8-113 A well-insulated room is heated by a steam radiator, and the warm air is distributed by a fan. The average temperature in the room after 30 min, the entropy changes of steam and air, and the exergy destruction during this process are to be determined.

Assumptions **1** Air is an ideal gas with constant specific heats at room temperature. **2** The kinetic and potential energy changes are negligible. **3** The air pressure in the room remains constant and thus the air expands as it is heated, and some warm air escapes. **4** The environment temperature is given to be T_0 = 10°C.

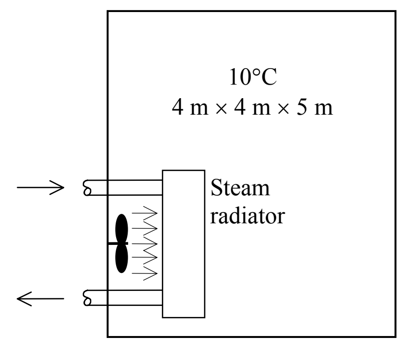
Properties The gas constant of air is R = 0.287 kPa.m^3/kg.K (Table A-1). Also, c_p = 1.005 kJ/kg.K for air at room temperature (Table A-2).

Analysis We first take the radiator 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

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

$$-Q_{\text{out}} = \Delta U = m(u_2 - u_1) \quad \text{(since } W = \text{KE} = \text{PE} = 0\text{)}$$

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



Using data from the steam tables (Tables A-4 through A-6), some properties are determined to be

$$\left.\begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = 200°\text{C} \end{array}\right\} \begin{array}{l} \boldsymbol{v}_1 = 1.0805 \text{ m}^3/\text{kg} \\ u_1 = 2654.6 \text{ kJ/kg} \\ s_1 = 7.5081 \text{ kJ/kg.K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 100 \text{ kPa} \\ (\boldsymbol{v}_2 = \boldsymbol{v}_1) \end{array}\right\} \begin{array}{l} \boldsymbol{v}_f = 0.001043, \quad \boldsymbol{v}_g = 1.6941 \text{ m}^3/\text{kg} \\ u_f = 417.40, \quad u_{fg} = 2088.2 \text{ kJ/kg} \\ s_f = 1.3028 \text{ kJ/kg.K}, \quad s_{fg} = 6.0562 \text{ kJ/kg.K} \end{array}$$

$$x_2 = \frac{\boldsymbol{v}_2 - \boldsymbol{v}_f}{\boldsymbol{v}_{fg}} = \frac{1.0805 - 0.001043}{1.6941 - 0.001043} = 0.6376$$

$$u_2 = u_f + x_2 u_{fg} = 417.40 + 0.6376 \times 2088.2 = 1748.7 \text{ kJ/kg}$$

$$s_2 = s_f + x_2 s_{fg} = 1.3028 + 0.6376 \times 6.0562 = 5.1639 \text{ kJ/kg.K}$$

$$m = \frac{\boldsymbol{V}_1}{\boldsymbol{v}_1} = \frac{0.015 \text{ m}^3}{1.0805 \text{ m}^3/\text{kg}} = 0.01388 \text{ kg}$$

Substituting,

$$Q_{\text{out}} = (0.01388 \text{ kg})(2654.6 - 1748.7)\text{kJ/kg} = 12.58 \text{ kJ}$$

The volume and the mass of the air in the room are $\boldsymbol{V}$= 4×4×5 = 80 m^3

and $$m_{\text{air}} = \frac{P_1\boldsymbol{V}_1}{RT_1} = \frac{(100 \text{ kPa})(80 \text{ m}^3)}{(0.2870 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(283 \text{ K})} = 98.5 \text{ kg}$$

The amount of fan work done in 24 min is

$$W_{\text{fan,in}} = \dot{W}_{\text{fan,in}}\Delta t = (0.150 \text{ kJ/s})(24 \times 60 \text{ s}) = 216 \text{ kJ}$$

We now take the air in the room as the system. The energy balance for this closed system is expressed as

$$E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{system}}$$

$$Q_{\text{in}} + W_{\text{fan,in}} - W_{\text{b,out}} = \Delta U$$

$$Q_{\text{in}} + W_{\text{fan,in}} = \Delta H \cong mc_p(T_2 - T_1)$$

since the boundary work and ΔU combine into ΔH for a constant pressure expansion or compression process. It can also be expressed as

$$(\dot{Q}_{\text{in}} + \dot{W}_{\text{fan,in}})\Delta t = mc_{p,\text{avg}}(T_2 - T_1)$$

Substituting, (12.58 kJ) + (216 kJ) = (98.5 kg)(1.005 kJ/kg°C)(T_2 - 10)°C

which yields T_2 = **12.3°C**

Therefore, the air temperature in the room rises from 10°C to 12.3°C in 24 minutes.

(*b*) The entropy change of the steam is

$$\Delta S_{\text{steam}} = m(s_2 - s_1) = (0.01388\text{ kg})(5.1639 - 7.5081)\text{kJ/kg}\cdot\text{K} = \mathbf{-0.0325\ \ kJ/K}$$

(*c*) Noting that air expands at constant pressure, the entropy change of the air in the room is

$$\Delta S_{\text{air}} = mc_p \ln\frac{T_2}{T_1} - mR\ln\frac{P_2}{P_1}^{\nearrow 0} = (98.5\text{ kg})(1.005\text{ kJ/kg}\cdot\text{K})\ln\frac{285.3\text{ K}}{283\text{ K}} = \mathbf{0.8012\ \ kJ/K}$$

(*d*) We take the contents of the room (including the steam radiator) as our system, which is a closed system. Noting that no heat or mass crosses the boundaries of this system, the entropy balance for it can be expressed as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$0 + S_{\text{gen}} = \Delta S_{\text{steam}} + \Delta S_{\text{air}}$$

Substituting, the entropy generated during this process is determined to be

$$S_{\text{gen}} = \Delta S_{\text{steam}} + \Delta S_{\text{air}} = -0.0325 + 0.8012 = 0.7687\text{ kJ/K}$$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (283\text{ K})(0.7687\text{ kJ/K}) = \mathbf{218\ \ kJ}$$

Alternative Solution In the solution above, we assumed the air pressure in the room to remain constant. This is an extreme case, and it is commonly used in practice since it gives higher results for heat loads, and thus allows the designer to be conservative results. The other extreme is to assume the house to be airtight, and thus the volume of the air in the house to remain constant as the air is heated. There is no expansion in this case and thus boundary work, and c_v is used in energy change relation instead of c_p. It gives the following results:

$$T_2 = 13.2°\text{C}$$

$$\Delta S_{\text{steam}} = m(s_2 - s_1) = (0.01388\text{ kg})(5.1639 - 7.5081)\text{kJ/kg}\cdot\text{K} = -0.0325\ \ \text{kJ/K}$$

$$\Delta S_{\text{air}} = mc_v \ln\frac{T_2}{T_1} + mR\ln\frac{V_2}{V_1}^{\nearrow 0} = (98.5\text{ kg})(0.718\text{ kJ/kg}\cdot\text{K})\ln\frac{286.2\text{ K}}{283\text{ K}} = 0.7952\text{ kJ/K}$$

$$S_{\text{gen}} = \Delta S_{\text{steam}} + \Delta S_{\text{air}} = -0.0325 + 0.7952 = 0.7627\text{ kJ/K}$$

and

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (283\text{ K})(0.7627\text{ kJ/K}) = 216\text{ kJ}$$

The actual value in practice will be between these two limits.

