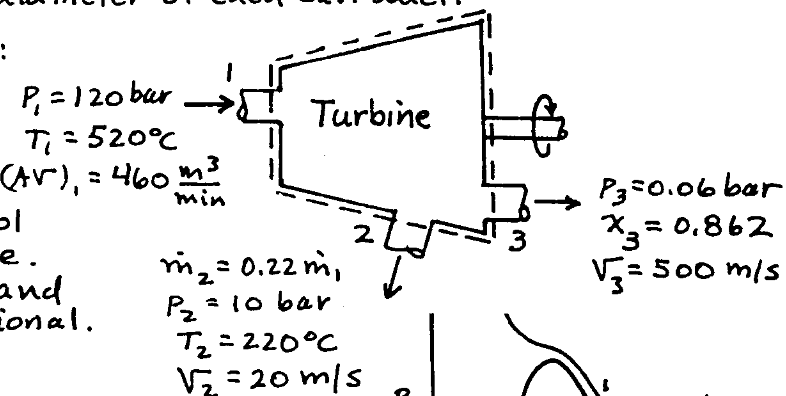
PROBLEM 4.14

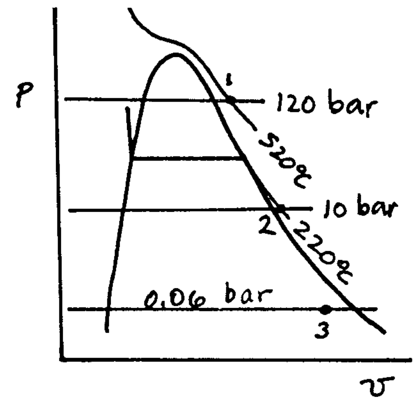
KNOWN: Data are given for steam flowing through a turbine with one inlet and two exits.

FIND: Determine the diameter of each exit duct.

SCHEMATIC & GIVEN DATA:



ASSUMPTIONS: (1) The control volume is at steady state. (2) The flow at the inlet and each exit is one-dimensional.



ANALYSIS: The mass flow rate at the inlet is

$$\dot{m}_1 = \frac{(AV)_1}{v_1}$$

From Table A-4, $v_1 = 0.02781\ m^3/kg$. Thus

$$\dot{m}_1 = \frac{(460\ m^3/min)}{(0.02781\ m^3/kg)}\left|\frac{1\ min}{60\ s}\right| = 275.7\ kg/s$$

and $\dot{m}_2 = 0.22\,\dot{m}_1 = 60.65\ kg/s$

Applying the mass rate balance

$$\cancel{\frac{dm_{cv}}{dt}}^{0} = \dot{m}_1 - \dot{m}_2 - \dot{m}_3 \Rightarrow \dot{m}_3 = \dot{m}_1 - \dot{m}_2 = 215.1\ kg/s$$

Now, with $\dot{m} = AV/v$, and from Table A-4; $v_2 = 0.21675\ m^3/kg$

$$A_2 = \frac{\dot{m}_2 v_2}{V_2} = \frac{(60.65\ kg/s)(0.21675\ m^3/kg)}{(20\ m/s)} = 0.657\ m^2$$

Noting that $A = \pi d^2/4$

$$d_2 = \sqrt{\frac{4A_2}{\pi}} = 0.915\ m \leftarrow$$ d_2

From Table A-3, at $P_3 = 0.06$ bar and $x_3 = 0.862$

$$v_3 = v_{f3} + x_3(v_{g3} - v_{f3})$$
$$= 1.0064\times10^{-3} + (.862)(23.739 - 1.0064\times10^{-3}) = 20.463\ m^3/kg$$

Thus

$$A_3 = \frac{\dot{m}_3 v_3}{V_3} = \frac{(215.1)(20.463)}{(500)} = 8.803\ m^2$$

and

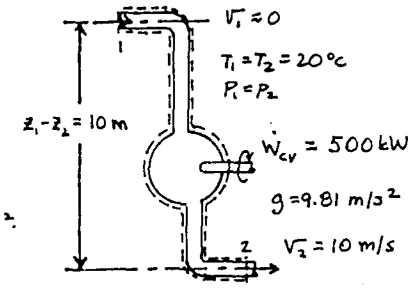
$$d_3 = \sqrt{\frac{4A_3}{\pi}} = 3.35\ m \leftarrow$$ d_3

PROBLEM 4.40

KNOWN: Water flows through a hydraulic turbine with known conditions at the inlet and exit. The power output is specified.

