Thermodynamics: An Engineering Approach, 6th Edition
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McGraw-Hill, 2008

Chapter (4)

ENERGY ANALYSIS OF CLOSED SYSTEMS

SOLVED PROBLEMS

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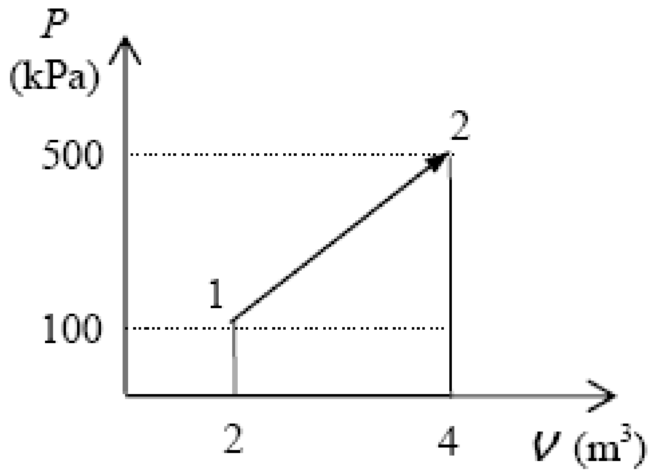
Boundary Work Problems

Problem (4-7)

4-7 The boundary work done during the process shown in the figure is to be determined.

Assumptions The process is quasi-equilibrium.

Analysis The work done is equal to the area under the process line 1-2:



$$W_{b,out} = \text{Area} = \frac{P_1 + P_2}{2}(V_2 - V_1)$$
$$= \frac{(100+500)\text{kPa}}{2}(4.0-2.0)\text{m}^3\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right)$$
$$= \mathbf{600\ kJ}$$

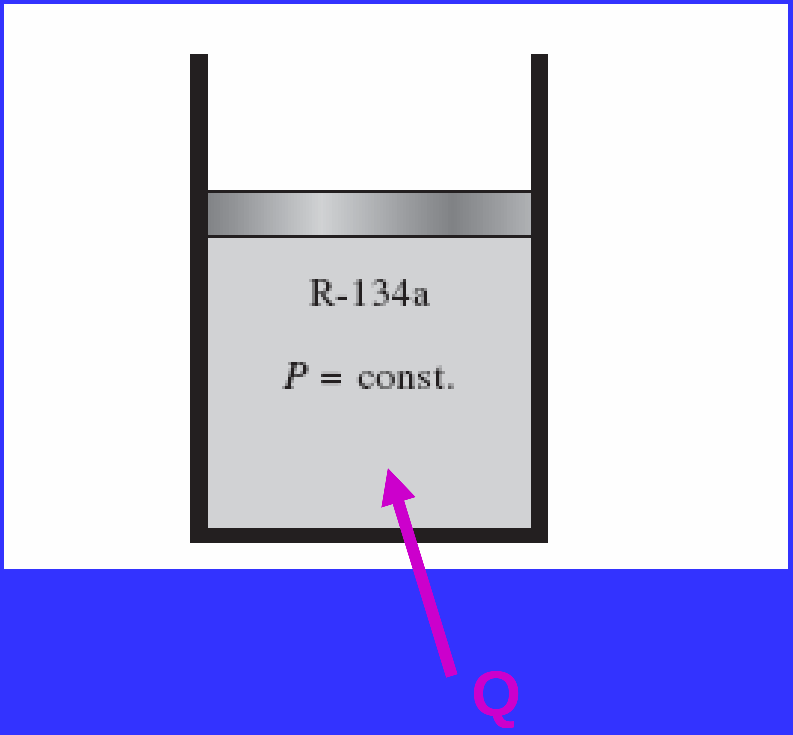
Problem (4-12)

Given :

$R-134a\,(saturated\ Liquid)$

$p_1 = p_2 = 900\,kPa$

$V_1 = 200\,L = 0.2\,m^3$



Find Boundary Work?

$$W_{b,out} = \int_1^2 P\,dV = P(V_2 - V_1) = mP(v_2 - v_1)$$

Problem (4-12)