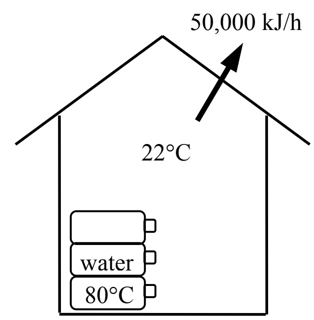
8-114 The heating of a passive solar house at night is to be assisted by solar heated water. The length of time that the electric heating system would run that night, the exergy destruction, and the minimum work input required that night are to be determined.

Assumptions **1** Water is an incompressible substance with constant specific heats. **2** The energy stored in the glass containers themselves is negligible relative to the energy stored in water. **3** The house is maintained at 22°C at all times. **4** The environment temperature is given to be T_0 = 5°C.

Properties The density and specific heat of water at room temperature are ρ = 1 kg/L and c = 4.18 kJ/kg·°C (Table A-3).

Analysis (*a*) The total mass of water is

$$m_w = \rho V = (1\text{ kg/L})(50\times 20\text{ L}) = 1000\text{ kg}$$



Taking the contents of the house, including the water as our system, the energy balance relation can be written as

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

$$W_{\text{e,in}} - Q_{\text{out}} = \Delta U = (\Delta U)_{\text{water}} + (\Delta U)_{\text{air}}^{\nearrow 0}$$
$$= (\Delta U)_{\text{water}} = mc(T_2 - T_1)_{\text{water}}$$

or, $$\dot{W}_{e,in}\Delta t - Q_{out} = [mc(T_2 - T_1)]_{\text{water}}$$

Substituting,

(15 kJ/s)Δt - (50,000 kJ/h)(10 h) = (1000 kg)(4.18 kJ/kg·°C)(22 - 80)°C

It gives

Δt = 17,170 s = **4.77 h**

(*b*) We take the house as the system, which is a closed system. The entropy generated during this process is determined by applying the entropy balance on an *extended system* that includes the house and its immediate surroundings so that the boundary temperature of the extended system is the temperature of the surroundings at all times. The entropy balance for the extended system can be expressed as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$-\frac{Q_{\text{out}}}{T_{\text{b,out}}} + S_{\text{gen}} = \Delta S_{\text{water}} + \Delta S_{\text{air}}^{\nearrow 0} = \Delta S_{\text{water}}$$

since the state of air in the house remains unchanged. Then the entropy generated during the 10-h period that night is

$$S_{\text{gen}} = \Delta S_{\text{water}} + \frac{Q_{\text{out}}}{T_{\text{b,out}}} = \left(mc\ln\frac{T_2}{T_1}\right)_{\text{water}} + \frac{Q_{\text{out}}}{T_0}$$
$$= (1000\text{ kg})(4.18\text{ kJ/kg}\cdot\text{K})\ln\frac{295\text{ K}}{353\text{ K}} + \frac{500{,}000\text{ kJ}}{278\text{ K}} = 1048\text{ kJ/K}$$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (278\text{ K})(1048\text{ kJ/K}) = \mathbf{291{,}400\ \ kJ}$$

(*c*) The actual work input during this process is

$$W_{\text{act,in}} = \dot{W}_{\text{act,in}}\Delta t = (15\text{ kJ/s})(17{,}170\text{ s}) = 257{,}550\text{ kJ}$$

The minimum work with which this process could be accomplished is the reversible work input, $W_{\text{rev, in}}$. which can be determined directly from

$$W_{\text{rev,in}} = W_{\text{act,in}} - X_{\text{destroyed}} = 257{,}550 - 291{,}400 = \text{-}33{,}850\text{ kJ}$$

$$W_{\text{rev,out}} = 33{,}850\text{ kJ} = \mathbf{9.40\ \ kWh}$$

That is, 9.40 kWh of electricity could be *generated* while heating the house by the solar heated water (instead of consuming electricity) if the process was done reversibly.

8-115 Steam expands in a two-stage adiabatic turbine from a specified state to specified pressure. Some steam is extracted at the end of the first stage. The wasted power potential 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 turbine is adiabatic and thus heat transfer is negligible. **4** The environment temperature is given to be $T_0 = 25°C$.

Analysis The wasted power potential is equivalent to the rate of exergy destruction during a process, which can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$.

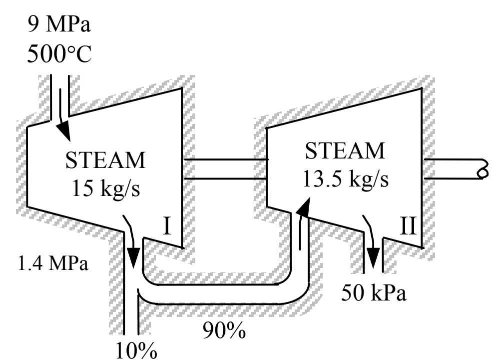
The total rate of entropy generation during this process is determined by taking the entire turbine, which is a control volume, as the system and applying the entropy balance. Noting that this is a steady-flow process and there is no heat transfer,

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy}\\ \text{generation}}} = \underbrace{\Delta \dot{S}_{\text{system}}^{\nearrow 0}}_{\substack{\text{Rate of change}\\ \text{of entropy}}} = 0$$

$$\dot{m}_1 s_1 - \dot{m}_2 s_2 - \dot{m}_3 s_3 + \dot{S}_{\text{gen}} = 0$$

$$\dot{m}_1 s_1 - 0.1\dot{m}_1 s_2 - 0.9\dot{m}_1 s_3 + \dot{S}_{\text{gen}} = 0 \rightarrow \dot{S}_{\text{gen}} = \dot{m}_1 [0.9 s_3 + 0.1 s_2 - s_1]$$

And $\quad X_{\text{destroyed}} = T_0 S_{\text{gen}} = T_0 \dot{m}_1 [0.9 s_3 + 0.1 s_2 - s_1]$



