} = \mathbf{8.91^\circ\text{C}}$$

(b) 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 adiabatic closed system can be expressed as

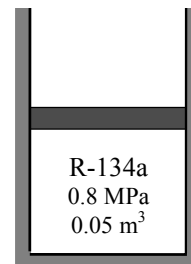
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$-W_{\text{b,out}} = \Delta U$$

$$W_{\text{b,out}} = m(u_1 - u_2)$$

Substituting, the work done during this isentropic process is determined to be

$$W_{\text{b,out}} = m(u_1 - u_2) = (1.952 \text{ kg})(246.79 - 232.91) \text{ kJ/kg} = \mathbf{27.09 \text{ kJ}}$$



**7-40 EES** Problem 7-39 is reconsidered. The work done by the refrigerant is to be calculated and plotted as a function of final pressure as the pressure varies from 0.8 MPa to 0.4 MPa. The work done for this process is to be compared to one for which the temperature is constant over the same pressure range.

**Analysis** The problem is solved using EES, and the results are tabulated and plotted below.

#### Procedure

```
IsothermWork(P_1,x_1,m_sys,P_2:Work_out_Isotherm,Q_isotherm,DELTAE_isotherm,T_isotherm)
```

```
T_isotherm=Temperature(R134a,P=P_1,x=x_1)
```

```
T=T_isotherm
```

```
u_1 = INTENERGY(R134a,P=P_1,x=x_1)
```

```
v_1 = volume(R134a,P=P_1,x=x_1)
```

```
s_1 = entropy(R134a,P=P_1,x=x_1)
```

```
u_2 = INTENERGY(R134a,P=P_2,T=T)
```

```
s_2 = entropy(R134a,P=P_2,T=T)
```

"The process is reversible and Isothermal thus the heat transfer is determined by:"

```
Q_isotherm = (T+273)*m_sys*(s_2 - s_1)
```

```
DELTAE_isotherm = m_sys*(u_2 - u_1)
```

```
E_in = Q_isotherm
```

```
E_out = DELTAE_isotherm+E_in
```

```
Work_out_isotherm=E_out
```

END

"Knowns:"

```
P_1 = 800 [kPa]
```

```
x_1 = 1.0
```

```
V_sys = 0.05[m^3]
```

```
"P_2 = 400 [kPa]"
```

"Analysis: "

" Treat the rigid tank as a closed system, with no heat transfer in, neglect changes in KE and PE of the R134a."

"The isentropic work is determined from:"

```
E_in - E_out = DELTAE_sys
```

```
E_out = Work_out_isen
```

```
E_in = 0
```

```
DELTAE_sys = m_sys*(u_2 - u_1)
```

```
u_1 = INTENERGY(R134a,P=P_1,x=x_1)
```

```
v_1 = volume(R134a,P=P_1,x=x_1)
```

```
s_1 = entropy(R134a,P=P_1,x=x_1)
```

```
V_sys = m_sys*v_1
```

"Rigid Tank: The process is reversible and adiabatic or isentropic.

Then P\_2 and s\_2 specify state 2."

```
s_2 = s_1
```

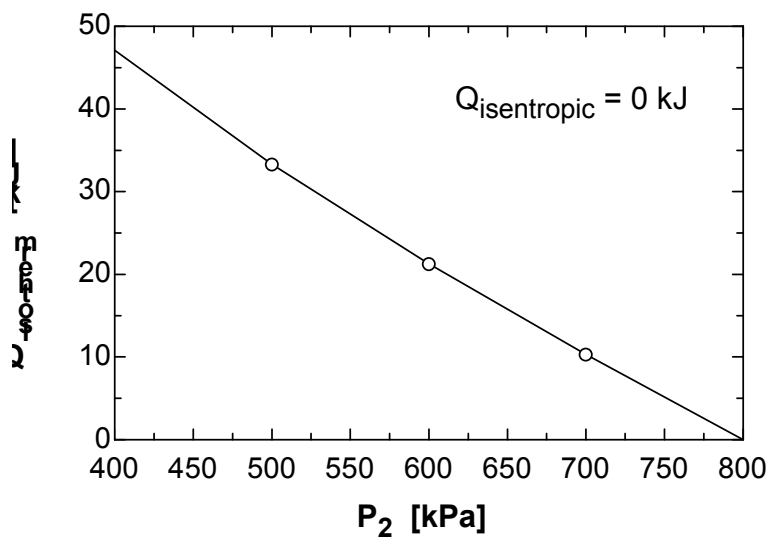
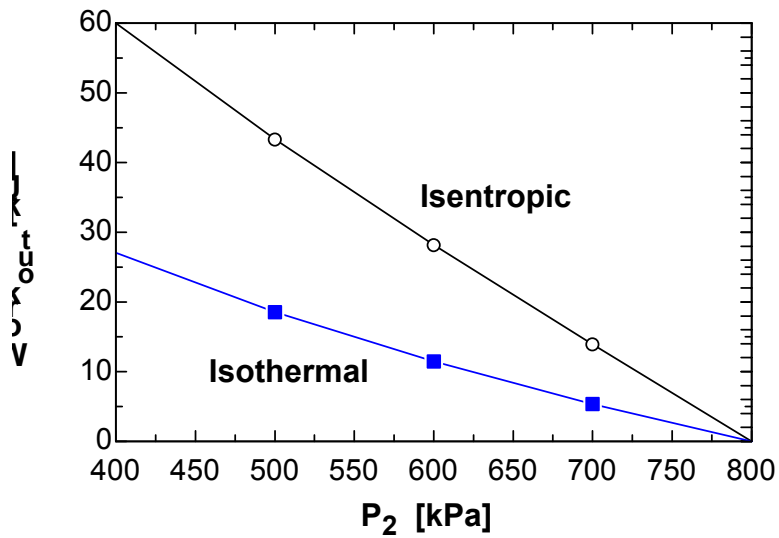
```
u_2 = INTENERGY(R134a,P=P_2,s=s_2)
```

```
T_2_isen = temperature(R134a,P=P_2,s=s_2)
```

