Entropy Change of Incompressible Substances

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

7-53 A hot copper block is dropped into water in an insulated tank. The final equilibrium temperature of the tank and the total entropy change are to be determined.

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

Properties The density and specific heat of water at 25°C are ρ = 997 kg/m^3 and c_p = 4.18 kJ/kg.°C. The specific heat of copper at 27°C is c_p = 0.386 kJ/kg.°C (Table A-3).

Analysis We take the entire contents of the tank, water + copper block, as the *system*. This is a *closed system* since no mass crosses the system boundary during the process. The energy balance for this system can be expressed as

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

$$0 = \Delta U$$

or,

$$\Delta U_{\text{Cu}} + \Delta U_{\text{water}} = 0$$

$$[mc(T_2 - T_1)]_{\text{Cu}} + [mc(T_2 - T_1)]_{\text{water}} = 0$$

where

$$m_{\text{water}} = \rho \mathbf{V} = (997 \text{ kg/m}^3)(0.120 \text{ m}^3) = 119.6 \text{ kg}$$

Using specific heat values for copper and liquid water at room temperature and substituting,

$$(50 \text{ kg})(0.386 \text{ kJ/kg} \cdot °\text{C})(T_2 - 80)°\text{C} + (119.6 \text{ kg})(4.18 \text{ kJ/kg} \cdot °\text{C})(T_2 - 25)°\text{C} = 0$$
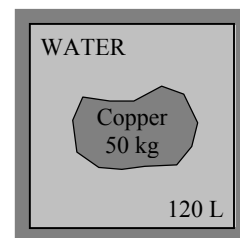
$$T_2 = \textbf{27.0°C}$$

The entropy generated during this process is determined from

$$\Delta S_{\text{copper}} = mc_{\text{avg}} \ln\left(\frac{T_2}{T_1}\right) = (50 \text{ kg})(0.386 \text{ kJ/kg} \cdot \text{K}) \ln\left(\frac{300.0 \text{ K}}{353 \text{ K}}\right) = -3.140 \text{ kJ/K}$$

$$\Delta S_{\text{water}} = mc_{\text{avg}} \ln\left(\frac{T_2}{T_1}\right) = (119.6 \text{ kg})(4.18 \text{ kJ/kg} \cdot \text{K}) \ln\left(\frac{300.0 \text{ K}}{298 \text{ K}}\right) = 3.344 \text{ kJ/K}$$

Thus,

$$\Delta S_{\text{total}} = \Delta S_{\text{copper}} + \Delta S_{\text{water}} = -3.140 + 3.344 = \textbf{0.204 kJ/K}$$

7-54 A hot iron block is dropped into water in an insulated tank. The total entropy change during this process is to be determined.

Assumptions **1** Both the water and the iron block are incompressible substances with constant specific heats at room temperature. **2** The system is stationary and thus the kinetic and potential energies are negligible. **3** The tank is well-insulated and thus there is no heat transfer. **4** The water that evaporates, condenses back.

Properties The specific heat of water at 25°C is c_p = 4.18 kJ/kg.°C. The specific heat of iron at room temperature is c_p = 0.45 kJ/kg.°C (Table A-3).

Analysis We take the entire contents of the tank, water + iron block, as the *system*. This is a *closed system* since no mass crosses the system boundary during the process. The energy balance for this system can be expressed as
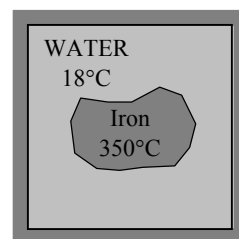
$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$0 = \Delta U$$

or,

$$\Delta U_{iron} + \Delta U_{water} = 0$$

$$[mc(T_2 - T_1)]_{iron} + [mc(T_2 - T_1)]_{water} = 0$$

Substituting,

$$(25 \text{ kg})(0.45 \text{ kJ/kg} \cdot \text{K})(T_2 - 350°\text{C}) + (100 \text{ kg})(4.18 \text{ kJ/kg} \cdot \text{K})(T_2 - 18°\text{C}) = 0$$

$$T_2 = \textbf{26.7°C}$$

The entropy generated during this process is determined from

$$\Delta S_{iron} = mc_{avg} \ln\left(\frac{T_2}{T_1}\right) = (25 \text{ kg})(0.45 \text{ kJ/kg} \cdot \text{K}) \ln\left(\frac{299.7 \text{ K}}{623 \text{ K}}\right) = -8.232 \text{ kJ/K}$$

$$\Delta S_{water} = mc_{avg} \ln\left(\frac{T_2}{T_1}\right) = (100 \text{ kg})(4.18 \text{ kJ/kg} \cdot \text{K}) \ln\left(\frac{299.7 \text{ K}}{291 \text{ K}}\right) = 12.314 \text{ kJ/K}$$

Thus,

$$S_{gen} = \Delta S_{total} = \Delta S_{iron} + \Delta S_{water} = -8.232 + 12.314 = \textbf{4.08 kJ/K}$$

Discussion The results can be improved somewhat by using specific heats at average temperature.

7-55 An aluminum block is brought into contact with an iron block in an insulated enclosure. The final equilibrium temperature and the total entropy change for this process are to be determined.

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

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

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

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

$$0 = \Delta U$$

Iron	Aluminum
20 kg	20 kg
100°C	200°C

or,

$$\Delta U_{alum} + \Delta U_{iron} = 0$$

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

Substituting,

$$(20 \text{ kg})(0.45 \text{ kJ/kg} \cdot \text{K})(T_2 - 100°\text{C}) + (20 \text{ kg})(0.973 \text{ kJ/kg} \cdot \text{K})(T_2 - 200°\text{C}) = 0$$

$$T_2 = \mathbf{168.4°C} = 441.4 \text{ K}$$

The total entropy change for this process is determined from

$$\Delta S_{iron} = mc_{avg} \ln\left(\frac{T_2}{T_1}\right) = (20 \text{ kg})(0.45 \text{ kJ/kg} \cdot \text{K})\ln\left(\frac{441.4 \text{ K}}{373 \text{ K}}\right) = 1.515 \text{ kJ/K}$$

$$\Delta S_{alum} = mc_{avg} \ln\left(\frac{T_2}{T_1}\right) = (20 \text{ kg})(0.973 \text{ kJ/kg} \cdot \text{K})\ln\left(\frac{441.4 \text{ K}}{473 \text{ K}}\right) = -1.346 \text{ kJ/K}$$

Thus,

$$\Delta S_{total} = \Delta S_{iron} + \Delta S_{alum} = 1.515 - 1.346 = \mathbf{0.169 \text{ kJ/K}}$$

7-56 EES Problem 7-55 is reconsidered. The effect of the mass of the iron block on the final equilibrium temperature and the total entropy change for the process is to be studied. The mass of the iron is to vary from 1 to 10 kg. The equilibrium temperature and the total entropy change are to be plotted as a function of iron mass.

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

"Knowns:"
T_1_iron = 100 [C]
{m_iron = 20 [kg]}
T_1_al = 200 [C]
m_al = 20 [kg]
C_al = 0.973 [kJ/kg-K] "FromTable A-3 at the anticipated average temperature of 450 K."
C_iron= 0.45 [kJ/kg-K] "FromTable A-3 at room temperature, the only value available."