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

$$\left.\begin{array}{l} P_1 = 9 \text{ MPa} \\ T_1 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 3387.4 \text{ kJ/kg} \\ s_1 = 6.6603 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1.4 \text{ MPa} \\ s_{2s} = s_1 \end{array}\right\} h_{2s} = 2882.4 \text{ kJ/kg}$$

and,

$$\eta_T = \frac{h_1 - h_2}{h_1 - h_{2s}} \longrightarrow h_2 = h_1 - \eta_T (h_1 - h_{2s})$$
$$= 3387.4 - 0.88(3387.4 - 2882.4)$$
$$= 2943.0 \text{ kJ/kg}$$

$$\left.\begin{array}{l} P_2 = 1.4 \text{ MPa} \\ h_2 = 2943.0 \text{ kJ/kg} \end{array}\right\} s_2 = 6.7776 \text{ kJ/kg}\cdot\text{K}$$

$$\left.\begin{array}{l} P_3 = 50 \text{ kPa} \\ s_{3s} = s_1 \end{array}\right\} \begin{array}{l} x_{3s} = \dfrac{s_{3s} - s_f}{s_{fg}} = \dfrac{6.6603 - 1.0912}{6.5019} = 0.8565 \\ h_{3s} = h_f + x_{3s} h_{fg} = 340.54 + 0.8565 \times 2304.7 = 2314.6 \text{ kJ/kg} \end{array}$$

and $\quad \eta_T = \dfrac{h_1 - h_3}{h_1 - h_{3s}} \longrightarrow h_3 = h_1 - \eta_T (h_1 - h_{3s})$

$$= 3387.4 - 0.88(3387.4 - 2314.6)$$
$$= 2443.3 \text{ kJ/kg}$$

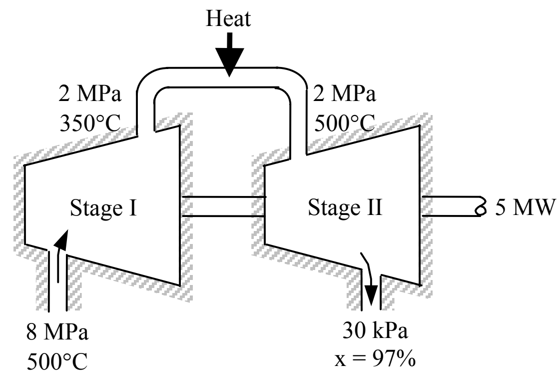
$$\left.\begin{array}{l} P_3 = 50 \text{ kPa} \\ h_3 = 2443.3 \text{ kJ/kg} \end{array}\right\} \begin{array}{l} x_3 = \dfrac{h_3 - h_f}{h_{fg}} = \dfrac{2443.3 - 340.54}{2304.7} = 0.9124 \\ s_3 = s_f + x_3 s_{fg} = 1.0912 + 0.9124 \times 6.5019 = 7.0235 \text{ kJ/kg}\cdot\text{K} \end{array}$$

Substituting, the wasted work potential is determined to be

$$\dot{X}_{\text{destroyed}} = T_0 \dot{S}_{\text{gen}} = (298 \text{ K})(15 \text{ kg/s})(0.9 \times 7.0235 + 0.1 \times 6.7776 - 6.6603)\text{kJ/kg} = \mathbf{1514\ kW}$$

8-116 Steam expands in a two-stage adiabatic turbine from a specified state to another specified state. Steam is reheated between the stages. For a given power output, the reversible power output and the rate of exergy destruction are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** The turbine is adiabatic and thus heat transfer is negligible. **4** The environment temperature is given to be $T_0 = 25°C$.



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

$$\left.\begin{array}{l} P_1 = 8\text{ MPa} \\ T_1 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 3399.5\text{ kJ/kg} \\ s_1 = 6.7266\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 2\text{ MPa} \\ T_2 = 350°\text{C} \end{array}\right\} \begin{array}{l} h_2 = 3137.7\text{ kJ/kg} \\ s_2 = 6.9583\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_3 = 2\text{ MPa} \\ T_3 = 500°\text{C} \end{array}\right\} \begin{array}{l} h_3 = 3468.3\text{ kJ/kg} \\ s_3 = 7.4337\text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 30\text{ kPa} \\ x_4 = 0.97 \end{array}\right\} \begin{array}{l} h_4 = h_f + x_4 h_{fg} = 289.27 + 0.97 \times 2335.3 = 2554.5\text{ kJ/kg} \\ s_4 = s_f + x_4 s_{fg} = 0.9441 + 0.97 \times 6.8234 = 7.5628\text{ kJ/kg}\cdot\text{K} \end{array}$$

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

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

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

$$\dot{m}h_1 + \dot{m}h_3 = \dot{m}h_2 + \dot{m}h_4 + \dot{W}_{\text{out}} \longrightarrow \dot{W}_{\text{out}} = \dot{m}[(h_1 - h_2) + (h_3 - h_4)]$$

Substituting, the mass flow rate of the steam is determined from the steady-flow energy equation applied to the actual process,

$$\dot{m} = \frac{\dot{W}_{\text{out}}}{h_1 - h_2 + h_3 - h_4} = \frac{5000\text{ kJ/s}}{(3399.5 - 3137.7 + 3468.3 - 2554.5)\text{kJ/kg}} = 4.253\text{ kg/s}$$

The reversible (or maximum) power output is determined from the rate form of the exergy balance applied on the turbine and setting the exergy destruction term equal to zero,

$$\underbrace{\dot{X}_{\text{in}} - \dot{X}_{\text{out}}}_{\substack{\text{Rate of net exergy transfer} \\ \text{by heat, work, and mass}}} - \underbrace{\dot{X}_{\text{destroyed}}^{\nearrow 0 \text{ (reversible)}}}_{\substack{\text{Rate of exergy} \\ \text{destruction}}} = \underbrace{\Delta \dot{X}_{\text{system}}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change} \\ \text{of exergy}}} = 0$$

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

$$\dot{m}\psi_1 + \dot{m}\psi_3 = \dot{m}\psi_2 + \dot{m}\psi_4 + \dot{W}_{\text{rev,out}}$$

$$\begin{aligned} \dot{W}_{\text{rev,out}} &= \dot{m}(\psi_1 - \psi_2) + \dot{m}(\psi_3 - \psi_4) \\ &= \dot{m}[(h_1 - h_2) + T_0(s_2 - s_1) - \Delta\text{ke}^{\nearrow 0} - \Delta\text{pe}^{\nearrow 0}] \\ &\quad + \dot{m}[(h_3 - h_4) + T_0(s_4 - s_3) - \Delta\text{ke}^{\nearrow 0} - \Delta\text{pe}^{\nearrow 0}] \end{aligned}$$

Then the reversible power becomes

$$\begin{aligned} \dot{W}_{\text{rev,out}} &= \dot{m}[h_1 - h_2 + h_3 - h_4 + T_0(s_2 - s_1 + s_4 - s_3)] \\ &= (4.253\text{ kg/s})[(3399.5 - 3137.7 + 3468.3 - 2554.5)\text{kJ/kg} \\ &\quad + (298\text{ K})(6.9583 - 6.7266 + 7.5628 - 7.4337)\text{kJ/kg}\cdot\text{K}] \\ &= \mathbf{5457\ kW} \end{aligned}$$

Then the rate of exergy destruction is determined from its definition,

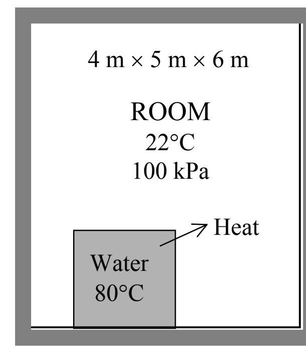
$$\dot{X}_{\text{destroyed}} = \dot{W}_{\text{rev,out}} - \dot{W}_{\text{out}} = 5457 - 5000 = \mathbf{457\ kW}$$

8-117 One ton of liquid water at 80°C is brought into a room. The final equilibrium temperature in the room and the entropy generated are to be determined.