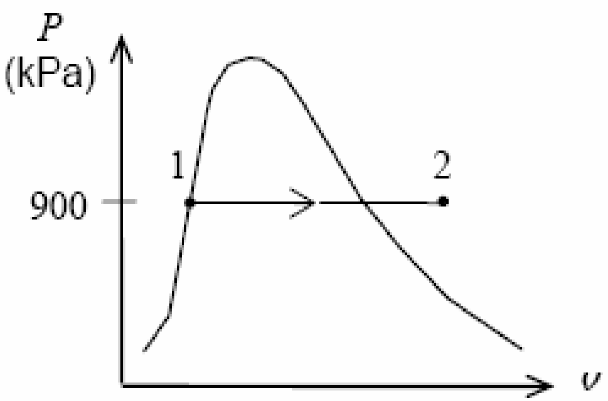
4-12 Refrigerant-134a in a cylinder is heated at constant pressure until its temperature rises to a specified value. The boundary work done during this process is to be determined.

Assumptions The process is quasi-equilibrium.

Properties Noting that the pressure remains constant during this process, the specific volumes at the initial and the final states are (Table A-11 through A-13)

$$\left.\begin{array}{l} P_1 = 900 \text{ kPa} \\ \text{Sat. liquid} \end{array}\right\} v_1 = v_{f\,@\,900\text{ kPa}} = 0.0008580 \text{ m}^3/\text{kg}$$

$$\left.\begin{array}{l} P_2 = 900 \text{ kPa} \\ T_2 = 70°\text{C} \end{array}\right\} v_2 = 0.027413 \text{ m}^3/\text{kg}$$



$At\ p_2 = 900\,kPa, T_{sat} = 35.51C$

Analysis The boundary work is determined from its definition to be

$$m = \frac{V_1}{v_1} = \frac{0.2 \text{ m}^3}{0.0008580 \text{ m}^3/\text{kg}} = 233.1 \text{ kg}$$

and

$$W_{b,\text{out}} = \int_1^2 P\,dV = P(V_2 - V_1) = mP(v_2 - v_1)$$

$$= (233.1 \text{ kg})(900 \text{ kPa})(0.027413 - 0.0008580)\text{m}^3/\text{kg}\left(\frac{1 \text{ kJ}}{1 \text{ kPa} \cdot \text{m}^3}\right)$$

$$= \mathbf{5571\ kJ}$$

Problem (4-21)

4-21 CO_2 gas in a cylinder is compressed until the volume drops to a specified value. The pressure changes during the process with volume as $P = a V^{-2}$. The boundary work done during this process is to be determined.

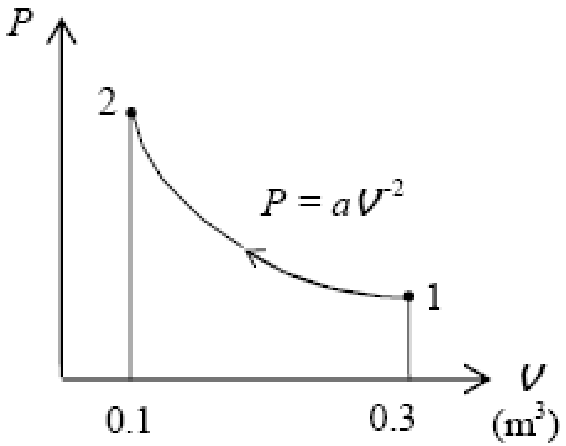
Assumptions The process is quasi-equilibrium.

Analysis The boundary work done during this process is determined from

$$W_{b,\text{out}} = \int_1^2 P\,dV = \int_1^2 \left(\frac{a}{V^2}\right) dV = -a\left(\frac{1}{V_2} - \frac{1}{V_1}\right)$$

$$= -(8\ \text{kPa}\cdot\text{m}^6)\left(\frac{1}{0.1\ \text{m}^3} - \frac{1}{0.3\ \text{m}^3}\right)\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right)$$

$$= \mathbf{-53.3\ kJ}$$



Discussion The negative sign indicates that work is done on the system (work input).