"Analysis: "
" Treat the iron plus aluminum as a closed system, with no heat transfer in, no work out, neglect changes in KE and PE of the system. "
"The final temperature is found from the energy balance."
E_in - E_out = DELTAE_sys
E_out = 0
E_in = 0
DELTAE_sys = m_iron*DELTAu_iron + m_al*DELTAu_al
DELTAu_iron = C_iron*(T_2_iron - T_1_iron)
DELTAu_al = C_al*(T_2_al - T_1_al)

"the iron and aluminum reach thermal equilibrium:"
T_2_iron = T_2
T_2_al = T_2
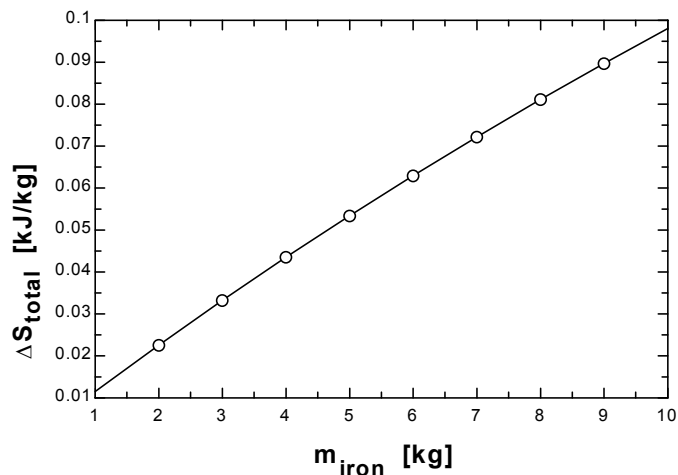DELTAS_iron = m_iron*C_iron*ln((T_2_iron+273) / (T_1_iron+273))
DELTAS_al = m_al*C_al*ln((T_2_al+273) / (T_1_al+273))
DELTAS_total = DELTAS_iron + DELTAS_al
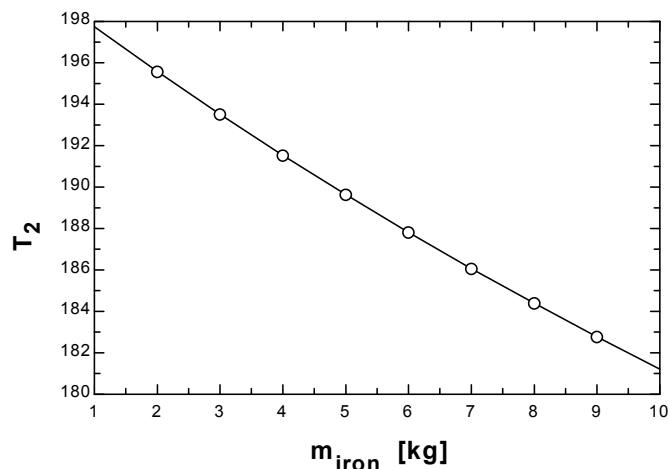
ΔS_{total} [kJ/kg]	m_{iron} [kg]	T_2 [C]
0.01152	1	197.7
0.0226	2	195.6
0.03326	3	193.5
0.04353	4	191.5
0.05344	5	189.6
0.06299	6	187.8
0.07221	7	186.1
0.08112	8	184.4
0.08973	9	182.8
0.09805	10	181.2

7-57 An iron block and a copper block are dropped into a large lake. The total amount of entropy change when both blocks cool to the lake temperature is to be determined.

Assumptions **1** Both the water and the iron block are incompressible substances with constant specific heats at room temperature. **2** Kinetic and potential energies are negligible.

Properties The specific heats of iron and copper at room temperature are $c_{iron} = 0.45$ kJ/kg.°C and $c_{copper} = 0.386$ kJ/kg.°C (Table A-3).

Analysis The thermal-energy capacity of the lake is very large, and thus the temperatures of both the iron and the copper blocks will drop to the lake temperature (15°C) when the thermal equilibrium is established. Then the entropy changes of the blocks become

$$\Delta S_{iron} = mc_{avg} \ln\left(\frac{T_2}{T_1}\right) = (50 \text{ kg})(0.45 \text{ kJ/kg} \cdot \text{K})\ln\left(\frac{288 \text{ K}}{353 \text{ K}}\right) = -4.579 \text{ kJ/K}$$

$$\Delta S_{copper} = mc_{avg} \ln\left(\frac{T_2}{T_1}\right) = (20 \text{ kg})(0.386 \text{ kJ/kg} \cdot \text{K})\ln\left(\frac{288 \text{ K}}{353 \text{ K}}\right) = -1.571 \text{ kJ/K}$$

We take both the iron and the copper blocks, as the *system*. This is a *closed system* since no mass crosses the system boundary during the process. The energy balance for this system can be expressed as

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

$$-Q_{out} = \Delta U = \Delta U_{iron} + \Delta U_{copper}$$

or,

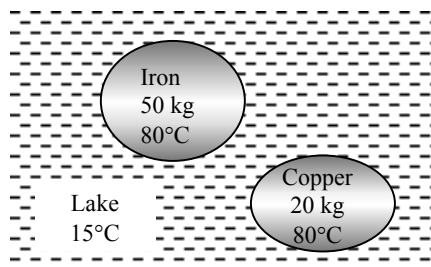$$Q_{out} = [mc(T_1 - T_2)]_{iron} + [mc(T_1 - T_2)]_{copper}$$

Substituting,

$$Q_{out} = (50 \text{ kg})(0.45 \text{ kJ/kg} \cdot \text{K})(353 - 288)\text{K} + (20 \text{ kg})(0.386 \text{ kJ/kg} \cdot \text{K})(353 - 288)\text{K}$$
$$= 1964 \text{ kJ}$$

Thus,

$$\Delta S_{lake} = \frac{Q_{lake,in}}{T_{lake}} = \frac{1964 \text{ kJ}}{288 \text{ K}} = 6.820 \text{ kJ/K}$$

Then the total entropy change for this process is

$$\Delta S_{total} = \Delta S_{iron} + \Delta S_{copper} + \Delta S_{lake} = -4.579 - 1.571 + 6.820 = \textbf{0.670 kJ/K}$$
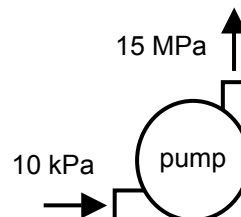
7-58 An adiabatic pump is used to compress saturated liquid water in a reversible manner. The work input is to be determined by different approaches.

Assumptions **1** Steady operating conditions exist. **2** Kinetic and potential energy changes are negligible. **3** Heat transfer to or from the fluid is negligible.

Analysis The properties of water at the inlet and exit of the pump are (Tables A-4 through A-6)

$$\begin{matrix} P_1 = 10 \text{ kPa} \\ x_1 = 0 \end{matrix} \Big\} \begin{matrix} h_1 = 191.81 \text{ kJ/kg} \\ s_1 = 0.6492 \text{ kJ/kg} \\ \boldsymbol{v}_1 = 0.001010 \text{ m}^3/\text{kg} \end{matrix}$$

$$\begin{matrix} P_2 = 15 \text{ MPa} \\ s_2 = s_1 \end{matrix} \Big\} \begin{matrix} h_2 = 206.90 \text{ kJ/kg} \\ \boldsymbol{v}_2 = 0.001004 \text{ m}^3/\text{kg} \end{matrix}$$

(*a*) Using the entropy data from the compressed liquid water table

$$w_P = h_2 - h_1 = 206.90 - 191.81 = \mathbf{15.10 \text{ kJ/kg}}$$

(*b*) Using inlet specific volume and pressure values

$$w_P = \boldsymbol{v}_1(P_2 - P_1) = (0.001010 \text{ m}^3/\text{kg})(15{,}000 - 10)\text{kPa} = \mathbf{15.14 \text{ kJ/kg}}$$

Error = **0.3%**

(*b*) Using average specific volume and pressure values

$$w_P = \boldsymbol{v}_{\text{avg}}(P_2 - P_1) = \left[1/2(0.001010 + 0.001004) \text{ m}^3/\text{kg}\right](15{,}000 - 10)\text{kPa} = \mathbf{15.10 \text{ kJ/kg}}$$

Error = **0%**

Discussion The results show that any of the method may be used to calculate reversible pump work.

Entropy Changes of Ideal Gases

7-59C For ideal gases, $c_p = c_v + R$ and

$$\frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1} \longrightarrow \frac{V_2}{V_1} = \frac{T_2 P_1}{T_1 P_2}$$

Thus,

$$s_2 - s_1 = c_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{V_2}{V_1}\right)$$

$$= c_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{T_2 P_1}{T_1 P_2}\right)$$

$$= c_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)$$

$$= c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)$$

7-60C For an ideal gas, $dh = c_p\, dT$ and $v = RT/P$. From the second Tds relation,

$$ds = \frac{dh}{T} - \frac{v dP}{T} = \frac{c_p dP}{T} - \frac{RT}{P}\frac{dP}{T} = c_p \frac{dT}{T} - R\frac{dP}{P}$$

Integrating,

$$s_2 - s_1 = c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)$$

Since c_p is assumed to be constant.