FIND: Determine the mass flow rate.

SCHEMATIC & GIVEN DATA:



ASSUMPTIONS: (1) The control volume is at steady state. (2) Heat transfer is negligible. (3) Changes in temperature and pressure from inlet to exit are negligible. (4) Kinetic energy can be neglected at the inlet. (5) The acceleration of gravity is constant; g = 9.81 m/s².

ANALYSIS: To find the mass flow rate, begin with steady state mass and energy rate balances

$$0 = \dot{m}_1 - \dot{m}_2 \Rightarrow \dot{m}_1 = \dot{m}_2 \equiv \dot{m}$$

and

$$0 = \cancel{\dot{Q}_{cv}}^{0} - \dot{W}_{cv} + \dot{m}\left[(\cancel{h_1 - h_2})^{0} + \left(\frac{\cancel{V_1^2}^{0} - V_2^2}{2}\right) + g(z_1 - z_2)\right]$$

where the enthalpy term is cancelled because of assumption (3). Solving

$$\dot{m} = \frac{\dot{W}_{cv}}{-\frac{V_2^2}{2} + g(z_1 - z_2)}$$

Inserting values

$$\dot{m} = \frac{(500\ \text{kW})\left|\frac{1\ \text{kJ/s}}{1\ \text{kW}}\right|}{\left[\left(-\frac{10^2}{2}\right)\frac{\text{m}^2}{\text{s}^2} + \left(9.81\frac{\text{m}}{\text{s}^2}\right)(10\ \text{m})\right]\left|\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right|\left|\frac{1\ \text{kJ}}{10^3\ \text{N}\cdot\text{m}}\right|}$$

$$= 10{,}400\ \text{kg/s} \longleftarrow \dot{m}$$

?

Inserting values

$$\dot{m}_2 = \frac{-(11{,}400\ \text{kW})\left|\frac{1\ \text{kJ/s}}{1\ \text{kW}}\right| + (14.25\ \text{kg/s})(3230.9 - 2325.9)\frac{\text{kJ}}{\text{kg}}}{(2812.0 - 2325.8)\frac{\text{kJ}}{\text{kg}}}$$

$$= 3.077\ \text{kg/s} = 11{,}079\ \text{kg/h} \longleftarrow \dot{m}_2$$

From (*)

$$\dot{m}_3 = \dot{m}_1 - \dot{m}_2 = 14.25\ \frac{\text{kg}}{\text{s}}\ \frac{3600\ \text{s}}{1\ \text{h}} - 11{,}079\ \frac{\text{kg}}{\text{h}}$$

$$= 40{,}221\ \text{kg/h} \longleftarrow \dot{m}_3$$

(b) To find d_2, begin with Eq. 4.11 b

$$\dot{m}_2 = \frac{A_2 V_2}{v_2}$$

or

$$A_2 = \frac{\dot{m}_2 v_2}{V_2} = \frac{(3.077\ \text{kg/s})(0.4045\ \text{m}^3/\text{kg})}{(20\ \text{m/s})} = 0.06223\ \text{m}^2$$

where the value of v_2 is from Table A-4. Finally, with $A_2 = \pi d_2^2/4$

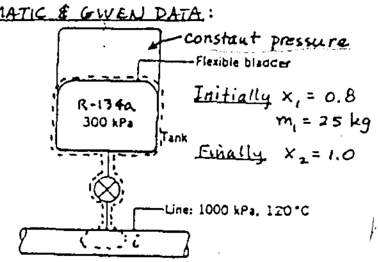
$$d_2 = \sqrt{\frac{4A_2}{\pi}} = \sqrt{\frac{(4)(0.6223\ \text{m}^2)}{\pi}} = 0.249\ \text{m} \longleftarrow d_2$$

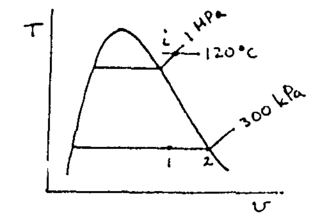
PROBLEM 4.98

KNOWN: A well-insulated tank containing R-134a is connected to a supply line. As refrigerant is allowed to flow into the tank, a flexible bladder in the tank expands to maintain the refrigerant in the tank at constant pressure.