Call

```
IsothermWork(P_1,x_1,m_sys,P_2:Work_out_Isotherm,Q_isotherm,DELTAE_isotherm,T_isotherm)
```

$P_2$ [kPa]	$W_{out,isen}$ [kJ]	$W_{out,isoth}$ [kJ]	$Q_{isoth}$ [kJ]
400	27.09	60.02	47.08
500	18.55	43.33	33.29
600	11.44	28.2	21.25
700	5.347	13.93	10.3
800	0	0	0



**7-41** Saturated Refrigerant-134a vapor at 160 kPa is compressed steadily by an adiabatic compressor. The minimum power input to the compressor 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.

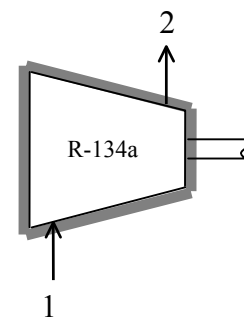
**Analysis** The power input to an adiabatic compressor will be a minimum when the compression process is reversible. For the reversible adiabatic process we have  $s_2 = s_1$ . From the refrigerant tables (Tables A-11 through A-13),

$$\left. \begin{array}{l} P_1 = 160 \text{ kPa} \\ \text{sat. vapor} \end{array} \right\} \begin{array}{l} \nu_1 = \nu_{g@160 \text{ kPa}} = 0.12348 \text{ m}^3/\text{kg} \\ h_1 = h_{g@160 \text{ kPa}} = 241.11 \text{ kJ/kg} \\ s_1 = s_{g@160 \text{ kPa}} = 0.9419 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left. \begin{array}{l} P_2 = 900 \text{ kPa} \\ s_2 = s_1 \end{array} \right\} h_2 = 277.06 \text{ kJ/kg}$$

Also,

$$\dot{m} = \frac{\dot{V}_1}{\nu_1} = \frac{2 \text{ m}^3/\text{min}}{0.12348 \text{ m}^3/\text{kg}} = 16.20 \text{ kg/min} = 0.27 \text{ kg/s}$$



There is only one inlet and one exit, and thus  $\dot{m}_1 = \dot{m}_2 = \dot{m}$ . We take the compressor 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

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

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

$$\dot{W}_{\text{in}} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \dot{Q} \cong \Delta ke \cong \Delta pe \cong 0)$$

$$\dot{W}_{\text{in}} = \dot{m}(h_2 - h_1)$$

Substituting, the minimum power supplied to the compressor is determined to be

$$\dot{W}_{\text{in}} = (0.27 \text{ kg/s})(277.06 - 241.11) \text{ kJ/kg} = \mathbf{9.71 \text{ kW}}$$



**7-42E** Steam expands in an adiabatic turbine. The maximum amount of work that can be done by 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.