Problem (4-25)

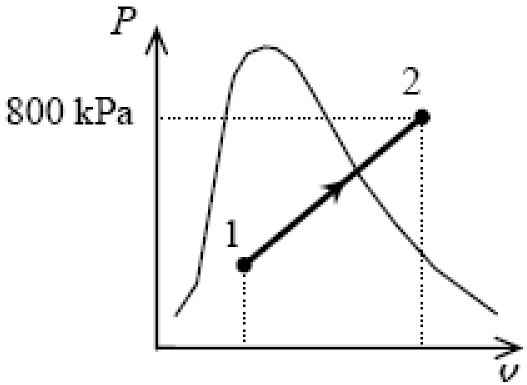
4-25 A saturated water mixture contained in a spring-loaded piston-cylinder device is heated until the pressure and temperature rises to specified values. The work done during this process is to be determined.

Assumptions The process is quasi-equilibrium.

Analysis The initial state is saturated mixture at 90°C. The pressure and the specific volume at this state are (Table A-4),

$$P_1 = 70.183 \text{ kPa}$$

$$\nu_1 = \nu_f + x\nu_{fg} = 0.001036 + (0.10)(2.3593 - 0.001036) = 0.23686 \text{ m}^3/\text{kg}$$



$$T_{sat\,@\,p=800} = 170.41\ ^{\circ}C$$

The final specific volume at 800 kPa and 250°C is (Table A-6)

$$\nu_2 = 0.29321 \text{ m}^3/\text{kg}$$

Superheated region

Since this is a linear process, the work done is equal to the area under the process line 1-2:

$$W_{b,out} = \text{Area} = \frac{P_1 + P_2}{2} m(\nu_2 - \nu_1)$$

$$= \frac{(70.183 + 800)\text{kPa}}{2}(1 \text{ kg})(0.29321 - 0.23686)\text{m}^3\left(\frac{1 \text{ kJ}}{1 \text{ kPa}\cdot\text{m}^3}\right)$$

$$= \mathbf{24.52\ kJ}$$

Closed System Energy Analysis

Problem (4-30)

4-30 The table is to be completed using conservation of energy principle for a closed system.

Analysis The energy balance for a closed system can be expressed as

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

$$Q_{in} - W_{out} = E_2 - E_1 = m(e_2 - e_1)$$

Application of this equation gives the following completed table:

Q_{in} (kJ)	W_{out} (kJ)	E_1 (kJ)	E_2 (kJ)	m (kg)	$e_2 - e_1$ (kJ/kg)
280	**440**	1020	860	3	**-53.3**
-350	130	550	**70**	5	**-96**
-40	260	300	**0**	2	-150
300	**550**	750	500	1	**-250**
-400	-200	**500**	300	2	-100

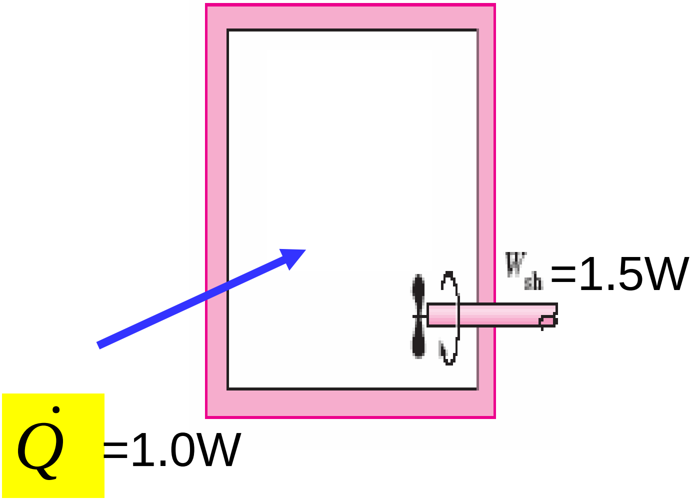
Problem (4-32)

4-32 Motor oil is contained in a rigid container that is equipped with a stirring device. The rate of specific energy increase is to be determined.