Assumptions **1** The room is well insulated and well sealed. **2** The thermal properties of water and air are constant at room temperature. **3** The system is stationary and thus the kinetic and potential energy changes are zero. **4** There are no work interactions involved.

Properties The gas constant of air is R = 0.287 kPa.m^3/kg.K (Table A-1). The constant volume specific heat of water at room temperature is c_v = 0.718 kJ/kg·°C (Table A-2). The specific heat of water at room temperature is c = 4.18 kJ/kg·°C (Table A-3).

Analysis The volume and the mass of the air in the room are



$$V = 4\text{x}5\text{x}6 = 120\ \text{m}^3$$

$$m_{\text{air}} = \frac{P_1 V_1}{RT_1} = \frac{(100\ \text{kPa})(120\ \text{m}^3)}{(0.2870\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(295\ \text{K})} = 141.74\ \text{kg}$$

Taking the contents of the room, including the water, as our system, the energy balance can be written as

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc. energies}}} \rightarrow 0 = \Delta U = (\Delta U)_{\text{water}} + (\Delta U)_{\text{air}}$$

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

Substituting, $$(1000\ \text{kg})(4.18\ \text{kJ/kg}\cdot^\circ\text{C})(T_f - 80)^\circ\text{C} + (141.74\ \text{kg})(0.718\ \text{kJ/kg}\cdot^\circ\text{C})(T_f - 22)^\circ\text{C} = 0$$

It gives the final equilibrium temperature in the room to be

T_f = **78.6°C**

(b) We again take the room and the water in it as the system, which is a closed system. Considering that the system is well-insulated and no mass is entering and leaving, the entropy balance for this system can be expressed as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$0 + S_{\text{gen}} = \Delta S_{\text{air}} + \Delta S_{\text{water}}$$

where

$$\Delta S_{\text{air}} = mc_v \ln\frac{T_2}{T_1} + mR\ln\cancelto{0}{\frac{V_2}{V_1}} = (141.74\ \text{kg})(0.718\ \text{kJ/kg}\cdot\text{K})\ln\frac{351.6\ \text{K}}{295\ \text{K}} = 17.87\ \text{kJ/K}$$

$$\Delta S_{\text{water}} = mc\ln\frac{T_2}{T_1} = (1000\ \text{kg})(4.18\ \text{kJ/kg}\cdot\text{K})\ln\frac{351.6\ \text{K}}{353\ \text{K}} = -16.36\ \text{kJ/K}$$

Substituting, the entropy generation is determined to be

S_{gen} = 17.87 - 16.36 = 1.51 kJ/K

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (283\ \text{K})(1.51\ \text{kJ/K}) = \mathbf{427\ kJ}$$

(c) The work potential (the maximum amount of work that can be produced) during a process is simply the reversible work output. Noting that the actual work for this process is zero, it becomes

$$X_{\text{destroyed}} = W_{\text{rev,out}} - W_{\text{act,out}} \rightarrow W_{\text{rev,out}} = X_{\text{destroyed}} = \mathbf{427\ kJ}$$

8-118 An insulated cylinder is divided into two parts. One side of the cylinder contains N_2 gas and the other side contains He gas at different states. The final equilibrium temperature in the cylinder and the wasted work potential are to be determined for the cases of piston being fixed and moving freely.

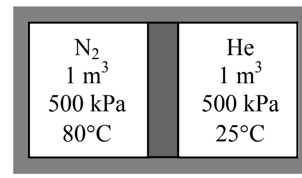
Assumptions **1** Both N_2 and He are ideal gases with constant specific heats. **2** The energy stored in the container itself is negligible. **3** The cylinder is well-insulated and thus heat transfer is negligible.

Properties The gas constants and the constant volume specific heats are R = 0.2968 kPa.m^3/kg.K is c_v = 0.743 kJ/kg·°C for N_2, and R = 2.0769 kPa.m^3/kg.K is c_v = 3.1156 kJ/kg·°C for He (Tables A-1 and A-2)

Analysis The mass of each gas in the cylinder is

$$m_{N_2} = \left(\frac{P_1 V_1}{RT_1}\right)_{N_2} = \frac{(500\text{ kPa})(1\text{ m}^3)}{(0.2968\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(353\text{ K})} = 4.77\text{ kg}$$

$$m_{He} = \left(\frac{P_1 V_1}{RT_1}\right)_{He} = \frac{(500\text{ kPa})(1\text{ m}^3)}{(2.0769\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})} = 0.808\text{ kg}$$



Taking the entire contents of the cylinder as our system, the 1st law relation can be written as

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

$$0 = \Delta U = (\Delta U)_{N_2} + (\Delta U)_{He}$$

$$0 = [mc_v(T_2 - T_1)]_{N_2} + [mc_v(T_2 - T_1)]_{He}$$

Substituting,

$$(4.77\text{ kg})(0.743\text{ kJ/kg}\cdot^\circ\text{C})(T_f - 80)^\circ\text{C} + (0.808\text{ kg})(3.1156\text{ kJ/kg}\cdot^\circ\text{C})(T_f - 25)^\circ\text{C} = 0$$

It gives T_f = **57.2°C**

where T_f is the final equilibrium temperature in the cylinder.

The answer would be the **same** if the piston were not free to move since it would effect only pressure, and not the specific heats.

(*b*) We take the entire cylinder as our system, which is a closed system. Noting that the cylinder is well-insulated and thus there is no heat transfer, the entropy balance for this closed system can be expressed as

$$\underbrace{S_{in} - S_{out}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{gen}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{system}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$0 + S_{gen} = \Delta S_{N_2} + \Delta S_{He}$$

But first we determine the final pressure in the cylinder:

$$N_{total} = N_{N_2} + N_{He} = \left(\frac{m}{M}\right)_{N_2} + \left(\frac{m}{M}\right)_{He} = \frac{4.77\text{ kg}}{28\text{ kg/kmol}} + \frac{0.808\text{ kg}}{4\text{ kg/kmol}} = 0.372\text{ kmol}$$

$$P_2 = \frac{N_{total} R_u T}{V_{total}} = \frac{(0.372\text{ kmol})(8.314\text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(330.2\text{ K})}{2\text{ m}^3} = 510.6\text{ kPa}$$

Then,

$$\Delta S_{N_2} = m\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right)_{N_2}$$

$$= (4.77\text{ kg})\left[(1.039\text{ kJ/kg}\cdot\text{K})\ln\frac{330.2\text{ K}}{353\text{ K}} - (0.2968\text{ kJ/kg}\cdot\text{K})\ln\frac{510.6\text{ kPa}}{500\text{ kPa}}\right] = -0.361\text{ kJ/K}$$

$$\Delta S_{\text{He}} = m\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right)_{\text{He}}$$

$$= (0.808\text{ kg})\left[(5.1926\text{ kJ/kg}\cdot\text{K})\ln\frac{330.2\text{ K}}{298\text{ K}} - (2.0769\text{ kJ/kg}\cdot\text{K})\ln\frac{510.6\text{ kPa}}{500\text{ kPa}}\right] = 0.395\text{ kJ/K}$$

$$S_{\text{gen}} = \Delta S_{\text{N}_2} + \Delta S_{\text{He}} = -0.361 + 0.395 = 0.034\text{ kJ/K}$$