**Analysis** The work output of an adiabatic turbine is maximum when the expansion process is reversible. For the reversible adiabatic process we have  $s_2 = s_1$ . From the steam tables (Tables A-4E through A-6E),

$$\left. \begin{array}{l} P_1 = 800 \text{ psia} \\ T_1 = 900^\circ\text{F} \end{array} \right\} \begin{array}{l} h_1 = 1456.0 \text{ Btu/lbm} \\ s_1 = 1.6413 \text{ Btu/lbm} \cdot \text{R} \end{array}$$

$$\left. \begin{array}{l} P_2 = 40 \text{ psia} \\ s_2 = s_1 \end{array} \right\} \begin{array}{l} x_2 = \frac{s_2 - s_f}{s_{fg}} = \frac{1.6413 - 0.39213}{1.28448} = 0.9725 \\ h_2 = h_f + x_2 h_{fg} = 236.14 + (0.9725)(933.69) = 1144.2 \text{ Btu/lbm} \end{array}$$

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

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

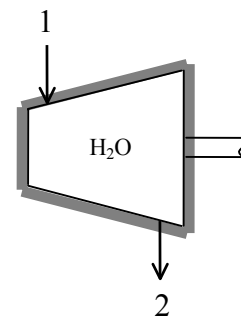
$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}h_1 = \dot{W}_{\text{out}} + \dot{m}h_2$$

$$\dot{W}_{\text{out}} = \dot{m}(h_1 - h_2)$$

Dividing by mass flow rate and substituting,

$$w_{\text{out}} = h_1 - h_2 = 1456.0 - 1144.2 = \mathbf{311.8 \text{ Btu/lbm}}$$



**7-43E EES** Problem 7-42E is reconsidered. The work done by the steam is to be calculated and plotted as a function of final pressure as the pressure varies from 800 psia to 40 psia. Also the effect of varying the turbine inlet temperature from the saturation temperature at 800 psia to 900°F on the turbine work is to be investigated.

**Analysis** The problem is solved using EES, and the results are tabulated and plotted below.

"Knowns:"

$$P_1 = 800 \text{ [psia]}$$

$$T_1 = 900 \text{ [F]}$$

$$P_2 = 40 \text{ [psia]}$$

$$T_{\text{sat},P_1} = \text{temperature}(\text{Fluid}\$,P=P_1,x=1.0)$$

$$\text{Fluid}\$ = \text{'Steam\_IAPWS'}$$

"Analysis: "

" Treat the turbine as a steady-flow control volume, with no heat transfer in, neglect changes in KE and PE of the Steam."

"The isentropic work is determined from the steady-flow energy equation written per unit mass:"

$$e_{\text{in}} - e_{\text{out}} = \Delta E_{\text{e\_sys}}$$

$$E_{\text{out}} = \text{Work}_{\text{out}} + h_2 \text{ "[Btu/lbm]"}$$

$$e_{\text{in}} = h_1 \text{ "[Btu/lbm]"}$$

$$\Delta E_{\text{e\_sys}} = 0 \text{ "[Btu/lbm]"}$$

$$h_1 = \text{enthalpy}(\text{Fluid}\$,P=P_1,T=T_1)$$

$$s_1 = \text{entropy}(\text{Fluid}\$,P=P_1,T=T_1)$$

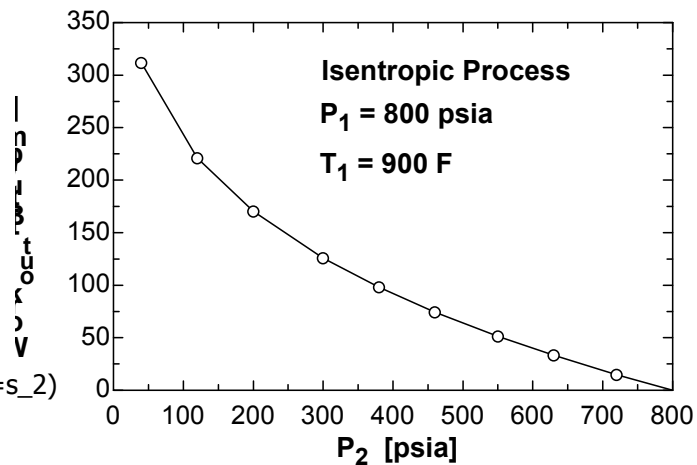
"The process is reversible and adiabatic or isentropic.

Then  $P_2$  and  $s_2$  specify state 2."