7-61C No. The entropy of an ideal gas depends on the pressure as well as the temperature.

7-62C Setting $\Delta s = 0$ gives

$$c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right) = 0 \longrightarrow \ln\left(\frac{T_2}{T_1}\right) = \frac{R}{c_p}\ln\left(\frac{P_2}{P_1}\right) \longrightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{R/C_p}$$

But

$$\frac{R}{c_p} = \frac{c_p - c_v}{c_p} = 1 - \frac{1}{k} = \frac{k-1}{k} \quad \text{since} \quad k = c_p/c_v. \text{ Thus,} \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$

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

7-64C The entropy of a gas *can* change during an isothermal process since entropy of an ideal gas depends on the pressure as well as the temperature.

7-65C The entropy change relations of an ideal gas simplify to

$\Delta s = c_p \ln(T_2/T_1)$ for a constant pressure process

and $\Delta s = c_v \ln(T_2/T_1)$ for a constant volume process.

Noting that $c_p > c_v$, the entropy change will be larger for a constant pressure process.

7-66 Oxygen gas is compressed from a specified initial state to a specified final state. The entropy change of oxygen during this process is to be determined for the case of constant specific heats.

*Assumptions* At specified conditions, oxygen can be treated as an ideal gas.

Properties The gas constant and molar mass of oxygen are $R = 0.2598$ kJ/kg.K and $M = 32$ kg/kmol (Table A-1).

Analysis The constant volume specific heat of oxygen at the average temperature is (Table A-2)

$$T_{avg} = \frac{298 + 560}{2} = 429 \text{ K} \longrightarrow c_{v,avg} = 0.690 \text{ kJ/kg} \cdot \text{K}$$

Thus,

$$s_2 - s_1 = c_{v,avg} \ln\frac{T_2}{T_1} + R \ln\frac{V_2}{V_1}$$

$$= (0.690 \text{ kJ/kg} \cdot \text{K}) \ln\frac{560 \text{ K}}{298 \text{ K}} + (0.2598 \text{ kJ/kg} \cdot \text{K}) \ln\frac{0.1 \text{ m}^3/\text{kg}}{0.8 \text{ m}^3/\text{kg}}$$

$$= -0.105 \text{ kJ/kg} \cdot \text{K}$$

O_2
0.8 m³/kg
25°C
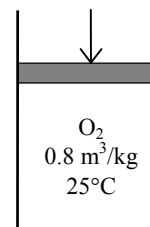
7-67 An insulated tank contains CO_2 gas at a specified pressure and volume. A paddle-wheel in the tank stirs the gas, and the pressure and temperature of CO_2 rises. The entropy change of CO_2 during this process is to be determined using constant specific heats.

Assumptions At specified conditions, CO_2 can be treated as an ideal gas with constant specific heats at room temperature.
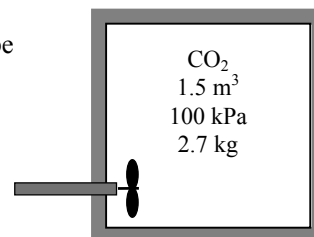
Properties The specific heat of CO_2 is $c_v = 0.657$ kJ/kg.K (Table A-2).

Analysis Using the ideal gas relation, the entropy change is determined to be

$$\frac{P_2 V}{T_2} = \frac{P_1 V}{T_1} \longrightarrow \frac{T_2}{T_1} = \frac{P_2}{P_1} = \frac{150 \text{ kPa}}{100 \text{ kPa}} = 1.5$$

CO_2
1.5 m³
100 kPa
2.7 kg

Thus,

$$\Delta S = m(s_2 - s_1) = m\left(c_{v,avg} \ln\frac{T_2}{T_1} + R \ln\frac{V_2}{V_1}^{\nearrow 0} \right) = mc_{v,avg} \ln\frac{T_2}{T_1}$$

$$= (2.7 \text{ kg})(0.657 \text{ kJ/kg} \cdot \text{K}) \ln(1.5)$$

$$= 0.719 \text{ kJ/K}$$

7-68 An insulated cylinder initially contains air at a specified state. A resistance heater inside the cylinder is turned on, and air is heated for 15 min at constant pressure. The entropy change of air during this process is to be determined for the cases of constant and variable specific heats.

Assumptions At specified conditions, air can be treated as an ideal gas.

Properties The gas constant of air is $R = 0.287$ kJ/kg.K (Table A-1).

Analysis The mass of the air and the electrical work done during this process are

$$m = \frac{P_1 V_1}{RT_1} = \frac{(120 \text{ kPa})(0.3 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(290 \text{ K})} = 0.4325 \text{ kg}$$

$$W_{e,in} = \dot{W}_{e,in}\Delta t = (0.2 \text{ kJ/s})(15 \times 60 \text{ s}) = 180 \text{ kJ}$$

The energy balance for this stationary closed system can be expressed as

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

$$W_{e,in} - W_{b,out} = \Delta U \longrightarrow W_{e,in} = m(h_2 - h_1) \cong c_p(T_2 - T_1)$$

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

(*a*) Using a constant c_p value at the anticipated average temperature of 450 K, the final temperature becomes

Thus, $$T_2 = T_1 + \frac{W_{e,in}}{mc_p} = 290 \text{ K} + \frac{180 \text{ kJ}}{(0.4325 \text{ kg})(1.02 \text{ kJ/kg}\cdot\text{K})} = 698 \text{ K}$$
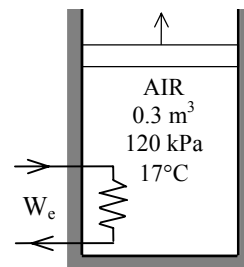
Then the entropy change becomes

$$\Delta S_{sys} = m(s_2 - s_1) = m\left(c_{p,avg} \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}^{\nearrow 0} \right) = mc_{p,avg} \ln\frac{T_2}{T_1}$$

$$= (0.4325 \text{ kg})(1.020 \text{ kJ/kg}\cdot\text{K})\ln\left(\frac{698 \text{ K}}{290 \text{ K}}\right) = \mathbf{0.387 \text{ kJ/K}}$$

(*b*) Assuming variable specific heats,

$$W_{e,in} = m(h_2 - h_1) \longrightarrow h_2 = h_1 + \frac{W_{e,in}}{m} = 290.16 \text{ kJ/kg} + \frac{180 \text{ kJ}}{0.4325 \text{ kg}} = 706.34 \text{ kJ/kg}$$

From the air table (Table A-17, we read $s_2^\circ = 2.5628$ kJ/kg·K corresponding to this h_2 value. Then,

$$\Delta S_{sys} = m\left(s_2^\circ - s_1^\circ + R\ln\frac{P_2}{P_1}^{\nearrow 0} \right) = m(s_2^\circ - s_1^\circ) = (0.4325 \text{ kg})(2.5628 - 1.66802)\text{kJ/kg}\cdot\text{K} = \mathbf{0.387 \text{ kJ/K}}$$

7-69 A cylinder contains N_2 gas at a specified pressure and temperature. It is compressed polytropically until the volume is reduced by half. The entropy change of nitrogen during this process is to be determined.

Assumptions 1 At specified conditions, N_2 can be treated as an ideal gas. **2** Nitrogen has constant specific heats at room temperature.
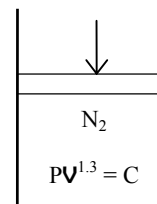
Properties The gas constant of nitrogen is $R = 0.297$ kJ/kg.K (Table A-1). The constant volume specific heat of nitrogen at room temperature is $c_v = 0.743$ kJ/kg.K (Table A-2).