The wasted work potential is equivalent to the exergy destroyed during a process, and it can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{gen}$,

$$X_{\text{destroyed}} = T_0 S_{gen} = (298\text{ K})(0.034\text{ kJ/K}) = \mathbf{10.1\text{ kJ}}$$

If the piston were not free to move, we would still have T_2 = 330.2 K but the volume of each gas would remain constant in this case:

$$\Delta S_{\text{N}_2} = m\left(c_v \ln\frac{T_2}{T_1} - R\ln\frac{V_2}{V_1}^{\nearrow 0}\right)_{\text{N}_2} = (4.77\text{ kg})(0.743\text{ kJ/kg}\cdot\text{K})\ln\frac{330.2\text{ K}}{353\text{ K}} = -0.237\text{ kJ/K}$$

$$\Delta S_{\text{He}} = m\left(c_v \ln\frac{T_2}{T_1} - R\ln\frac{V_2}{V_1}^{\nearrow 0}\right)_{\text{He}} = (0.808\text{ kg})(3.1156\text{ kJ/kg}\cdot\text{K})\ln\frac{330.2\text{ K}}{298\text{ K}} = 0.258\text{ kJ/K}$$

$$S_{\text{gen}} = \Delta S_{\text{N}_2} + \Delta S_{\text{He}} = -0.237 + 0.258 = 0.021\text{ kJ/K}$$

and $$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (298\text{ K})(0.021\text{ kJ/K}) = \mathbf{6.26\ \ kJ}$$

8-119 An insulated cylinder is divided into two parts. One side of the cylinder contains N_2 gas and the other side contains He gas at different states. The final equilibrium temperature in the cylinder and the wasted work potential are to be determined for the cases of piston being fixed and moving freely. √

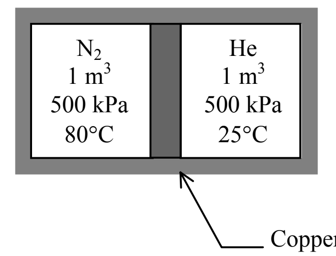
Assumptions **1** Both N_2 and He are ideal gases with constant specific heats. **2** The energy stored in the container itself, except the piston, is negligible. **3** The cylinder is well-insulated and thus heat transfer is negligible. **4** Initially, the piston is at the average temperature of the two gases.

Properties The gas constants and the constant volume specific heats are R = 0.2968 kPa.m^3/kg.K is c_v = 0.743 kJ/kg·°C for N_2, and R = 2.0769 kPa.m^3/kg.K is c_v = 3.1156 kJ/kg·°C for He (Tables A-1 and A-2). The specific heat of copper piston is c = 0.386 kJ/kg·°C (Table A-3).

Analysis The mass of each gas in the cylinder is

$$m_{N_2} = \left(\frac{P_1 V_1}{RT_1}\right)_{N_2} = \frac{(500\text{ kPa})(1\text{ m}^3)}{(0.2968\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(353\text{ K})} = 4.77\text{ kg}$$

$$m_{He} = \left(\frac{P_1 V_1}{RT_1}\right)_{He} = \frac{(500\text{ kPa})(1\text{ m}^3)}{(2.0769\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(353\text{ K})} = 0.808\text{ kg}$$



Taking the entire contents of the cylinder as our system, the 1st law relation can be written as

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

$$0 = \Delta U = (\Delta U)_{N_2} + (\Delta U)_{He} + (\Delta U)_{Cu}$$

$$0 = [mc_v(T_2 - T_1)]_{N_2} + [mc_v(T_2 - T_1)]_{He} + [mc(T_2 - T_1)]_{Cu}$$

where

$$T_{1,\,Cu} = (80 + 25) / 2 = 52.5°\text{C}$$

Substituting,

$$(4.77\text{ kg})(0.743\text{ kJ/kg}\cdot^\circ\text{C})(T_f - 80)^\circ\text{C} + (0.808\text{ kg})(3.1156\text{ kJ/kg}\cdot^\circ\text{C})(T_f - 25)^\circ\text{C}$$
$$+ (5.0\text{ kg})(0.386\text{ kJ/kg}\cdot^\circ\text{C})(T_f - 52.5)^\circ\text{C} = 0$$

It gives

T_f = **56.0°C**

where T_f is the final equilibrium temperature in the cylinder.

The answer would be the **same** if the piston were not free to move since it would effect only pressure, and not the specific heats.

(b) We take the entire cylinder as our system, which is a closed system. Noting that the cylinder is well-insulated and thus there is no heat transfer, the entropy balance for this closed system can be expressed as

$$\underbrace{S_{in} - S_{out}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{gen}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{system}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$0 + S_{gen} = \Delta S_{N_2} + \Delta S_{He} + \Delta S_{piston}$$

But first we determine the final pressure in the cylinder:

$$N_{total} = N_{N_2} + N_{He} = \left(\frac{m}{M}\right)_{N_2} + \left(\frac{m}{M}\right)_{He} = \frac{4.77\text{ kg}}{28\text{ kg/kmol}} + \frac{0.808\text{ kg}}{4\text{ kg/kmol}} = 0.372\text{ kmol}$$

$$P_2 = \frac{N_{total} R_u T}{V_{total}} = \frac{(0.372\text{ kmol})(8.314\text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(329\text{ K})}{2\text{ m}^3} = 508.8\text{ kPa}$$

Then,

$$\Delta S_{N_2} = m\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right)_{N_2}$$

$$= (4.77\text{ kg})\left[(1.039\text{ kJ/kg}\cdot\text{K})\ln\frac{329\text{ K}}{353\text{ K}} - (0.2968\text{ kJ/kg}\cdot\text{K})\ln\frac{508.8\text{ kPa}}{500\text{ kPa}}\right] = -0.374\text{ kJ/K}$$

$$\Delta S_{He} = m\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right)_{He}$$

$$= (0.808\text{ kg})\left[(5.1926\text{ kJ/kg}\cdot\text{K})\ln\frac{329\text{ K}}{353\text{ K}} - (2.0769\text{ kJ/kg}\cdot\text{K})\ln\frac{508.8\text{ kPa}}{500\text{ kPa}}\right] = 0.386\text{ kJ/K}$$

$$\Delta S_{piston} = \left(mc\ln\frac{T_2}{T_1}\right)_{piston} = (5\text{ kg})(0.386\text{ kJ/kg}\cdot\text{K})\ln\frac{329\text{ K}}{325.5\text{ K}} = 0.021\text{ kJ/K}$$

$$S_{gen} = \Delta S_{N_2} + \Delta S_{He} + \Delta S_{piston} = -0.374 + 0.386 + 0.021 = 0.0334\ \text{kJ/K}$$

The wasted work potential is equivalent to the exergy destroyed during a process, and it can be determined from an exergy balance or directly from its definition $X_{destroyed} = T_0 S_{gen}$,

$$X_{destroyed} = T_0 S_{gen} = (298\text{ K})(0.033\text{ kJ/K}) = \mathbf{9.83\ kJ}$$