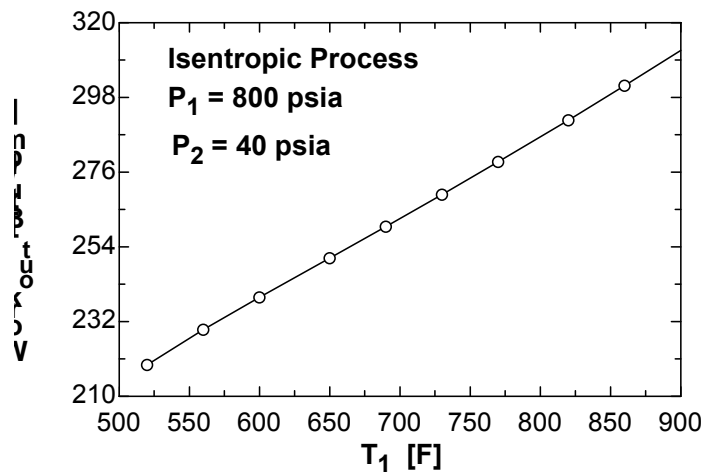
$$s_2 = s_1 \text{ "[Btu/lbm-R]"}$$

$$h_2 = \text{enthalpy}(\text{Fluid}\$,P=P_2,s=s_2)$$

$$T_{2,\text{isen}} = \text{temperature}(\text{Fluid}\$,P=P_2,s=s_2)$$



$T_1$ [F]	Work <sub>out</sub> [Btu/lbm]
520	219.3
560	229.6
600	239.1
650	250.7
690	260
730	269.4
770	279
820	291.3
860	301.5
900	311.9



**7-44** An insulated cylinder is initially filled with superheated steam at a specified state. The steam is compressed in a reversible manner until the pressure drops to a specified value. The work input during this process is to be determined.

**Assumptions** **1** The kinetic and potential energy changes are negligible. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The process is stated to be reversible.

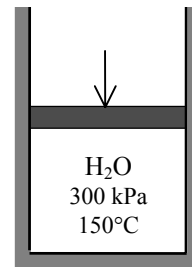
**Analysis** This is a reversible adiabatic (i.e., isentropic) process, and thus  $s_2 = s_1$ . From the steam tables (Tables A-4 through A-6),

$$\left. \begin{array}{l} P_1 = 300 \text{ kPa} \\ T_1 = 150^\circ\text{C} \end{array} \right\} \begin{array}{l} v_1 = 0.63402 \text{ m}^3/\text{kg} \\ u_1 = 2571.0 \text{ kJ/kg} \\ s_1 = 7.0792 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left. \begin{array}{l} P_2 = 1 \text{ MPa} \\ s_2 = s_1 \end{array} \right\} u_2 = 2773.8 \text{ kJ/kg}$$

Also,

$$m = \frac{V}{v_1} = \frac{0.05 \text{ m}^3}{0.63402 \text{ m}^3/\text{kg}} = 0.0789 \text{ kg}$$



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 adiabatic closed system can be expressed as

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

$$W_{\text{b,in}} = \Delta U = m(u_2 - u_1)$$

Substituting, the work input during this adiabatic process is determined to be

$$W_{\text{b,in}} = m(u_2 - u_1) = (0.0789 \text{ kg})(2773.8 - 2571.0) \text{ kJ/kg} = \mathbf{16.0 \text{ kJ}}$$

**7-45 EES** Problem 7-44 is reconsidered. The work done on the steam is to be determined and plotted as a function of final pressure as the pressure varies from 300 kPa to 1 MPa.

**Analysis** The problem is solved using EES, and the results are tabulated and plotted below.

"Knowns:"

P\_1 = 300 [kPa]

T\_1 = 150 [C]

V\_sys = 0.05 [m^3]

"P\_2 = 1000 [kPa]"

"Analysis: "

Fluid\$='Steam\_IAPWS'

" Treat the piston-cylinder as a closed system, with no heat transfer in, neglect changes in KE and PE of the Steam. The process is reversible and adiabatic thus isentropic."

"The isentropic work is determined from:"

E\_in - E\_out = DELTAE\_sys

E\_out = 0 [kJ]

E\_in = Work\_in

DELTA E\_sys = m\_sys\*(u\_2 - u\_1)

u\_1 = INTENERGY(Fluid\$,P=P\_1,T=T\_1)

v\_1 = volume(Fluid\$,P=P\_1,T=T\_1)

s\_1 = entropy(Fluid\$,P=P\_1,T=T\_1)

V\_sys = m\_sys\*v\_1

" The process is reversible and adiabatic or isentropic.

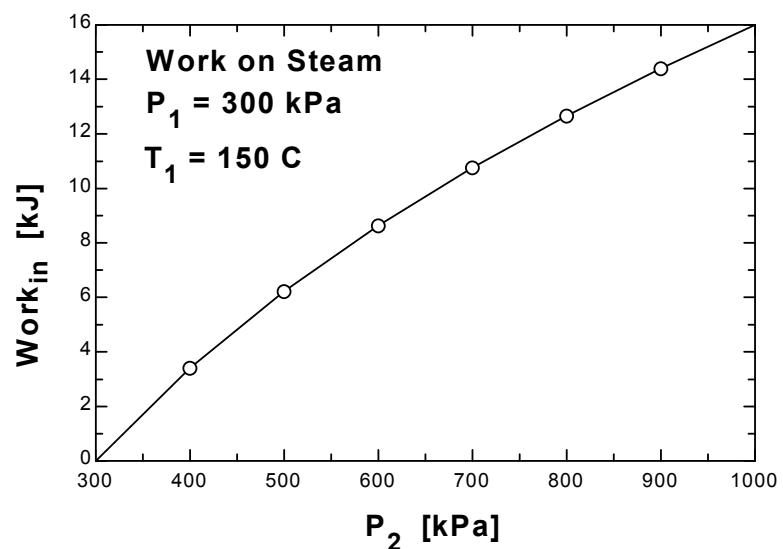
Then P\_2 and s\_2 specify state 2."

