Homework-8 Solutions

Q 7-69

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 The water, the iron block and the copper block are incompressible substances with constant specific heats at room temperature. **2** Kinetic and potential energies are negligible.

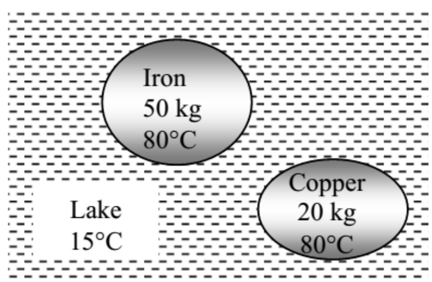
Properties: The specific heats of iron and copper at room temperature are c_{iron} = 0.45 kJ/kg.°C and c_{copper} = 0.386 kJ/kg.°C (Table A-3).

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

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

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

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



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

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

or,

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

Substituting,

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

Thus,

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

Then the total entropy change for this process is

$$\Delta S_{\text{total}} = \Delta S_{\text{iron}} + \Delta S_{\text{copper}} + \Delta S_{\text{lake}} = -4.579 - 1.571 + 6.820 = \mathbf{0.670\ kJ/K}$$

Q 7-89

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.

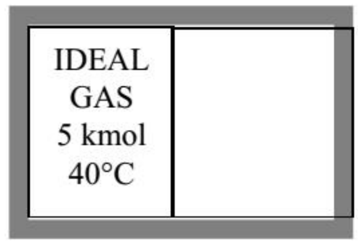
Assumptions The gas in the tank is given to be an ideal gas, and thus ideal gas relations apply.
Analysis Taking the entire rigid tank as the system, the energy balance can be expressed as

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

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

$$u_2 = u_1$$

$$T_2 = T_1$$



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

$$\Delta S = N\left(\bar{c}_{\boldsymbol{v},\text{avg}} \ln\frac{T_2}{T_1}^{\nearrow 0} + R_u \ln\frac{\boldsymbol{V}_2}{\boldsymbol{V}_1}\right) = NR_u \ln\frac{\boldsymbol{V}_2}{\boldsymbol{V}_1}$$

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

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

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

Q 7-95

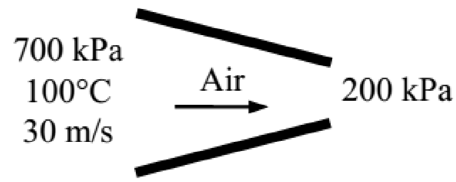
Air is expanded in an adiabatic nozzle by a polytropic process. The temperature and velocity at the exit are to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** There is no heat transfer or shaft work associated with the process. **3** Air is an ideal gas with constant specific heats.
Properties The properties of air at room temperature are c_p = 1.005 kJ/kg·K and k = 1.4 (Table A-2a).

Analysis For the polytropic process of an ideal gas, Pv^n = Constant, and the exit temperature is given by

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{(n-1)/n} = (373\text{ K})\left(\frac{200\text{ kPa}}{700\text{ kPa}}\right)^{0.3/1.3} = \mathbf{279\ K}$$

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



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

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

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

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

Solving for the exit velocity,

$$\begin{aligned}
V_2 &= \left[V_1^2 + 2(h_1 - h_2)\right]^{0.5} \\
&= \left[V_1^2 + 2c_p(T_1 - T_2)\right]^{0.5} \\
&= \left[(30\text{ m/s})^2 + 2(1.005\text{ kJ/kg}\cdot\text{K})(373-279)\text{K}\left(\frac{1000\text{ m}^2/\text{s}^2}{1\text{ kJ/kg}}\right)\right]^{0.5} \\
&= \mathbf{436\ m/s}
\end{aligned}$$

Q 7-100

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

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

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

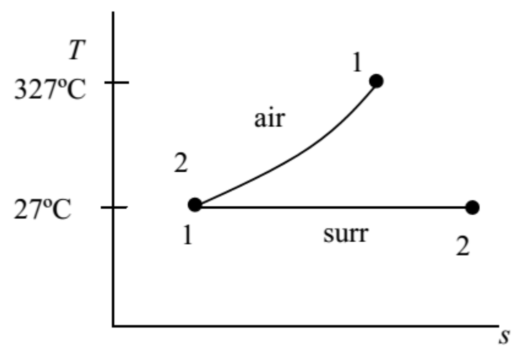
$$= \mathbf{-2.488\ kJ/K}$$

(b) An energy balance on the system gives

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

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

$$= 1077\text{ kJ}$$



The entropy change of the surroundings is

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

The entropy change of universe due to this process is

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

Q 7-110

The reversible work produced during the process shown in the figure is to be determined.

Assumptions The process is reversible.