Analysis From the polytropic relation,

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{n-1} \longrightarrow T_2 = T_1\left(\frac{v_1}{v_2}\right)^{n-1} = (300 \text{ K})(2)^{1.3-1} = 369.3 \text{ K}$$

Then the entropy change of nitrogen becomes

$$\Delta S_{N_2} = m\left(c_{v,avg} \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1} \right)$$

$$= (1.2 \text{ kg})\left((0.743 \text{ kJ/kg}\cdot\text{K})\ln\frac{369.3 \text{ K}}{300 \text{ K}} + (0.297 \text{ kJ/kg}\cdot\text{K})\ln(0.5) \right) = \mathbf{-0.0617 \text{ kJ/K}}$$

7-70 EES Problem 7-69 is reconsidered. The effect of varying the polytropic exponent from 1 to 1.4 on the entropy change of the nitrogen is to be investigated, and the processes are to be shown on a common $P\text{-}v$ diagram.

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

```
Function BoundWork(P[1],V[1],P[2],V[2],n)
"This function returns the Boundary Work for the polytropic process.  This function is required
since the expression for boundary work depens on whether n=1 or n<>1"
  If n<>1 then
    BoundWork:=(P[2]*V[2]-P[1]*V[1])/(1-n)"Use Equation 3-22 when n=1"
  else
    BoundWork:= P[1]*V[1]*ln(V[2]/V[1]) "Use Equation 3-20 when n=1"
  endif
end

n=1
P[1] = 120 [kPa]
T[1] = 27 [C]
m = 1.2 [kg]
V[2]=V[1]/2
Gas$='N2'
MM=molarmass(Gas$)
R=R_u/MM
R_u=8.314 [kJ/kmol-K]
"System:  The gas enclosed in the piston-cylinder device."
"Process: Polytropic expansion or compression, P*V^n = C"
P[1]*V[1]=m*R*(T[1]+273)
P[2]*V[2]^n=P[1]*V[1]^n
W_b = BoundWork(P[1],V[1],P[2],V[2],n)
"Find the temperature at state 2 from the pressure and specific volume."
T[2]=temperature(gas$,P=P[2],v=V[2]/m)
"The entropy at states 1 and 2 is:"
s[1]=entropy(gas$,P=P[1],v=V[1]/m)
s[2]=entropy(gas$,P=P[2],v=V[2]/m)
DELTAS=m*(s[2] - s[1])
"Remove the {} to generate the P-v plot data"
{Nsteps = 10
VP[1]=V[1]
PP[1]=P[1]
Duplicate i=2,Nsteps
    VP[i]=V[1]-i*(V[1]-V[2])/Nsteps
    PP[i]=P[1]*(V[1]/VP[i])^n
END }
```

| ΔS [kJ/kg]	n	W_b [kJ]
-0.2469	1	-74.06
-0.2159	1.05	-75.36
-0.1849	1.1	-76.69
-0.1539	1.15	-78.05
-0.1229	1.2	-79.44
-0.09191	1.25	-80.86
-0.06095	1.3	-82.32
-0.02999	1.35	-83.82
0.0009849	1.4	-85.34
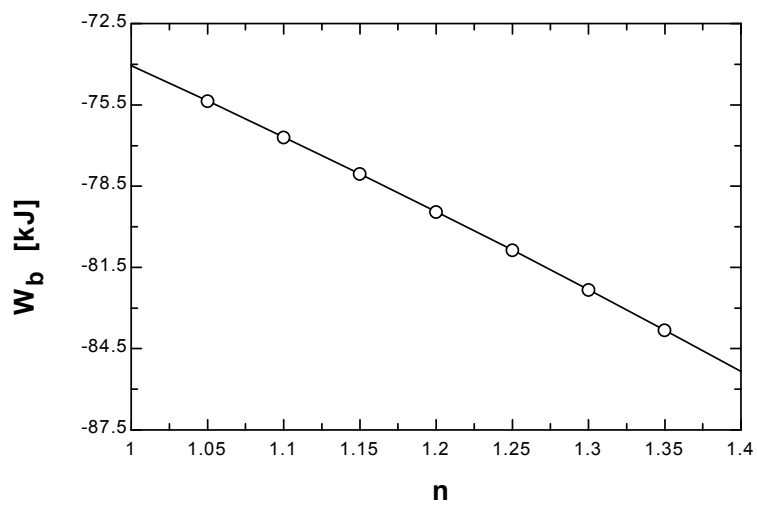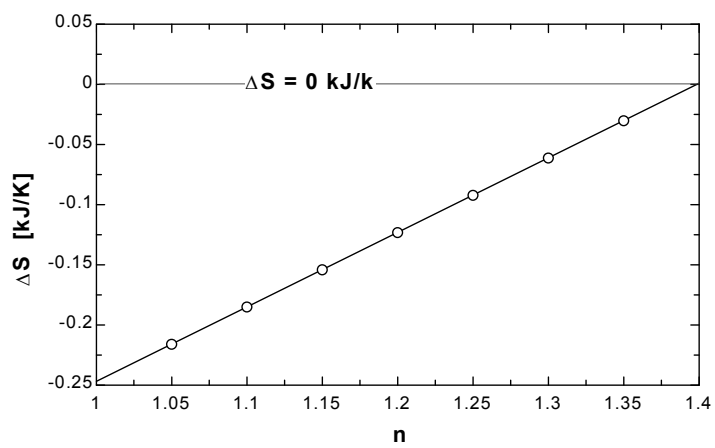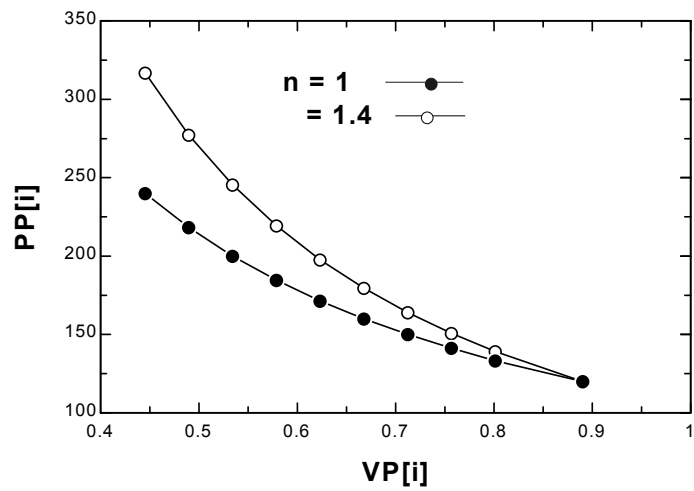
7-71E A fixed mass of helium undergoes a process from one specified state to another specified state. The entropy change of helium is to be determined for the cases of reversible and irreversible processes.

Assumptions **1** At specified conditions, helium can be treated as an ideal gas. **2** Helium has constant specific heats at room temperature.

Properties The gas constant of helium is $R = 0.4961$ Btu/lbm.R (Table A-1E). The constant volume specific heat of helium is $c_v = 0.753$ Btu/lbm.R (Table A-2E).

Analysis From the ideal-gas entropy change relation,

$$\Delta S_{\text{He}} = m\left(c_{v,\text{ave}} \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1} \right)$$

$$= (15 \text{ lbm})\left((0.753 \text{ Btu/lbm} \cdot \text{R}) \ln\frac{660 \text{ R}}{540 \text{ R}} + (0.4961 \text{ Btu/lbm} \cdot \text{R})\ln\left(\frac{10 \text{ ft}^3/\text{lbm}}{50 \text{ ft}^3/\text{lbm}} \right) \right)$$

$$= -\mathbf{9.71 \, Btu/R}$$
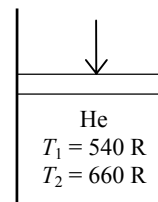
The entropy change will be the same for both cases.

He
$T_1 = 540$ R
$T_2 = 660$ R

7-72 Air is compressed in a piston-cylinder device in a reversible and isothermal manner. The entropy change of air and the work done are to be determined.

Assumptions **1** At specified conditions, air can be treated as an ideal gas. **2** The process is specified to be reversible.

Properties The gas constant of air is $R = 0.287$ kJ/kg.K (Table A-1).