s\_2 = s\_1

u\_2 = INTENERGY(Fluid\$,P=P\_2,s=s\_2)

T\_2\_isen = temperature(Fluid\$,P=P\_2,s=s\_2)

P <sub>2</sub> [kPa]	Work <sub>in</sub> [kJ]
300	0
400	3.411
500	6.224
600	8.638
700	10.76
800	12.67
900	14.4
1000	16



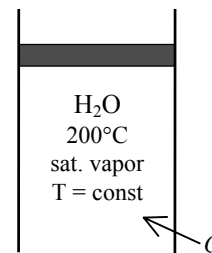
**7-46** A cylinder is initially filled with saturated water vapor at a specified temperature. Heat is transferred to the steam, and it expands in a reversible and isothermal manner until the pressure drops to a specified value. The heat transfer and the work output for this process are to be determined.

**Assumptions** **1** The kinetic and potential energy changes are negligible. **2** The cylinder is well-insulated and thus heat transfer is negligible. **3** The thermal energy stored in the cylinder itself is negligible. **4** The process is stated to be reversible and isothermal.

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

$$\left. \begin{array}{l} T_1 = 200^\circ\text{C} \\ \text{sat. vapor} \end{array} \right\} \begin{array}{l} u_1 = u_{g@200^\circ\text{C}} = 2594.2 \text{ kJ/kg} \\ s_1 = s_{g@200^\circ\text{C}} = 6.4302 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left. \begin{array}{l} P_2 = 800 \text{ kPa} \\ T_2 = T_1 \end{array} \right\} \begin{array}{l} u_2 = 2631.1 \text{ kJ/kg} \\ s_2 = 6.8177 \text{ kJ/kg} \cdot \text{K} \end{array}$$



The heat transfer for this reversible isothermal process can be determined from

$$Q = T\Delta S = Tm(s_2 - s_1) = (473 \text{ K})(1.2 \text{ kg})(6.8177 - 6.4302) \text{ kJ/kg} \cdot \text{K} = \mathbf{219.9 \text{ kJ}}$$

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 closed system can be expressed as

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

$$Q_{\text{in}} - W_{\text{b,out}} = \Delta U = m(u_2 - u_1)$$

$$W_{\text{b,out}} = Q_{\text{in}} - m(u_2 - u_1)$$

Substituting, the work done during this process is determined to be

$$W_{\text{b,out}} = 219.9 \text{ kJ} - (1.2 \text{ kg})(2631.1 - 2594.2) \text{ kJ/kg} = \mathbf{175.6 \text{ kJ}}$$

7-47 EES Problem 7-46 is reconsidered. The heat transferred to the steam and the work done are to be determined and plotted as a function of final pressure as the pressure varies from the initial value to the final value of 800 kPa.

**Analysis** The problem is solved using EES, and the results are tabulated and plotted below.

"Knowns:"

T\_1 = 200 [C]  
 x\_1 = 1.0  
 m\_sys = 1.2 [kg]  
 {P\_2 = 800"[kPa]"}

"Analysis: "

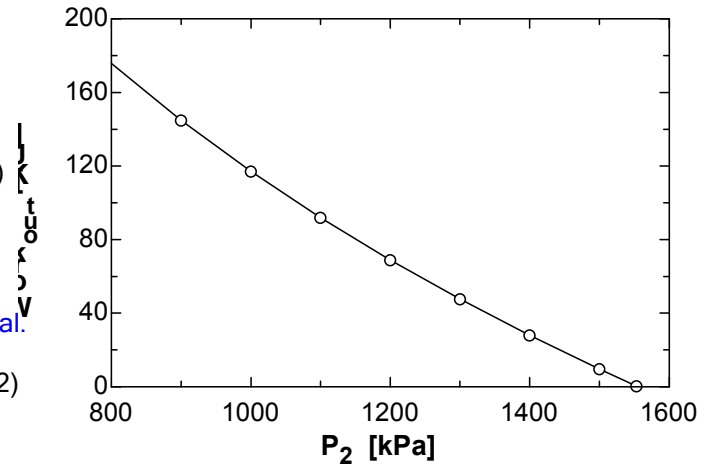
Fluid\$='Steam\_IAPWS'

" Treat the piston-cylinder as a closed system, neglect changes in KE and PE of the Steam. The process is reversible and isothermal ."