Analysis This is a closed system since no mass enters or leaves. The energy balance for closed system can be expressed as

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

$$\dot{Q}_{in} + \dot{W}_{sh,in} = \Delta \dot{E}$$



Then,

$$\Delta \dot{E} = \dot{Q}_{in} + \dot{W}_{sh,in} = 1 + 1.5 = 2.5 = 2.5\ \text{W}$$

Dividing this by the mass in the system gives

$$\Delta \dot{e} = \frac{\Delta \dot{E}}{m} = \frac{2.5\ \text{J/s}}{1.5\ \text{kg}} = \mathbf{1.67\ J/kg \cdot s}$$

Closed System Energy Analysis

Ideal Gases

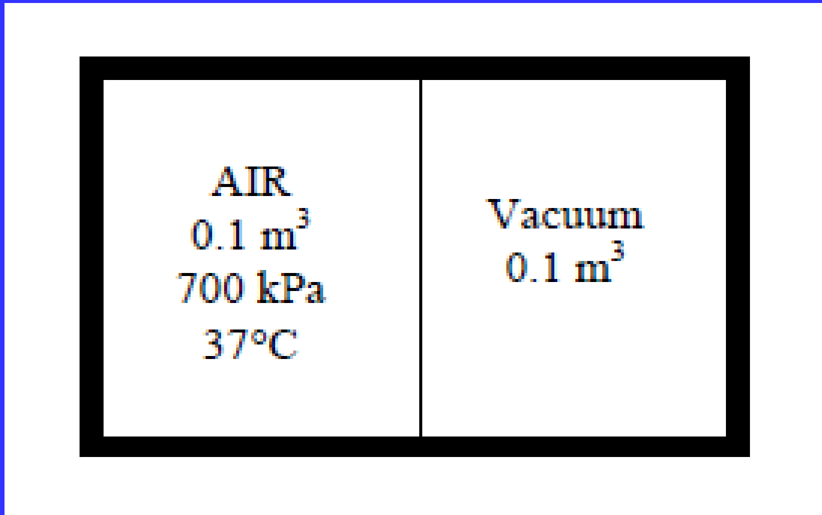
Problem (4-65)

Determine the internal energy change when the membrane is ruptured.

Determine the final air pressure when the membrane is ruptured.

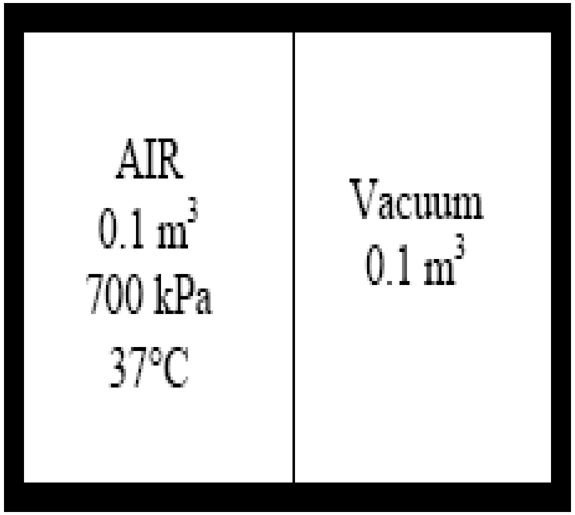
Assumptions 1 Air is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of 132.5 K and 3.77 MPa. 2 The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$. 3 Constant specific heats at room temperature can be used for air. This assumption results in negligible error in heating and air-conditioning applications. 3 The tank is insulated and thus heat transfer is negligible.

Adiabatic Process



Problem (4-65)

Analysis We take the entire tank as the system. This is a *closed system* since no mass crosses the boundaries of the system. The energy balance for this system can be expressed as



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

$$0 = \Delta U = mc_v(T_2 - T_1)$$

Since the internal energy does not change, the temperature of the air will also not change. Applying the ideal gas equation gives

$$P_1V_1 = P_2V_2 \longrightarrow P_2 = P_1\frac{V_1}{V_2} = P_1\frac{V_2/2}{V_2} = \frac{P_1}{2} = \frac{700\text{ kPa}}{2} = \mathbf{350\ kPa}$$

Problem (4-69)

4-69 Argon in a piston-cylinder device undergoes an isothermal process. The mass of argon and the work done are to be determined.