Analysis (*a*) Noting that the temperature remains constant, the entropy change of air is determined from

$$\Delta S_{\text{air}} = c_{p,\text{avg}} \ln\frac{T_2}{T_1}^{\nearrow 0} - R\ln\frac{P_2}{P_1} = -R\ln\frac{P_2}{P_1}$$

$$= -(0.287 \text{ kJ/kg} \cdot \text{K})\ln\left(\frac{400 \text{ kPa}}{90 \text{ kPa}} \right) = -\mathbf{0.428 \, kJ/kg \cdot K}$$

AIR
$T = \text{const}$
Q
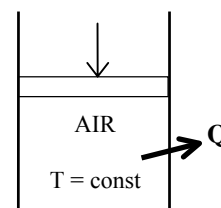
Also, for a reversible isothermal process,

$$q = T\Delta s = (293 \text{ K})(- 0.428 \text{ kJ/kg} \cdot \text{K}) = -125.4 \text{ kJ/kg} \longrightarrow q_{\text{out}} = 125.4 \text{ kJ/kg}$$

(*b*) The work done during this process is determined from the closed system energy balance,

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

$$W_{\text{in}} - Q_{\text{out}} = \Delta U = mc_v(T_2 - T_1) = 0$$

$$w_{\text{in}} = q_{\text{out}} = \mathbf{125.4 \, kJ/kg}$$

7-73 Air is compressed steadily by a 5-kW compressor from one specified state to another specified state. The rate of entropy change of air is to be determined.

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

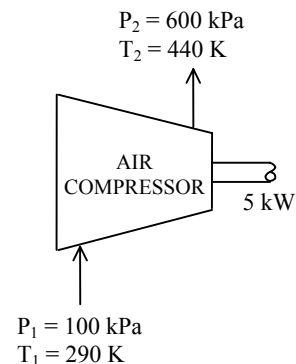*Properties* The gas constant of air is $R = 0.287$ kJ/kg.K (Table A-1).

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

$$\left.\begin{array}{l} T_1 = 290 \text{ K} \\ P_1 = 100 \text{ kPa} \end{array}\right\} s_1^\circ = 1.66802 \text{ kJ/kg} \cdot \text{K}$$

$$\left.\begin{array}{l} T_2 = 440 \text{ K} \\ P_2 = 600 \text{ kPa} \end{array}\right\} s_2^\circ = 2.0887 \text{ kJ/kg} \cdot \text{K}$$

Then the rate of entropy change of air becomes

$$\Delta \dot{S}_{\text{sys}} = \dot{m}\left(s_2^\circ - s_1^\circ - R \ln \frac{P_2}{P_1} \right)$$

$$= (1.6/60 \text{ kg/s})\left(2.0887 - 1.66802 - (0.287 \text{ kJ/kg} \cdot \text{K}) \ln\left(\frac{600 \text{ kPa}}{100 \text{ kPa}} \right) \right)$$

$$= \mathbf{-0.00250 \text{ kW/K}}$$

$P_2 = 600$ kPa
$T_2 = 440$ K

AIR
COMPRESSOR

5 kW

$P_1 = 100$ kPa
$T_1 = 290$ K

7-74 One side of a partitioned insulated rigid tank contains an ideal gas at a specified temperature and pressure while the other side is evacuated. The partition is removed, and the gas fills the entire tank. The total entropy change during this process is to be determined.

Assumptions The gas in the tank is given to be an ideal gas, and thus ideal gas relations apply.

Analysis Taking the entire rigid tank as the system, the energy balance can be expressed as

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

$$0 = \Delta U = m(u_2 - u_1)$$

$$u_2 = u_1$$

$$T_2 = T_1$$
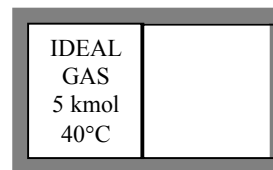
IDEAL
GAS
5 kmol
40°C

since $u = u(T)$ for an ideal gas. Then the entropy change of the gas becomes

$$\Delta S = N\left(\overline{c}_{v,\text{avg}} \ln \frac{T_2}{T_1}^{\nearrow 0} + R_u \ln \frac{V_2}{V_1} \right) = NR_u \ln \frac{V_2}{V_1}$$

$$= (5 \text{ kmol})(8.314 \text{ kJ/kmol} \cdot \text{K}) \ln(2)$$

$$= \mathbf{28.81 \text{ kJ/K}}$$

This also represents the **total entropy change** since the tank does not contain anything else, and there are no interactions with the surroundings.

7-75 Air is compressed in a piston-cylinder device in a reversible and adiabatic manner. The final temperature and the work are to be determined for the cases of constant and variable specific heats.

Assumptions **1** At specified conditions, air can be treated as an ideal gas. **2** The process is given to be reversible and adiabatic, and thus isentropic. Therefore, isentropic relations of ideal gases apply.

Properties The gas constant of air is $R = 0.287$ kJ/kg.K (Table A-1). The specific heat ratio of air at low to moderately high temperatures is $k = 1.4$ (Table A-2).

Analysis (*a*) Assuming constant specific heats, the ideal gas isentropic relations give

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{(k-1)/k} = (290 \text{ K}) \left(\frac{800 \text{ kPa}}{100 \text{ kPa}} \right)^{0.4/1.4} = \textbf{525.3 K}$$

Then,

$$T_{\text{avg}} = (290 + 525.3)/2 = 407.7\text{K} \longrightarrow c_{\nu,\text{avg}} = 0.727\text{kJ/kg} \cdot \text{K}$$

We take the air in the cylinder as the system. The energy balance for this stationary closed system can be expressed as

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

$$W_{\text{in}} = \Delta U = m(u_2 - u_1) \cong mc_\nu (T_2 - T_1)$$

Thus,

$$w_{\text{in}} = c_{\nu,\text{avg}}(T_2 - T_1) = (0.727 \text{ kJ/kg} \cdot \text{K})(525.3 - 290)\text{K} = \textbf{171.1 kJ/kg}$$

(*b*) Assuming variable specific heats, the final temperature can be determined using the relative pressure data (Table A-17),
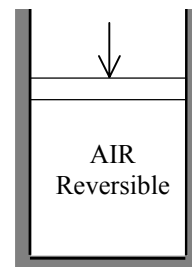
$$T_1 = 290 \text{ K} \longrightarrow \begin{array}{l} P_{r_1} = 1.2311 \\ u_1 = 206.91 \text{ kJ/kg} \end{array}$$

and

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = \frac{800 \text{ kPa}}{100 \text{ kPa}}(1.2311) = 9.849 \longrightarrow \begin{array}{l} T_2 = \textbf{522.4 K} \\ u_2 = 376.16 \text{ kJ/kg} \end{array}$$

Then the work input becomes

$$w_{\text{in}} = u_2 - u_1 = (376.16 - 206.91) \text{ kJ/kg} = \textbf{169.25 kJ/kg}$$

AIR
Reversible

7-76 EES Problem 7-75 is reconsidered. The work done and final temperature during the compression process are to be calculated and plotted as functions of the final pressure for the two cases as the final pressure varies from 100 kPa to 800 kPa.

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

```
Procedure ConstPropSol(P_1,T_1,P_2,Gas$:Work_in_ConstProp,T2_ConstProp)
C_P=SPECHEAT(Gas$,T=27)
MM=MOLARMASS(Gas$)
R_u=8.314 [kJ/kmol-K]
R=R_u/MM
C_V = C_P - R
k = C_P/C_V
T2= (T_1+273)*(P_2/P_1)^((k-1)/k)
T2_ConstProp=T2-273 "[C]"
DELTAu = C_v*(T2-(T_1+273))
Work_in_ConstProp = DELTAu
End
```

"Knowns:"
P_1 = 100 [kPa]
T_1 = 17 [C]
P_2 = 800 [kPa]