Analysis The reversible work relation is

$$w_{12} = \int_1^2 v\,dP$$

When combined with the ideal gas equation of state

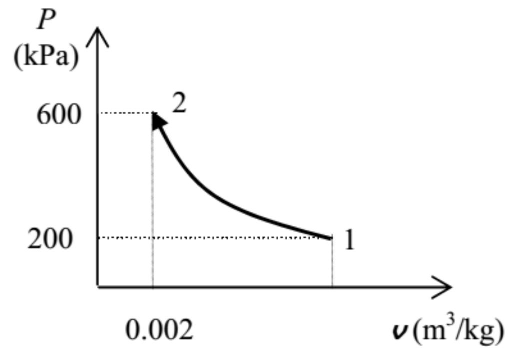
$$v = \frac{RT}{P}$$

The work expression reduces to

$$w_{12} = \int_1^2 v\,dP = -RT\int_1^2 \frac{dP}{P} = -RT\ln\frac{P_2}{P_1} = -P_2 v_2 \ln\frac{P_2}{P_1}$$

$$= -(600\text{ kPa})(0.002\text{ m}^3/\text{kg})\ln\frac{600\text{ kPa}}{200\text{ kPa}}\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right)$$

$$= \mathbf{-1.32\ kJ/kg}$$



The negative sign indicates that work is done on the system in the amount of 1.32 kJ/kg.

Q 7-111

Liquid is to be pumped by a 25-kW pump at a specified rate. The highest pressure the water can be pumped to be determined.

Assumptions: **1** Liquid water is an incompressible substance. **2** Kinetic and potential energy changes are negligible. **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 pressure the liquid can have at the pump exit can be determined from the reversible steady-flow work relation for liquid,

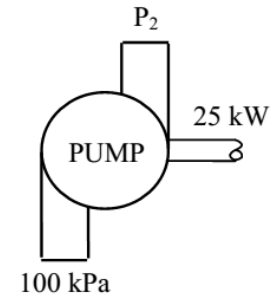
$$\dot{W}_{in} = \dot{m}\left(\int_1^2 \boldsymbol{v} dP + \Delta ke^{\nearrow 0} + \Delta pe^{\nearrow 0}\right) = \dot{m}\boldsymbol{v}_1(P_2 - P_1)$$

Thus,

$$25 \text{ kJ/s} = (5 \text{ kg/s})(0.001 \text{ m}^3\text{/kg})(P_2 - 100)\text{k Pa}\left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3}\right)$$

It yields

$$P_2 = \mathbf{5100\ kPa}$$



Q 7-146

Water is heated by hot oil in a heat exchanger. The outlet temperature of the oil and the rate of entropy generation within the heat exchanger are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** Fluid properties are constant.

Properties: The specific heats of water and oil are given to be 4.18 and 2.3 kJ/kg.°C, respectively.

Analysis: (a) We take the cold water tubes as the system, which is a control volume. The energy balance for this steady-flow system can be expressed in the rate form as

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

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

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

$$\dot{Q}_{in} = \dot{m}c_p(T_2 - T_1)$$

Then the rate of heat transfer to the cold water in this heat exchanger becomes

$$\dot{Q} = [\dot{m}c_p(T_{out} - T_{in})]_{water} = (4.5 \text{ kg/s})(4.18 \text{ kJ/kg.°C})(70°\text{C} - 20°\text{C}) = 940.5 \text{ kW}$$

Noting that heat gain by the water is equal to the heat loss by the oil, the outlet temperature of the hot oil is determined from

$$\dot{Q} = [\dot{m}c_p(T_{\text{in}} - T_{\text{out}})]_{\text{oil}} \rightarrow T_{\text{out}} = T_{\text{in}} - \frac{\dot{Q}}{\dot{m}c_p} = 170°\text{C} - \frac{940.5\text{ kW}}{(10\text{ kg/s})(2.3\text{ kJ/kg.°C})} = \mathbf{129.1°C}$$

(*b*) The rate of entropy generation within the heat exchanger is determined by applying the rate form of the entropy balance on the entire heat exchanger:

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

$$\dot{m}_1 s_1 + \dot{m}_3 s_3 - \dot{m}_2 s_2 - \dot{m}_3 s_4 + \dot{S}_{\text{gen}} = 0 \quad (\text{since } Q = 0)$$

$$\dot{m}_{\text{water}} s_1 + \dot{m}_{\text{oil}} s_3 - \dot{m}_{\text{water}} s_2 - \dot{m}_{\text{oil}} s_4 + \dot{S}_{\text{gen}} = 0$$

$$\dot{S}_{\text{gen}} = \dot{m}_{\text{water}}(s_2 - s_1) + \dot{m}_{\text{oil}}(s_4 - s_3)$$

Noting that both fluid streams are liquids (incompressible substances), the rate of entropy generation is determined to be

$$\begin{aligned}
\dot{S}_{\text{gen}} &= \dot{m}_{\text{water}} c_p \ln\frac{T_2}{T_1} + \dot{m}_{\text{oil}} c_p \ln\frac{T_4}{T_3} \\
&= (4.5\text{ kg/s})(4.18\text{ kJ/kg.K})\ln\frac{70 + 273}{20 + 273} + (10\text{ kg/s})(2.3\text{ kJ/kg.K})\ln\frac{129.1 + 273}{170 + 273} \\
&= \mathbf{0.736\text{ kW/K}}
\end{aligned}$$