Assumptions 1 Argon is an ideal gas since it is at a high temperature and low pressure relative to its critical point values of 151 K and 4.86 MPa. 2 The kinetic and potential energy changes are negligible, $\Delta ke \cong \Delta pe \cong 0$.

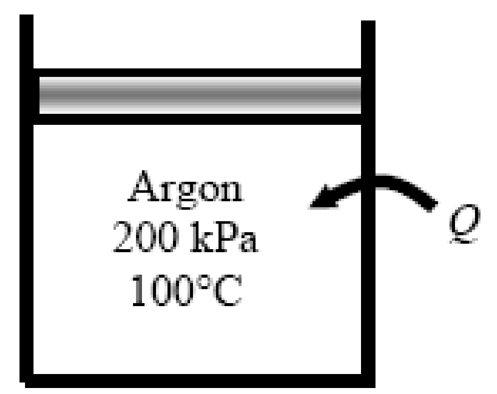
Properties The gas constant of argon is $R = 0.2081 \text{ kJ/kg·K}$ (Table A-1).

Given :

$p_1 = 200\, kPa \,, p_2 = 50\, kPa$

$T_1 = T_2 = 50 C (Isothermal\ \ process)$

$Q = 1500\, kJ$



Problem (4-69)

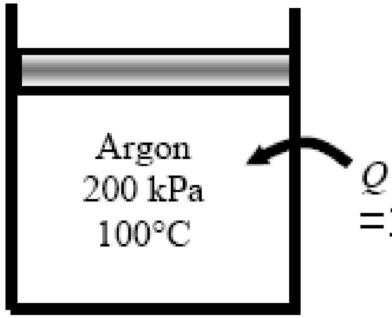
Analysis We take argon as the system. This is a *closed system* since no mass crosses the boundaries of the system. The energy balance for this system can be expressed as

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

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

$$Q_{in} - W_{b,out} = 0 \quad (\text{since } T_1 = T_2)$$

$$Q_{in} = W_{b,out}$$



Thus,

$$W_{b,out} = Q_{in} = \mathbf{1500\ kJ}$$

Using the boundary work relation for the isothermal process of an ideal gas gives

$$W_{b,out} = m\int_1^2 P\,dv = mRT\int_1^2 \frac{dv}{v} = mRT\ln\frac{v_2}{v_1} = mRT\ln\frac{P_1}{P_2}$$

Solving for the mass of the system,

$$m = \frac{W_{b,out}}{RT\ln\frac{P_1}{P_2}} = \frac{1500\text{ kJ}}{(0.2081\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(373\text{ K})\ln\frac{200\text{ kPa}}{50\text{ kPa}}} = \mathbf{13.94\ kg}$$

Closed System Energy Analysis

Solids and Liquids

Problem (4-82)

Given :

$T_1 = 20C, T_2 = 80C$

4-82 An iron block is heated. The internal energy and enthalpy changes are to be determined for a given temperature change.

Assumptions Iron is an incompressible substance with a constant specific heat.

Properties The specific heat of iron is 0.45 kJ/kg·K (Table A-3*b*).

Analysis The internal energy and enthalpy changes are equal for a solid. Then,

$$\Delta H = \Delta U = mc\Delta T = (1\text{ kg})(0.45\text{ kJ/kg}\cdot\text{K})(80-20)\text{K} = \mathbf{27\ kJ}$$

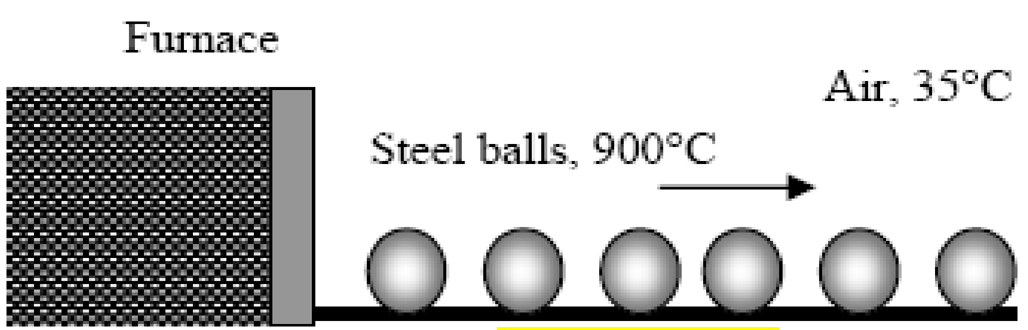
Problem (4-86)