"Analysis: "
" Treat the piston-cylinder as a closed system, with no heat transfer in, neglect
changes in KE and PE of the air. The process is reversible and adiabatic thus isentropic."
"The isentropic work is determined from:"
e_in - e_out = DELTAe_sys
e_out = 0 [kJ/kg]
e_in = Work_in
DELTAE_sys = (u_2 - u_1)
u_1 = INTENERGY(air,T=T_1)
v_1 = volume(air,P=P_1,T=T_1)
s_1 = entropy(air,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
u_2 = INTENERGY(air,P=P_2,s=s_2)
T_2_isen=temperature(air,P=P_2,s=s_2)
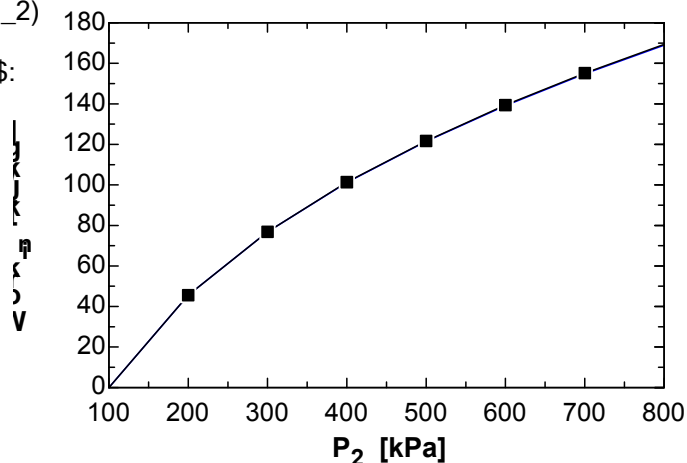Gas$ = 'air'
Call ConstPropSol(P_1,T_1,P_2,Gas$:
 Work_in_ConstProp,T2_ConstProp)

P_2 [kPa]	Work$_{in}$ [kJ/kg]	Work$_{in,ConstProp}$ [kJ/kg]
100	0	0
200	45.63	45.6
300	76.84	76.77
400	101.3	101.2
500	121.7	121.5
600	139.4	139.1
700	155.2	154.8
800	169.3	168.9

7-77 Helium gas is compressed in a piston-cylinder device in a reversible and adiabatic manner. The final temperature and the work are to be determined for the cases of the process taking place in a piston-cylinder device and a steady-flow compressor.

Assumptions **1** Helium is an ideal gas with constant specific heats. **2** The process is given to be reversible and adiabatic, and thus isentropic. Therefore, isentropic relations of ideal gases apply.

Properties The specific heats and the specific heat ratio of helium are c_v = 3.1156 kJ/kg.K, c_p = 5.1926 kJ/kg.K, and k = 1.667 (Table A-2).

Analysis (*a*) From the ideal gas isentropic relations,

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (303\ \text{K})\left(\frac{450\ \text{kPa}}{90\ \text{kPa}}\right)^{0.667/1.667} = \textbf{576.9 K}$$

(*a*) We take the air in the cylinder as the system. The energy balance for this stationary closed system can be expressed as

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

$$W_{\text{in}} = \Delta U = m(u_2 - u_1) \cong mc_v(T_2 - T_1)$$

Thus, $w_{\text{in}} = c_v(T_2 - T_1) = (3.1156\ \text{kJ/kg} \cdot \text{K})(576.9 - 303)\text{K} = \textbf{853.4 kJ/kg}$

(*b*) If the process takes place in a steady-flow device, the final temperature will remain the same but the work done should be determined from an energy balance on this steady-flow device,

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

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

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

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

Thus, $w_{\text{in}} = c_p(T_2 - T_1) = (5.1926\ \text{kJ/kg} \cdot \text{K})(576.9 - 303)\text{K} = \textbf{1422.3 kJ/kg}$
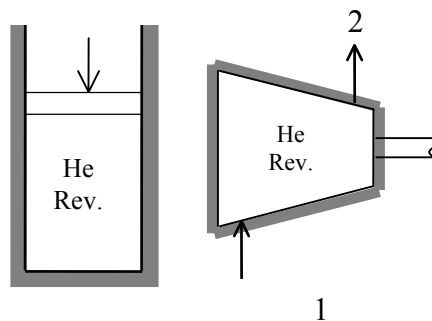
7-78 An insulated rigid tank contains argon gas at a specified pressure and temperature. A valve is opened, and argon escapes until the pressure drops to a specified value. The final mass in the tank is to be determined.

Assumptions **1** At specified conditions, argon can be treated as an ideal gas. **2** The process is given to be reversible and adiabatic, and thus isentropic. Therefore, isentropic relations of ideal gases apply.
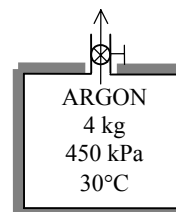
Properties The specific heat ratio of argon is k = 1.667 (Table A-2).

Analysis From the ideal gas isentropic relations,

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (303\ \text{K})\left(\frac{200\ \text{kPa}}{450\ \text{kPa}}\right)^{0.667/1.667} = 219.0\ \text{K}$$

The final mass in the tank is determined from the ideal gas relation,

$$\frac{P_1 \mathcal{V}}{P_2 \mathcal{V}} = \frac{m_1 R T_1}{m_2 R T_2} \longrightarrow m_2 = \frac{P_2 T_1}{P_1 T_2}m_1 = \frac{(200\ \text{kPa})(303\ \text{K})}{(450\ \text{kPa})(219\ \text{K})}(4\ \text{kg}) = \textbf{2.46 kg}$$

7-79 EES Problem 7-78 is reconsidered. The effect of the final pressure on the final mass in the tank is to be investigated as the pressure varies from 450 kPa to 150 kPa, and the results are to be plotted.

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

"UNIFORM_FLOW SOLUTION:"
"Knowns:"
C_P = 0.5203"[kJ/kg-K]"
C_V = 0.3122 "[kJ/kg-K]"
R=0.2081 "[kPa-m^3/kg-K]"
P_1= 450"[kPa]"
T_1 = 30"[C]"
m_1 = 4"[kg]"
P_2= 150"[kPa]"

"Analysis:
We assume the mass that stays in the tank undergoes an isentropic expansion
process. This allows us to determine the final temperature of that gas at the final
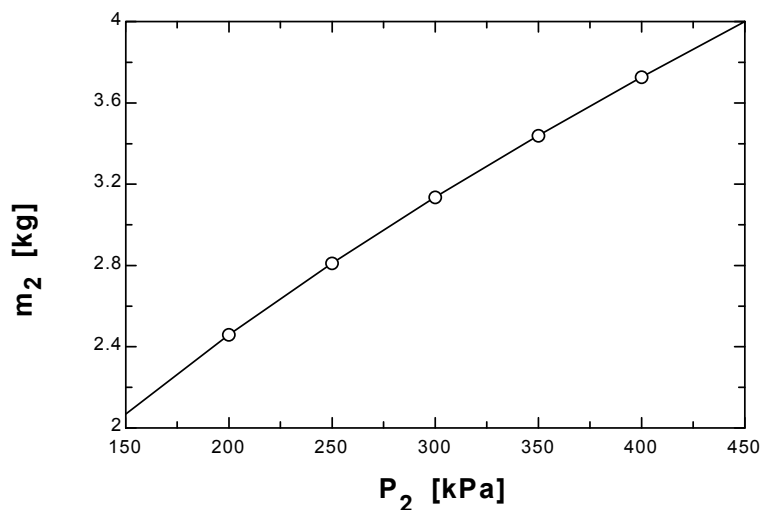pressure in the tank by using the isentropic relation:"

k = C_P/C_V
T_2 = ((T_1+273)*(P_2/P_1)^((k-1)/k)-273)"[C]"
V_2 = V_1
P_1*V_1=m_1*R*(T_1+273)
P_2*V_2=m_2*R*(T_2+273)

m_2 [kg]	P_2 [kPa]
2.069	150
2.459	200
2.811	250
3.136	300
3.44	350
3.727	400
4	450

7-80E Air is accelerated in an adiabatic nozzle. Disregarding irreversibilities, the exit velocity of air is to be determined.

Assumptions **1** Air is an ideal gas with variable specific heats. **2** The process is given to be reversible and adiabatic, and thus isentropic. Therefore, isentropic relations of ideal gases apply. **2** The nozzle operates steadily.