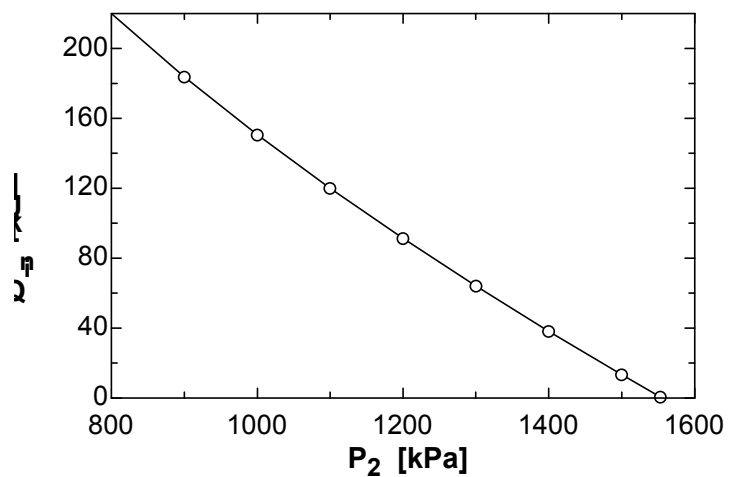
T\_2 = T\_1  
 E\_in - E\_out = DELTAE\_sys  
 E\_in = Q\_in  
 E\_out = Work\_out  
 DELTAE\_sys = m\_sys\*(u\_2 - u\_1)  
 P\_1 = pressure(Fluid\$,T=T\_1,x=1.0)  
 u\_1 = INTENERGY(Fluid\$,T=T\_1,x=1.0)  
 v\_1 = volume(Fluid\$,T=T\_1,x=1.0)  
 s\_1 = entropy(Fluid\$,T=T\_1,x=1.0)  
 V\_sys = m\_sys\*v\_1

" The process is reversible and isothermal. Then P\_2 and T\_2 specify state 2."

u\_2 = INTENERGY(Fluid\$,P=P\_2,T=T\_2)  
 s\_2 = entropy(Fluid\$,P=P\_2,T=T\_2)  
 Q\_in = (T\_1+273)\*m\_sys\*(s\_2-s\_1)



P <sub>2</sub> [kPa]	Q <sub>in</sub> [kJ]	Work <sub>out</sub> [kJ]
800	219.9	175.7
900	183.7	144.7
1000	150.6	117
1100	120	91.84
1200	91.23	68.85
1300	64.08	47.65
1400	38.2	27.98
1500	13.32	9.605
1553	219.9	175.7



**7-48** A cylinder is initially filled with saturated water vapor mixture at a specified temperature. Steam undergoes a reversible heat addition and an isentropic process. The processes are to be sketched and heat transfer for the first process and work done during the second process are to be determined.

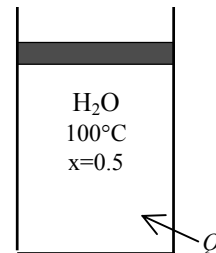
**Assumptions 1** The kinetic and potential energy changes are negligible. **2** The thermal energy stored in the cylinder itself is negligible. **3** Both processes are reversible.

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

$$\left. \begin{array}{l} T_1 = 100^\circ\text{C} \\ x = 0.5 \end{array} \right\} h_1 = h_f + xh_{fg} = 419.17 + (0.5)(2256.4) = 1547.4 \text{ kJ/kg}$$

$$\left. \begin{array}{l} T_2 = 100^\circ\text{C} \\ x_2 = 1 \end{array} \right\} \begin{array}{l} h_2 = h_g = 2675.6 \text{ kJ/kg} \\ u_2 = u_g = 2506.0 \text{ kJ/kg} \\ s_2 = 7.3542 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left. \begin{array}{l} P_3 = 15 \text{ kPa} \\ s_3 = s_2 \end{array} \right\} u_3 = 2247.9 \text{ kJ/kg}$$



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 closed system can be expressed as

