7-88 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.

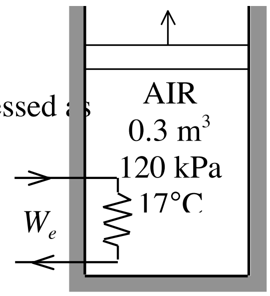
Assumptions At specified conditions, air can be treated as an ideal gas.

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

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

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



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

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

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

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, $T_2 = T_1 + \dfrac{W_{\text{e,in}}}{mc_p} = 290 \text{ K} + \dfrac{180 \text{ kJ}}{(0.4325 \text{ kg})(1.02 \text{ kJ/kg}\cdot\text{K})} = 698 \text{ K}$

Then the entropy change becomes

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

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

(b) Assuming variable specific heats,

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

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

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

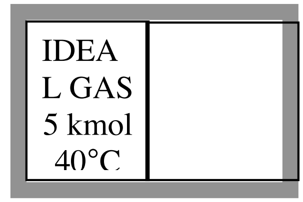
7-92 One side of a partitioned insulated rigid tank contains an ideal gas at a specified temperature and pressure while the other side is evacuated. The partition is removed, and the gas fills the entire tank. The total entropy change during this process is to be determined.

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

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

$$0 = \Delta U = m(u_2 - u_1)$$
$$u_2 = u_1$$
$$T_2 = T_1$$



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

$$\Delta S = N\left(\bar{c}_{v,\text{avg}} \ln\frac{T_2}{T_1}^{\nearrow 0} + R_u \ln\frac{V_2}{V_1}\right) = NR_u \ln\frac{V_2}{V_1}$$
$$= (5 \text{ kmol})(8.314 \text{ kJ/kmol}\cdot\text{K})\ln(2)$$
$$= \mathbf{28.81 \text{ kJ/K}}$$

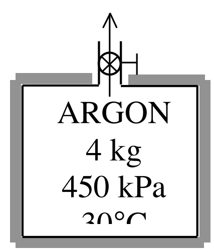
This also represents the **total entropy change** since the tank does not contain anything else, and there are no interactions with the surroundings.

7-95 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,

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

7-99 Nitrogen is compressed in an adiabatic compressor. The minimum work input is to be determined.

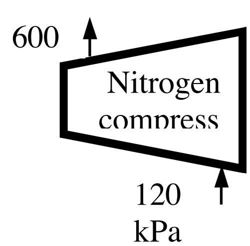
Assumptions **1** This is a steady-flow process since there is no change with time. **2** The process is adiabatic, and thus there is no heat transfer. **3** Nitrogen is an ideal gas with constant specific heats.

Properties The properties of nitrogen at an anticipated average temperature of 400 K are $c_p = 1.044$ kJ/kg·K and $k = 1.397$ (Table A-2*b*).

Analysis 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

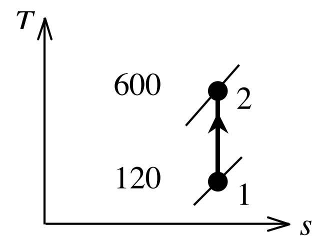
$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}}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

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



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

For the minimum work input to the compressor, the process must be reversible as well as adiabatic (i.e., isentropic). This being the case, the exit temperature will be



$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{(k-1)/k} = (303\ \text{K}) \left(\frac{600\ \text{kPa}}{120\ \text{kPa}} \right)^{0.397/1.397} = 479\ \text{K}$$

Substituting into the energy balance equation gives

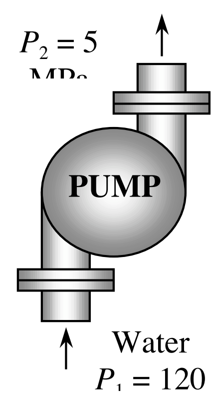
$$w_{in} = h_2 - h_1 = c_p (T_2 - T_1) = (1.044\ \text{kJ/kg}\cdot\text{K})(479 - 303)\text{K} = \mathbf{184\ kJ/kg}$$

7-108C The work associated with steady-flow devices is proportional to the specific volume of the gas. Cooling a gas during compression will reduce its specific volume, and thus the power consumed by the compressor.

7-109C Cooling the steam as it expands in a turbine will reduce its specific volume, and thus the work output of the turbine. Therefore, this is not a good proposal.

7-118 Liquid water is pumped by a 70-kW pump to a specified pressure at a specified level. The highest possible mass flow rate of water is to be determined.

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



Properties The specific volume of liquid water is given to be $v_1 = 0.001\ \text{m}^3/\text{kg}$.

Analysis The highest mass flow rate will be realized when the entire process is reversible. Thus it is determined from the reversible steady-flow work relation for a liquid,

$$\dot{W}_{in} = \dot{m}\left(\int_1^2 v\, dP + \Delta ke^{\nearrow 0} + \Delta pe \right) = \dot{m}\left\{ v(P_2 - P_1) + g(z_2 - z_1) \right\}$$

Thus,

$$7\ \text{kJ/s} = \dot{m}\left\{ (0.001\ \text{m}^3/\text{kg})(5000 - 120)\text{kPa}\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3} \right) + (9.8\ \text{m/s}^2)(10\ \text{m})\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2} \right) \right\}$$

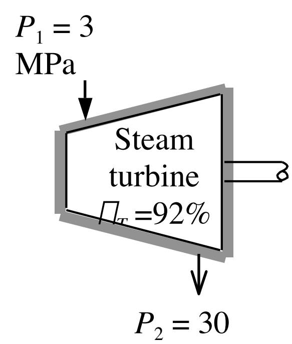
It yields

$$\dot{m} = \mathbf{1.41\ kg/s}$$

7-128 Steam is expanded in an adiabatic turbine with an isentropic efficiency of 0.92. The power output of the turbine is to be determined.

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

Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the actual turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as



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

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

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

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

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

$$\left.\begin{array}{l} P_1 = 3 \text{ MPa} \\ T_1 = 400°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 3231.7 \text{ kJ/kg} \\ s_1 = 6.9235 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$\left.\begin{array}{l} P_{2s} = 30 \text{ kPa} \\ s_{2s} = s_1 \end{array}\right\} \begin{array}{l} x_{2s} = \dfrac{s_{2s} - s_f}{s_{fg}} = \dfrac{6.9235 - 0.9441}{6.8234} = 0.8763 \\ h_{2s} = h_f + x_{2s}h_{fg} = 289.27 + (0.8763)(2335.3) = 2335.7 \text{ kJ/kg} \end{array}$$

The actual power output may be determined by multiplying the isentropic power output with the isentropic efficiency. Then,

$$\begin{aligned} \dot{W}_{a,out} &= \eta_T \dot{W}_{s,out} \\ &= \eta_T \dot{m}(h_1 - h_{2s}) \\ &= (0.92)(2 \text{ kg/s})(3231.7 - 2335.7)\text{kJ/kg} \\ &= \mathbf{1649\ kW} \end{aligned}$$