If the piston were not free to move, we would still have T_2 = 330.2 K but the volume of each gas would remain constant in this case:

$$\Delta S_{N_2} = m\left(c_v \ln\frac{T_2}{T_1} - R\ln\frac{V_2}{V_1}^{\nearrow 0}\right)_{N_2} = (4.77\text{ kg})(0.743\text{ kJ/kg}\cdot\text{K})\ln\frac{329\text{ K}}{353\text{ K}} = -0.250\text{ kJ/K}$$

$$\Delta S_{He} = m\left(c_v \ln\frac{T_2}{T_1} - R\ln\frac{V_2}{V_1}^{\nearrow 0}\right)_{He} = (0.808\text{ kg})(3.1156\text{ kJ/kg}\cdot\text{K})\ln\frac{329\text{ K}}{353\text{ K}} = 0.249\text{ kJ/K}$$

$$S_{gen} = \Delta S_{N_2} + \Delta S_{He} + \Delta S_{piston} = -0.250 + 0.249 + 0.021 = \mathbf{0.020\ kJ/K}$$

and $$X_{destroyed} = T_0 S_{gen} = (298\text{ K})(0.020\text{ kJ/K}) = \mathbf{6.0\ kJ}$$

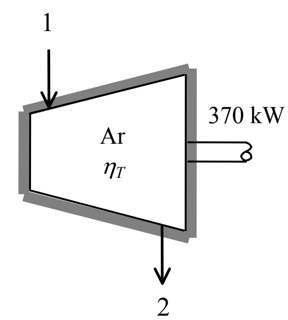
8-120E Argon enters an adiabatic turbine at a specified state with a specified mass flow rate, and leaves at a specified pressure. The isentropic efficiency of turbine is to be determined.

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

Properties The specific heat ratio of argon is k = 1.667. The constant pressure specific heat of argon is c_p = 0.1253 Btu/lbm.R (Table A-2E).

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

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



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

$$\dot{m}h_1 = \dot{W}_{s,out} + \dot{m}h_{2s} \quad (\text{since } \dot{Q} \cong \Delta ke \cong \Delta pe \cong 0)$$

$$\dot{W}_{s,out} = \dot{m}(h_1 - h_{2s})$$

From the isentropic relations,

$$T_{2s} = T_1\left(\frac{P_{2s}}{P_1}\right)^{(k-1)/k} = (1960\ \mathrm{R})\left(\frac{30\ \mathrm{psia}}{200\ \mathrm{psia}}\right)^{0.667/1.667} = 917.5\ \mathrm{R}$$

Then the power output of the isentropic turbine becomes

$$\dot{W}_{s,out} = \dot{m}c_p(T_1 - T_{2s}) = (40\ \mathrm{lbm/min})(0.1253\ \mathrm{Btu/lbm\cdot R})(1960 - 917.5)\mathrm{R}\left(\frac{1\ \mathrm{hp}}{42.41\ \mathrm{Btu/min}}\right) = 123.2\ \mathrm{hp}$$

Then the isentropic efficiency of the turbine is determined from

$$\eta_T = \frac{\dot{W}_{a,out}}{\dot{W}_{s,out}} = \frac{95\ \mathrm{hp}}{123.2\ \mathrm{hp}} = 0.771 = \mathbf{77.1\%}$$

(*b*) Using the steady-flow energy balance relation $\dot{W}_{a,out} = \dot{m}c_p(T_1 - T_2)$ above, the actual turbine exit temperature is determined to be

$$T_2 = T_1 - \frac{\dot{W}_{a,out}}{\dot{m}c_p} = 1500 - \frac{95\ \mathrm{hp}}{(40\ \mathrm{lbm/min})(0.1253\ \mathrm{Btu/lbm\cdot R})}\left(\frac{42.41\ \mathrm{Btu/min}}{1\ \mathrm{hp}}\right) = 696.1°\mathrm{F} = 1156.1\ \mathrm{R}$$

The entropy generation during this process can be determined from an entropy balance on the turbine,

$$\underbrace{\dot{S}_{in} - \dot{S}_{out}}_{\substack{\text{Rate of net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{\dot{S}_{gen}}_{\substack{\text{Rate of entropy}\\ \text{generation}}} = \underbrace{\Delta \dot{S}_{system}^{\nearrow 0}}_{\substack{\text{Rate of change}\\ \text{of entropy}}} = 0 \longrightarrow \dot{m}s_1 - \dot{m}s_2 + \dot{S}_{gen} = 0 \longrightarrow \dot{S}_{gen} = \dot{m}(s_2 - s_1)$$

where

$$s_2 - s_1 = c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1} = (0.1253\ \mathrm{Btu/lbm\cdot R})\ln\frac{1156.1\ \mathrm{R}}{1960\ \mathrm{R}} - (0.04971\ \mathrm{Btu/lbm\cdot R})\ln\frac{30\ \mathrm{psia}}{200\ \mathrm{psia}}$$

$$= 0.02816\ \mathrm{Btu/lbm.R}$$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{destroyed} = T_0 S_{gen}$,

$$\dot{X}_{destroyed} = T_0\dot{S}_{gen} = \dot{m}T_0(s_2 - s_1) = (40\ \mathrm{lbm/min})(537\ \mathrm{R})(0.02816\ \mathrm{Btu/lbm\cdot R})\left(\frac{1\ \mathrm{hp}}{42.41\ \mathrm{Btu/min}}\right) = 14.3\ \mathrm{hp}$$

Then the reversible power and second-law efficiency become

$$\dot{W}_{rev,out} = \dot{W}_{a,out} + \dot{X}_{destroyed} = 95 + 14.3 = 109.3\ \mathrm{hp}$$

and $$\eta_{II} = \frac{\dot{W}}{\dot{W}_{rev}} = \frac{95\ \mathrm{hp}}{109.3\ \mathrm{hp}} = \mathbf{86.9\%}$$

8-121 [*Also solved by EES on enclosed CD*] The feedwater of a steam power plant is preheated using steam extracted from the turbine. The ratio of the mass flow rates of the extracted steam and the feedwater are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** Heat loss from the device to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid.