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

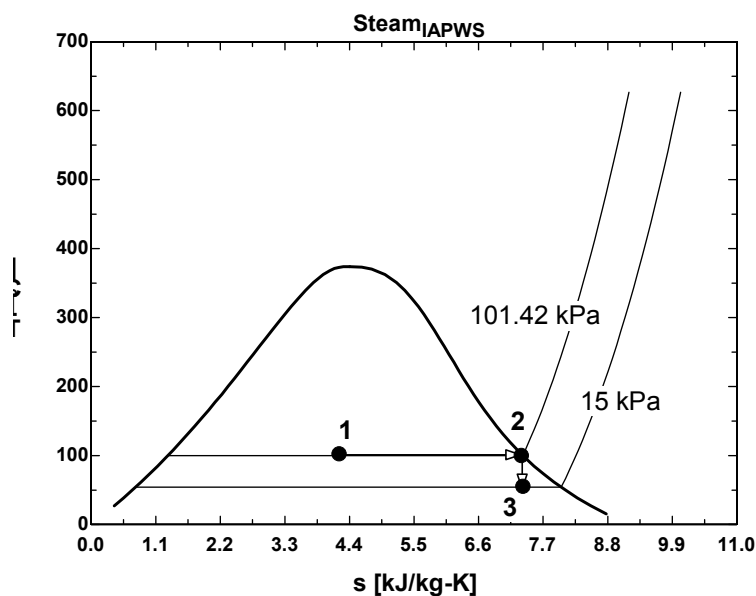
$$Q_{\text{in}} - W_{\text{b,out}} = \Delta U = m(u_2 - u_1)$$

For process 1-2, it reduces to

$$Q_{12,\text{in}} = m(h_2 - h_1) = (5 \text{ kg})(2675.6 - 1547.4) \text{ kJ/kg} = \mathbf{5641 \text{ kJ}}$$

(c) For process 2-3, it reduces to

$$W_{23,\text{b,out}} = m(u_2 - u_3) = (5 \text{ kg})(2506.0 - 2247.9) \text{ kJ/kg} = \mathbf{1291 \text{ kJ}}$$



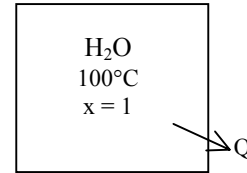
**7-49** A rigid tank contains saturated water vapor at a specified temperature. Steam is cooled to ambient temperature. The process is to be sketched and entropy changes for the steam and for the process are to be determined.

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

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

$$T_1 = 100^\circ\text{C} \left\{ \begin{array}{l} v_1 = v_g = 1.6720 \text{ kJ/kg} \\ u_1 = u_g = 2506.0 \text{ kJ/kg} \\ s_1 = 7.3542 \text{ kJ/kg}\cdot\text{K} \end{array} \right.$$

$$T_2 = 25^\circ\text{C} \left\{ \begin{array}{l} x_2 = 0.0386 \\ u_2 = 193.78 \text{ kJ/kg} \\ s_2 = 1.0715 \text{ kJ/kg}\cdot\text{K} \end{array} \right.$$



The entropy change of steam is determined from

$$\Delta S_w = m(s_2 - s_1) = (5 \text{ kg})(1.0715 - 7.3542) \text{ kJ/kg}\cdot\text{K} = \mathbf{-31.41 \text{ kJ/K}}$$

(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

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

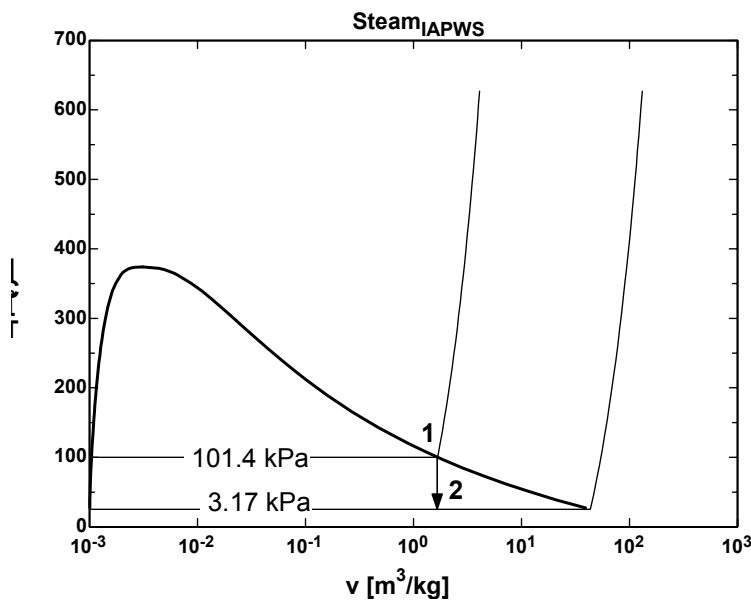
$$-Q_{\text{out}} = \Delta U = m(u_2 - u_1)$$

That is,

$$Q_{\text{out}} = m(u_1 - u_2) = (5 \text{ kg})(2506.0 - 193.78) \text{ kJ/kg} = 11,511 \text{ kJ}$$

The total entropy change for the process is

$$S_{\text{gen}} = \Delta S_w + \frac{Q_{\text{out}}}{T_{\text{surr}}} = -31.41 \text{ kJ/K} + \frac{11,511 \text{ kJ}}{298 \text{ K}} = \mathbf{7.39 \text{ kJ/K}}$$