4-86 Carbon steel balls are to be annealed at a rate of 2500/h by heating them first and then allowing them to cool slowly in ambient air at a specified rate. The total rate of heat transfer from the balls to the ambient air is to be determined.

Assumptions **1** The thermal properties of the balls are constant. **2** There are no changes in kinetic and potential energies. **3** The balls are at a uniform temperature at the end of the process

Properties The density and specific heat of the balls are given to be $\rho = 7833$ kg/m^3 and $c_p = 0.465$ kJ/kg.°C.

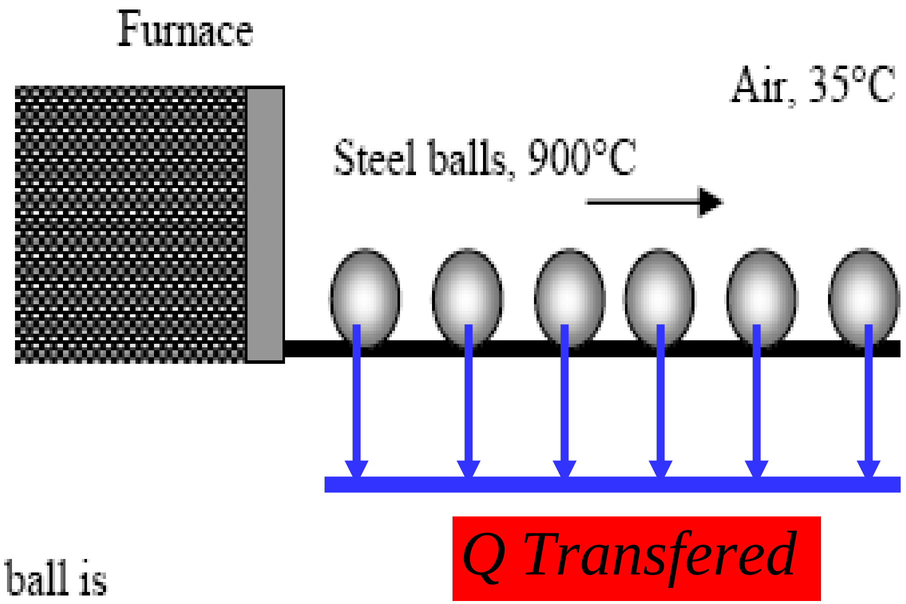
Steel Balls are heated to $T = 900\ ^{\circ}C$ **and then cooled to** $T = 100\ ^{\circ}C$ **at an air temperature of** $T_{air} = 25\ ^{\circ}C$



$d_{Ball} = 8\,mm$

Problem (4-86)

Analysis We take a single ball as the system. The energy balance for this closed system can be expressed as



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

$$-Q_{out} = \Delta U_{ball} = m(u_2 - u_1)$$

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

(*b*) The amount of heat transfer from a single ball is

$$m = \rho V = \rho\frac{\pi D^3}{6} = (7833\,\text{kg/m}^3)\frac{\pi(0.008\,\text{m})^3}{6} = \underline{0.00210\,\text{kg}}$$

$$Q_{out} = mc_p(T_1 - T_2) = (0.0021\,\text{kg})(0.465\,\text{kJ/kg.°C})(900 - 100)\text{°C} = \underline{0.781\,\text{kJ (per ball)}}$$

Then the total rate of heat transfer from the balls to the ambient air becomes

$$\dot{Q}_{out} = \dot{n}_{ball}Q_{out} = (2500\,\text{balls/h})\times(0.781\,\text{kJ/ball}) = \underline{1{,}953\,\text{kJ/h} = \mathbf{542\,W}}$$

<u>THE END</u>