Analysis Assuming variable specific heats, the inlet and exit properties are determined to be

$$T_1 = 1000 \text{ R} \longrightarrow \begin{array}{l} P_{r_1} = 12.30 \\ h_1 = 240.98 \text{ Btu/lbm} \end{array}$$

and

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = \frac{12 \text{ psia}}{60 \text{ psia}}(12.30) = 2.46 \longrightarrow \begin{array}{l} T_2 = 635.9 \text{ R} \\ h_2 = 152.11 \text{ Btu/lbm} \end{array}$$
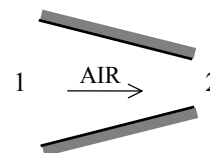
We take the nozzle as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

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

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

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2)$$

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

Therefore,

$$V_2 = \sqrt{2(h_1 - h_2) + V_1^2} = \sqrt{2(240.98 - 152.11)\text{Btu/lbm}\left(\frac{25{,}037 \text{ ft}^2/\text{s}^2}{1 \text{ Btu/lbm}}\right) + (200 \text{ ft/s})^2}$$

$$= \textbf{2119 ft/s}$$

7-81 Air is accelerated in an nozzle, and some heat is lost in the process. The exit temperature of air and the total entropy change during the process are to be determined.

Assumptions **1** Air is an ideal gas with variable specific heats. **2** The nozzle operates steadily.

Analysis (*a*) Assuming variable specific heats, the inlet properties are determined to be,

$$T_1 = 350 \text{ K} \longrightarrow \begin{array}{l} h_1 = 350.49 \text{ kJ}/\text{kg} \\ s_1^\circ = 1.85708 / \text{kJ}/\text{kg} \cdot \text{K} \end{array} \quad \text{(Table A-17)}$$

We take the nozzle as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as
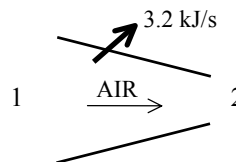
$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}}^{\nearrow 0 \text{ (steady)}} = 0$$

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

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2) + \dot{Q}_{out}$$

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

Therefore,

$$h_2 = h_1 - q_{out} - \frac{V_2^2 - V_1^2}{2} = 350.49 - 3.2 - \frac{(320 \text{ m/s})^2 - (50 \text{ m/s})^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right)$$

$$= 297.34 \text{ kJ/kg}$$

At this h_2 value we read, from Table A-17, $T_2 = $ **297.2 K**, $s_2^\circ = 1.6924 \text{ kJ}/\text{kg} \cdot \text{K}$

(*b*) The total entropy change is the sum of the entropy changes of the air and of the surroundings, and is determined from

$$\Delta s_{total} = \Delta s_{air} + \Delta s_{surr}$$

where

$$\Delta s_{air} = s_2^\circ - s_1^\circ - R \ln \frac{P_2}{P_1} = 1.6924 - 1.85708 - (0.287 \text{ kJ/kg} \cdot \text{K}) \ln \frac{85 \text{ kPa}}{280 \text{ kPa}} = 0.1775 \text{ kJ/kg} \cdot \text{K}$$

and

$$\Delta s_{surr} = \frac{q_{surr,in}}{T_{surr}} = \frac{3.2 \text{ kJ/kg}}{293 \text{ K}} = 0.0109 \text{ kJ/kg} \cdot \text{K}$$

Thus,

$$\Delta s_{total} = 0.1775 + 0.0109 = \textbf{0.1884 kJ/kg} \cdot \textbf{K}$$

7-82 EES Problem 7-76 is reconsidered. The effect of varying the surrounding medium temperature from 10°C to 40°C on the exit temperature and the total entropy change for this process is to be studied, and the results are to be plotted.

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

```
Function HCal(WorkFluid$, Tx, Px)
"Function to calculate the enthalpy of an ideal gas or real gas"
   If  'Air' = WorkFluid$  then
      HCal:=ENTHALPY('Air',T=Tx) "Ideal gas equ."
   else
      HCal:=ENTHALPY(WorkFluid$,T=Tx, P=Px)"Real gas equ."
   endif
end  HCal


"System: control volume for the nozzle"
"Property relation: Air is an ideal gas"
"Process: Steady state, steady flow, adiabatic, no work"
"Knowns - obtain from the input diagram"
WorkFluid$ = 'Air'
T[1] = 77 [C]
P[1] = 280   [kPa]
Vel[1] = 50  [m/s]
P[2] = 85  [kPa]
Vel[2] = 320  [m/s]
q_out = 3.2 [kJ/kg]
"T_surr = 20 [C]"

"Property Data - since the Enthalpy function has different parameters
for ideal gas and real fluids, a function was used to determine h."
h[1]=HCal(WorkFluid$,T[1],P[1])
h[2]=HCal(WorkFluid$,T[2],P[2])

"The Volume function has the same form for an ideal gas as for a real fluid."
v[1]=volume(workFluid$,T=T[1],p=P[1])
v[2]=volume(WorkFluid$,T=T[2],p=P[2])

"If we knew the inlet or exit area, we could calculate the mass flow rate.  Since we don't know
these areas, we write the conservation of energy per unit mass."
"Conservation of mass: m_dot[1]= m_dot[2]"
"Conservation of Energy - SSSF energy balance for neglecting the change in potential energy, no
work, but heat transfer out is:"
h[1]+Vel[1]^2/2*Convert(m^2/s^2, kJ/kg) = h[2]+Vel[2]^2/2*Convert(m^2/s^2, kJ/kg)+q_out
s[1]=entropy(workFluid$,T=T[1],p=P[1])
s[2]=entropy(WorkFluid$,T=T[2],p=P[2])

"Entropy change of the air and the surroundings are:"
DELTAs_air = s[2] - s[1]
q_in_surr = q_out
DELTAs_surr = q_in_surr/(T_surr+273)
DELTAs_total = DELTAs_air + DELTAs_surr
```
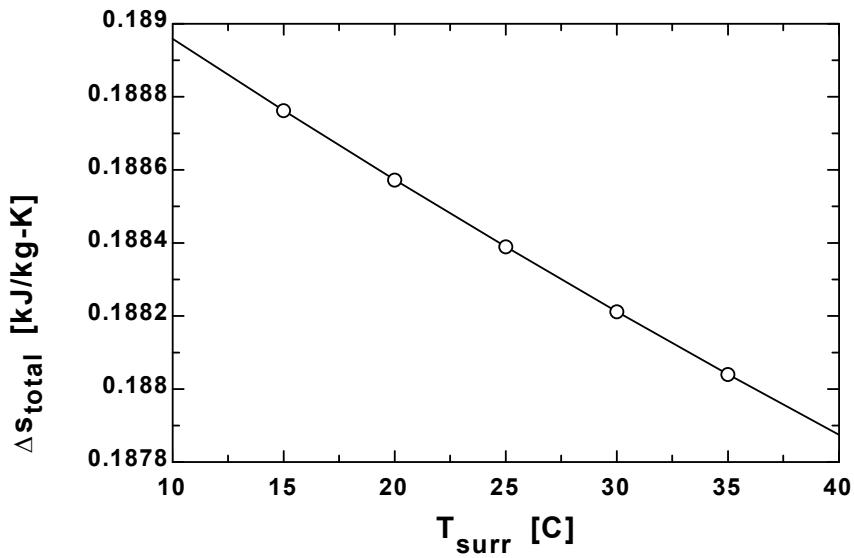
Δs_{total} [kJ/kg-K]	T_{surr} [C]	T_2 [C]
0.189	10	24.22
0.1888	15	24.22
0.1886	20	24.22
0.1884	25	24.22
0.1882	30	24.22
0.188	35	24.22
0.1879	40	24.22

7-83 A container is filled with liquid water is placed in a room and heat transfer takes place between the container and the air in the room until the thermal equilibrium is established. The final temperature, the amount of heat transfer between the water and the air, and the entropy generation are to be determined.

Assumptions 1 Kinetic and potential energy changes are negligible. **2** Air is an ideal gas with constant specific heats. **3** The room is well-sealed and there is no heat transfer from the room to the surroundings. **4** Sea level atmospheric pressure is assumed. $P = 101.3$ kPa.