**7-50** Steam expands in an adiabatic turbine. Steam leaves the turbine at two different pressures. The process is to be sketched on a  $T$ - $s$  diagram and the work done by the steam per unit mass of the steam at the inlet 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),

$$\left. \begin{array}{l} T_1 = 500^\circ\text{C} \\ P_1 = 6 \text{ MPa} \end{array} \right\} \begin{array}{l} h_1 = 3423.1 \text{ kJ/kg} \\ s_1 = 6.8826 \text{ kJ/kg}\cdot\text{K} \end{array} \quad \left. \begin{array}{l} P_2 = 1 \text{ MPa} \\ s_2 = s_1 \end{array} \right\} h_{2s} = 2921.3 \text{ kJ/kg}$$

$$\left. \begin{array}{l} P_3 = 10 \text{ kPa} \\ s_3 = s_1 \end{array} \right\} \begin{array}{l} h_{3s} = 2179.6 \text{ kJ/kg} \\ x_{3s} = 0.831 \end{array}$$

A mass balance on the control volume gives

$$\dot{m}_1 = \dot{m}_2 + \dot{m}_3 \quad \text{where} \quad \begin{array}{l} \dot{m}_2 = 0.1\dot{m}_1 \\ \dot{m}_3 = 0.9\dot{m}_1 \end{array}$$

We take the turbine as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

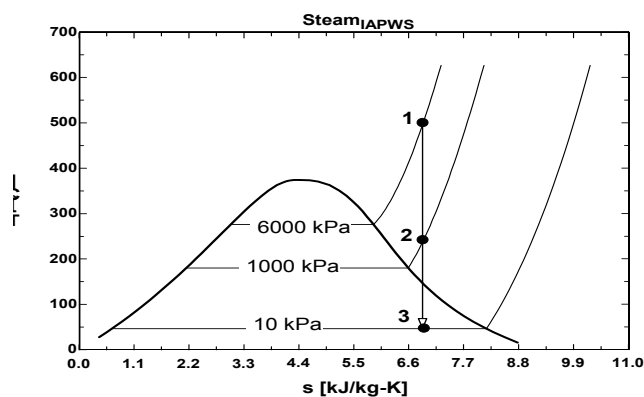
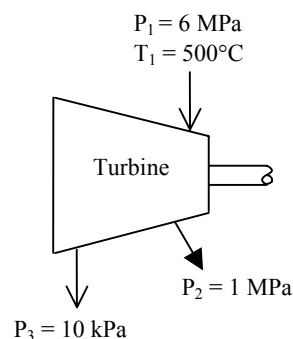
$$\begin{aligned} \dot{E}_{\text{in}} &= \dot{E}_{\text{out}} \\ \dot{m}_1 h_1 &= \dot{W}_{s,\text{out}} + \dot{m}_2 h_2 + \dot{m}_3 h_3 \\ \dot{m}_1 h_1 &= \dot{W}_{s,\text{out}} + 0.1\dot{m}_1 h_2 + 0.9\dot{m}_1 h_3 \end{aligned}$$

or

$$\begin{aligned} h_1 &= w_{s,\text{out}} + 0.1h_2 + 0.9h_3 \\ w_{s,\text{out}} &= h_1 - 0.1h_2 - 0.9h_3 \\ &= 3423.1 - (0.1)(2921.3) - (0.9)(2179.6) = 1169.3 \text{ kJ/kg} \end{aligned}$$

The actual work output per unit mass of steam at the inlet is

$$w_{\text{out}} = \eta_T w_{s,\text{out}} = (0.85)(1169.3 \text{ kJ/kg}) = \mathbf{993.9 \text{ kJ/kg}}$$



**7-51E** 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)

$$\left. \begin{array}{l} P_1 = 140 \text{ psia} \\ T_1 = 70^\circ\text{F} \end{array} \right\} s_1 \cong s_f @ 70^\circ\text{F} = 0.07306 \text{ Btu/lbm}\cdot\text{R}$$

$$\left. \begin{array}{l} P_2 = 20 \text{ psia} \\ s_2 = s_1 \end{array} \right\} \begin{array}{l} x_2 = \frac{s_2 - s_f}{s_{fg}} = \frac{0.07306 - 0.02605}{0.19962} = 0.2355 \\ \nu_2 = \nu_f + x_2 \nu_{fg} = 0.01182 + (0.2355)(2.2772 - 0.01182) = 0.5453 \text{ ft}^3/\text{lbm} \end{array}$$

Thus the final mass of the refrigerant in the can is

$$m = \frac{\mathcal{V}}{\nu_2} = \frac{1.2 \text{ ft}^3}{0.5453 \text{ ft}^3/\text{lbm}} = \mathbf{2.201 \text{ lbm}}$$