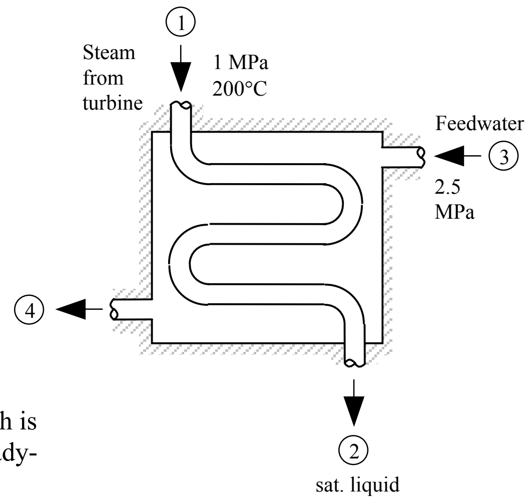
Properties The properties of steam and feedwater are (Tables A-4 through A-6)

$$\left.\begin{array}{l} P_1 = 1 \text{ MPa} \\ T_1 = 200°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 2828.3 \text{kJ/kg} \\ s_1 = 6.6956 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_2 = 1 \text{ MPa} \\ \text{sat. liquid} \end{array}\right\} \begin{array}{l} h_2 = h_{f@1\text{ MPa}} = 762.51 \text{ kJ/kg} \\ s_2 = s_{f@1\text{ MPa}} = 2.1381 \text{ kJ/kg}\cdot\text{K} \\ T_2 = 179.88°\text{C} \end{array}$$

$$\left.\begin{array}{l} P_3 = 2.5 \text{ MPa} \\ T_3 = 50°\text{C} \end{array}\right\} \begin{array}{l} h_3 \cong h_{f@50^\circ\text{C}} = 209.34 \text{ kJ/kg} \\ s_3 \cong s_{f@50^\circ\text{C}} = 0.7038 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_4 = 2.5 \text{ MPa} \\ T_4 = T_2 - 10°\text{C} \cong 170°\text{C} \end{array}\right\} \begin{array}{l} h_4 \cong h_{f@170^\circ\text{C}} = 719.08 \text{ kJ/kg} \\ s_4 \cong s_{f@170^\circ\text{C}} = 2.0417 \text{ kJ/kg}\cdot\text{K} \end{array}$$



Analysis (*a*) We take the heat exchanger as the system, which is a control volume. The mass and energy balances for this steady-flow system can be expressed in the rate form as follows:

Mass balance (for each fluid stream):

$$\dot{m}_{\text{in}} - \dot{m}_{\text{out}} = \Delta\dot{m}_{\text{system}}^{\nearrow 0 \text{ (steady)}} = 0 \rightarrow \dot{m}_{\text{in}} = \dot{m}_{\text{out}} \rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}_s \quad \text{and} \quad \dot{m}_3 = \dot{m}_4 = \dot{m}_{fw}$$

Energy balance (for the heat exchanger):

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

$$\dot{m}_1 h_1 + \dot{m}_3 h_3 = \dot{m}_2 h_2 + \dot{m}_4 h_4 \quad (\text{since } \dot{Q} = \dot{W} = \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

Combining the two, $\dot{m}_s(h_2 - h_1) = \dot{m}_{fw}(h_3 - h_4)$

Dividing by $\dot{m}_{fw}$ and substituting,

$$\frac{\dot{m}_s}{\dot{m}_{fw}} = \frac{h_3 - h_4}{h_2 - h_1} = \frac{(209.34 - 719.08)\text{kJ/kg}}{(762.51 - 2828.3)\text{kJ/kg}} = \mathbf{0.247}$$

(*b*) The entropy generation during this process per unit mass of feedwater can be determined from an entropy balance on the feedwater heater expressed in the rate form as

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy} \\ \text{generation}}} = \underbrace{\Delta\dot{S}_{\text{system}}^{\nearrow 0}}_{\substack{\text{Rate of change} \\ \text{of entropy}}} = 0$$

$$\dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{m}_3 s_3 - \dot{m}_4 s_4 + \dot{S}_{\text{gen}} = 0$$

$$\dot{m}_s (s_1 - s_2) + \dot{m}_{fw} (s_3 - s_4) + \dot{S}_{\text{gen}} = 0$$

$$\frac{\dot{S}_{\text{gen}}}{\dot{m}_{fw}} = \frac{\dot{m}_s}{\dot{m}_{fw}}(s_2 - s_1) + (s_4 - s_3) = (0.247)(2.1381 - 6.6956) + (2.0417 - 0.7038) = 0.213 \text{ kJ/K}\cdot\text{kg fw}$$

Noting that this process involves no actual work, the reversible work and exergy destruction become equivalent since $X_{\text{destroyed}} = W_{\text{rev,out}} - W_{\text{act,out}} \rightarrow W_{\text{rev,out}} = X_{\text{destroyed}}$. The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (298 \text{ K})(0.213 \text{ kJ/K}\cdot\text{kgfw}) = \mathbf{63.5 \ kJ/kgfeedwater}$$

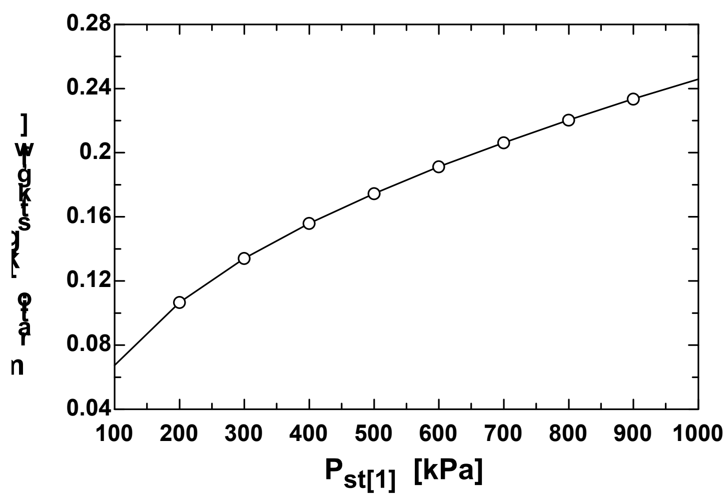
8-122 EES Problem 8-121 is reconsidered. The effect of the state of the steam at the inlet of the feedwater heater on the ratio of mass flow rates and the reversible power is to be investigated.