Properties The properties of air at room temperature are $R = 0.287$ kPa.m^3/kg.K, $c_p = 1.005$ kJ/kg.K, $c_v = 0.718$ kJ/kg.K. The specific heat of water at room temperature is $c_w = 4.18$ kJ/kg.K (Tables A-2, A-3).
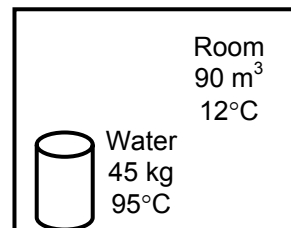
Analysis (*a*) The mass of the air in the room is

$$m_a = \frac{PV}{RT_{a1}} = \frac{(101.3\,\text{kPa})(90\,\text{m}^3)}{(0.287\,\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(12+273\,\text{K})} = 111.5\,\text{kg}$$

An energy balance on the system that consists of the water in the container and the air in the room gives the final equilibrium temperature

$$0 = m_w c_w (T_2 - T_{w1}) + m_a c_v (T_2 - T_{a1})$$

$$0 = (45\,\text{kg})(4.18\,\text{kJ/kg.K})(T_2 - 95) + (111.5\,\text{kg})(0.718\,\text{kJ/kg.K})(T_2 - 12) \longrightarrow T_2 = \textbf{70.2°C}$$

(*b*) The heat transfer to the air is

$$Q = m_a c_v (T_2 - T_{a1}) = (111.5\,\text{kg})(0.718\,\text{kJ/kg.K})(70.2 - 12) = \textbf{4660 kJ}$$

(*c*) The entropy generation associated with this heat transfer process may be obtained by calculating total entropy change, which is the sum of the entropy changes of water and the air.

$$\Delta S_w = m_w c_w \ln\frac{T_2}{T_{w1}} = (45\,\text{kg})(4.18\,\text{kJ/kg.K})\ln\frac{(70.2+273)\,\text{K}}{(95+273)\,\text{K}} = -13.11\,\text{kJ/K}$$

$$P_2 = \frac{m_a R T_2}{V} = \frac{(111.5\,\text{kg})(0.287\,\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(70.2+273\,\text{K})}{(90\,\text{m}^3)} = 122\,\text{kPa}$$

$$\Delta S_a = m_a\left(c_p \ln\frac{T_2}{T_{a1}} - R\ln\frac{P_2}{P_1}\right)$$

$$= (111.5\,\text{kg})\left[(1.005\,\text{kJ/kg.K})\ln\frac{(70.2+273)\,\text{K}}{(12+273)\,\text{K}} - (0.287\,\text{kJ/kg.K})\ln\frac{122\,\text{kPa}}{101.3\,\text{kPa}}\right] = 14.88\,\text{kJ/K}$$

$$S_{gen} = \Delta S_{total} = \Delta S_w + \Delta S_a = -13.11 + 14.88 = \textbf{1.77 kJ/K}$$

7-84 Air is accelerated in an isentropic nozzle. The maximum velocity at the exit is to be determined.

***Assumptions* 1** Air is an ideal gas with constant specific heats. **2** The nozzle operates steadily.

Properties The properties of air at room temperature are $c_p = 1.005$ kJ/kg.K, $k = 1.4$ (Table A-2a).

Analysis The exit temperature is determined from ideal gas isentropic relation to be,

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (400 + 273 \text{ K})\left(\frac{100 \text{ kPa}}{800 \text{ kPa}}\right)^{0.4/1.4} = 371.5 \text{ K}$$

We take the nozzle as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as
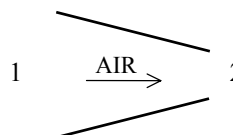
$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}}^{\nearrow 0 \text{ (steady)}} = 0$$

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

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2)$$

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

$$0 = c_p(T_2 - T_1) + \frac{V_2^2}{2}$$

Therefore,

$$V_2 = \sqrt{2c_p(T_2 - T_1)} = \sqrt{2(1.005 \text{ kJ/kg.K})(673 - 371.5)\text{K}} = \textbf{778.5 m/s}$$

7-85 An ideal gas is compressed in an isentropic compressor. 10% of gas is compressed to 400 kPa and 90% is compressed to 600 kPa. The compression process is to be sketched, and the exit temperatures at the two exits, and the mass flow rate into the compressor are to be determined.

Assumptions **1** The compressor operates steadily. **2** The process is reversible-adiabatic (isentropic)

Properties The properties of ideal gas are given to be c_p = 1.1 kJ/kg.K and c_v = 0.8 kJ/kg.K.

Analysis (b) The specific heat ratio of the gas is

$$k = \frac{c_p}{c_v} = \frac{1.1}{0.8} = 1.375$$

The exit temperatures are determined from ideal gas isentropic relations to be,

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (27 + 273 \text{ K})\left(\frac{400 \text{ kPa}}{100 \text{ kPa}}\right)^{0.375/1.375} = \textbf{437.8 K}$$

$$T_3 = T_1 \left(\frac{P_3}{P_1}\right)^{(k-1)/k} = (27 + 273 \text{ K})\left(\frac{600 \text{ kPa}}{100 \text{ kPa}}\right)^{0.375/1.375} = \textbf{489.0 K}$$

(c) A mass balance on the control volume gives

$$\dot{m}_1 = \dot{m}_2 + \dot{m}_3$$

where
$$\dot{m}_2 = 0.1\dot{m}_1$$
$$\dot{m}_3 = 0.9\dot{m}_1$$

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

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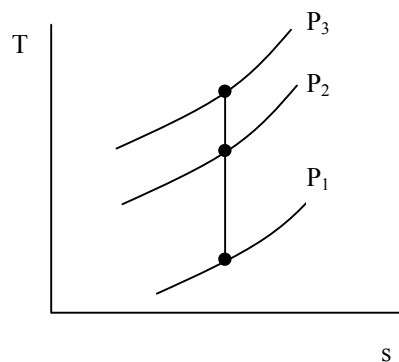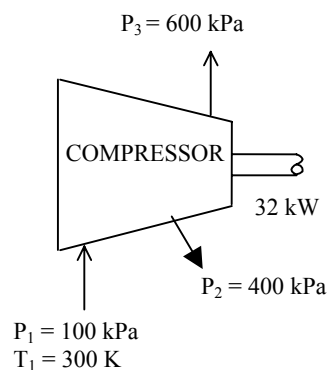
$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}_1 h_1 + \dot{W}_{\text{in}} = \dot{m}_2 h_2 + \dot{m}_3 h_3$$

$$\dot{m}_1 c_p T_1 + \dot{W}_{\text{in}} = 0.1\dot{m}_1 c_p T_2 + 0.9\dot{m}_1 c_p T_3$$

Solving for the inlet mass flow rate, we obtain

$$\dot{m}_1 = \frac{\dot{W}_{\text{in}}}{c_p\left[0.1(T_2 - T_1) + 0.9(T_3 - T_1)\right]}$$

$$= \frac{32 \text{ kW}}{(1.1 \text{ kJ/kg} \cdot \text{K})\left[0.1(437.8 - 300) + 0.9(489.0 - 300)\right]}$$

$$= \textbf{0.158 kg/s}$$

7-86 Air contained in a constant-volume tank s cooled to ambient temperature. The entropy changes of the air and the universe due to this process are to be determined and the process is to be sketched on a T-s diagram.

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

Properties The specific heat of air at room temperature is $c_v = 0.718$ kJ/kg.K (Table A-2a).

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

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

$$= (5\,\text{kg})(0.718\,\text{kJ/kg.K})\ln\frac{(27+273)\,\text{K}}{(327+273)\,\text{K}}$$

$$= -\textbf{2.488 kJ/K}$$

(b) An energy balance on the system gives

$$Q_{out} = mc_v(T_2 - T_1)$$

$$= (5\,\text{kg})(0.718\,\text{kJ/kg.K})(327 - 27)$$

$$= 1077\,\text{kJ}$$

The entropy change of the surroundings is

$$\Delta s_{surr} = \frac{Q_{out}}{T_{surr}} = \frac{1077\,\text{kJ}}{300\,\text{K}} = 3.59\,\text{kJ/K}$$

The entropy change of universe due to this process is

$$S_{gen} = \Delta S_{total} = \Delta S_{air} + \Delta S_{surr} = -2.488 + 3.59 = \textbf{1.10 kJ/K}$$

Air
5 kg
327°C
100 kPa