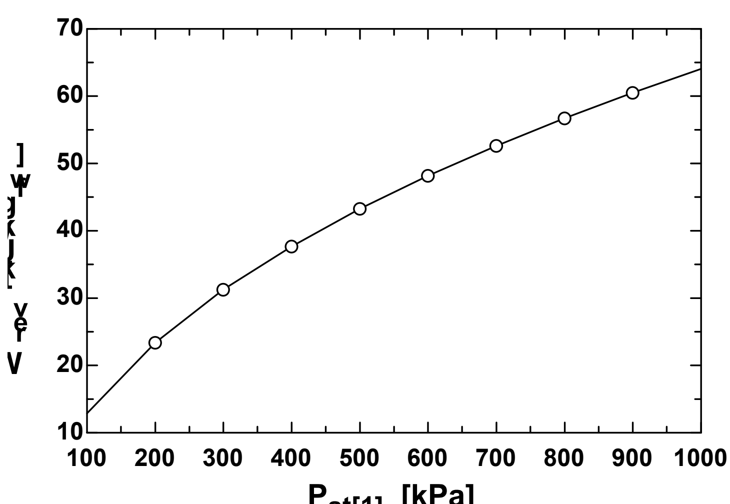
Analysis Using EES, the problem is solved as follows:

```
"Input Data"
"Steam (let st=steam data):"
Fluid$='Steam_IAPWS'
T_st[1]=200 [C]
{P_st[1]=1000 [kPa]}
P_st[2] = P_st[1]
x_st[2]=0 "saturated liquid, quality = 0%"
T_st[2]=temperature(steam, P=P_st[2], x=x_st[2])

"Feedwater (let fw=feedwater data):"
T_fw[1]=50 [C]
P_fw[1]=2500 [kPa]
P_fw[2]=P_fw[1]  "assume no pressure drop for the feedwater"
T_fw[2]=T_st[2]-10

"Surroundings:"
T_o = 25 [C]
P_o = 100 [kPa] "Assumed value for the surrroundings pressure"
"Conservation of mass:"
"There is one entrance, one exit for both the steam and feedwater."
"Steam: m_dot_st[1] = m_dot_st[2]"
"Feedwater: m_dot_fw[1] = m_dot_fw[2]"
"Let m_ratio = m_dot_st/m_dot_fw"
"Conservation of Energy:"
"We write the conservation of energy for steady-flow control volume
having two entrances and two exits with the above assumptions.  Since
neither of the flow rates is know or can be found, write the conservation
of energy per unit mass of  the feedwater."
E_in - E_out =DELTAE_cv
DELTAE_cv=0  "Steady-flow requirement"
 E_in = m_ratio*h_st[1] + h_fw[1]
h_st[1]=enthalpy(Fluid$, T=T_st[1], P=P_st[1])
h_fw[1]=enthalpy(Fluid$,T=T_fw[1], P=P_fw[1])
E_out = m_ratio*h_st[2] + h_fw[2]
h_fw[2]=enthalpy(Fluid$, T=T_fw[2], P=P_fw[2])
h_st[2]=enthalpy(Fluid$, x=x_st[2], P=P_st[2])

"The reversible work is given by Eq. 7-47, where the heat transfer is zero
(the feedwater heater is adiabatic) and the Exergy destroyed is set equal
to zero"
W_rev = m_ratio*(Psi_st[1]-Psi_st[2]) +(Psi_fw[1]-Psi_fw[2])
Psi_st[1]=h_st[1]-h_st_o -(T_o + 273)*(s_st[1]-s_st_o)
s_st[1]=entropy(Fluid$,T=T_st[1], P=P_st[1])
h_st_o=enthalpy(Fluid$, T=T_o, P=P_o)
s_st_o=entropy(Fluid$, T=T_o, P=P_o)
Psi_st[2]=h_st[2]-h_st_o -(T_o + 273)*(s_st[2]-s_st_o)
s_st[2]=entropy(Fluid$,x=x_st[2], P=P_st[2])
Psi_fw[1]=h_fw[1]-h_fw_o -(T_o + 273)*(s_fw[1]-s_fw_o)
h_fw_o=enthalpy(Fluid$, T=T_o, P=P_o)
s_fw[1]=entropy(Fluid$,T=T_fw[1], P=P_fw[1])
s_fw_o=entropy(Fluid$, T=T_o, P=P_o)
```

```
Psi_fw[2]=h_fw[2]-h_fw_o -(T_o + 273)*(s_fw[2]-s_fw_o)
s_fw[2]=entropy(Fluid$,T=T_fw[2], P=P_fw[2])
```

m_{ratio} [kg/kg]	W_{rev} [kJ/kg]	$P_{st,1}$ [kPa]
0.06745	12.9	100
0.1067	23.38	200
0.1341	31.24	300
0.1559	37.7	400
0.1746	43.26	500
0.1912	48.19	600
0.2064	52.64	700
0.2204	56.72	800
0.2335	60.5	900
0.246	64.03	1000



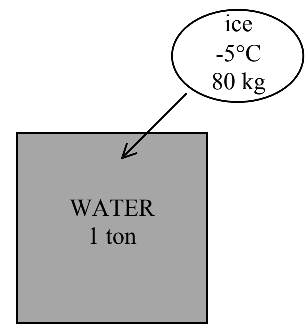


8-123 A 1-ton (1000 kg) of water is to be cooled in a tank by pouring ice into it. The final equilibrium temperature in the tank and the exergy destruction are to be determined.

Assumptions **1** Thermal properties of the ice and water are constant. **2** Heat transfer to the water tank is negligible. **3** There is no stirring by hand or a mechanical device (it will add energy).

Properties The specific heat of water at room temperature is c = 4.18 kJ/kg·°C, and the specific heat of ice at about 0°C is c = 2.11 kJ/kg·°C (Table A-3). The melting temperature and the heat of fusion of ice at 1 atm are 0°C and 333.7 kJ/kg..

Analysis (*a*) We take the ice and the water as the system, and disregard any heat transfer between the system and the surroundings. Then the energy balance for this process can be written as



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

$$0 = \Delta U$$

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

$$[mc(0^\circ\text{C} - T_1)_{\text{solid}} + mh_{if} + mc(T_2 - 0^\circ\text{C})_{\text{liquid}}]_{\text{ice}} + [mc(T_2 - T_1)]_{\text{water}} = 0$$

Substituting,

$$(80\text{ kg})\{(2.11\text{ kJ/kg}\cdot^\circ\text{C})[0-(-5)]^\circ\text{C} + 333.7\text{ kJ/kg} + (4.18\text{ kJ/kg}\cdot^\circ\text{C})(T_2 - 0)^\circ\text{C}\}$$
$$+ (1000\text{ kg})(4.18\text{ kJ/kg}\cdot^\circ\text{C})(T_2 - 20)^\circ\text{C} = 0$$

It gives T_2 = **12.42°C**

which is the final equilibrium temperature in the tank.

(*b*) We take the ice and the water as our system, which is a closed system .Considering that the tank is well-insulated and thus there is no heat transfer, the entropy balance for this closed system can be expressed as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

$$0 + S_{\text{gen}} = \Delta S_{\text{ice}} + \Delta S_{water}$$

where

$$\Delta S_{\text{water}} = \left(mc\ln\frac{T_2}{T_1}\right)_{\text{water}} = (1000\text{ kg})(4.18\text{ kJ/kg}\cdot\text{K})\ln\frac{285.42\text{ K}}{293\text{ K}} = -109.590\text{ kJ/K}$$

$$\Delta S_{\text{ice}} = \left(\Delta S_{\text{solid}} + \Delta S_{\text{melting}} + \Delta S_{\text{liquid}}\right)_{\text{ice}}$$

$$= \left(\left(mc\ln\frac{T_{\text{melting}}}{T_1}\right)_{\text{solid}} + \frac{mh_{ig}}{T_{\text{melting}}} + \left(mc\ln\frac{T_2}{T_1}\right)_{\text{liquid}}\right)_{\text{ice}}$$

$$= (80\text{ kg})\left((2.11\text{ kJ/kg}\cdot\text{K})\ln\frac{273\text{ K}}{268\text{ K}} + \frac{333.7\text{ kJ/kg}}{273\text{ K}} + (4.18\text{ kJ/kg}\cdot\text{K})\ln\frac{285.42\text{ K}}{273\text{ K}}\right)$$

$$= 115.783\text{ kJ/K}$$

Then, $\quad S_{\text{gen}} = \Delta S_{\text{water}} + \Delta S_{\text{ice}} = -109.590 + 115.783 = 6.193\text{ kJ/K}$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition $X_{\text{destroyed}} = T_0 S_{\text{gen}}$,

$$X_{\text{destroyed}} = T_0 S_{\text{gen}} = (293\text{ K})(6.193\text{ kJ/K}) = \mathbf{1815\ kJ}$$