FIND: Determine the amount of mass admitted to the tank between the initial time and the instant when all the liquid in the tank is vaporized.

SCHEMATIC & GIVEN DATA:





ASSUMPTIONS: (1) The control volume is shown with $\dot{Q}_{cv} = 0$. (2) Conditions in the supply line remain constant. (3) The pressure remains constant in the tank. (4) Kinetic and potential energy effects are negligible.

ANALYSIS: The mass rate balance takes the form; $dm_{cv}/dt = \dot{m}_i$. With the assumptions listed, the energy rate balance is

$$\frac{dU_{cv}}{dt} = \cancel{\dot{Q}_{cv}}^{0} - \dot{W}_{cv} + \dot{m}_i h_i$$

The specific enthalpy h_i is constant by assumption (2). Thus, combining the mass and energy rate balances and integrating

$$\Delta U_{cv} = -W_{cv} + \int_{t_1}^{t_2} \dot{m}_i h_i\, dt$$

Since h_i is constant

$$\Delta U_{cv} = -W_{cv} + h_i \int_{t_1}^{t_2} \dot{m}_i\, dt = -W_{cv} + h_i(m_2 - m_1) \qquad (1)$$

To evaluate the work, note that the pressure in the tank is constant. Thus

$$W_{cv} = \int p\, dV = p(V_2 - V_1) = p(m_2 v_2 - m_1 v_1) \qquad (2)$$

Combining (1) and (2), and noting that $\Delta U_{cv} = m_2 u_2 - m_1 u_1$

$$m_2 u_2 - m_1 u_1 = -p(m_2 v_2 - m_1 v_1) + h_i(m_2 - m_1)$$

or

$$m_2[(u_2 + p v_2) - h_i] = m_1[(u_1 + p v_1) - h_i]$$

$$m_2[h_2 - h_i] = m_1[h_1 - h_i]$$

Solving for m_2

$$m_2 = m_1\left(\frac{h_1 - h_i}{h_2 - h_i}\right)$$

Using data from Table A-11 at 3 bar: $h_f = 50.85$, $h_g = 247.59$ kJ/kg

$h_1 = (50.85) + (0.8)[247.59 - 50.85] = 208.24$ kJ/kg

$h_2 = 247.59$ kJ/kg

From Table A-12, $h_i = 356.52$ kJ/kg. Thus

$$m_2 = 25\ \text{kg}\left(\frac{208.24 - 356.52}{247.59 - 356.52}\right) = 34.03\ \text{kg}$$

Finally,

$$\Delta m = m_2 - m_1$$

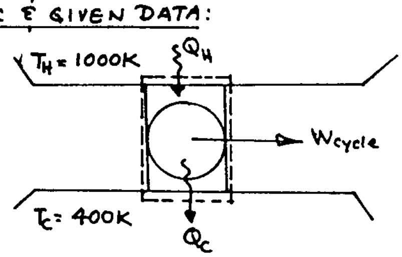
$$= 34.03 - 25 = 9.03\ \text{kg} \longleftarrow$$

PROBLEM 5.19

KNOWN: Operating data are provided for a system undergoing a power cycle while receiving and discharging energy by heat transfer with two thermal reservoirs at specified temperatures.

FIND: For each of three sets of data, determine if any principles of thermodynamics are violated.

SCHEMATIC & GIVEN DATA:



Energy balance:

$$W_{cycle} = Q_H - Q_C$$

Definition:

$$\eta = \frac{W_{cycle}}{Q_H}$$

ASSUMPTION: The system shown in the accompanying figure undergoes a power cycle.

ANALYSIS:

(a) $Q_H = 600\text{ kJ}$, $W_{cycle} = 200\text{ kJ}$, $Q_C = 400\text{ kJ}$. These values satisfy the energy balance, and give

$$\eta = \frac{W_{cycle}}{Q_H} = \frac{200\text{ kJ}}{600\text{ kJ}} = 0.33\ (33\%).$$

The maximum thermal efficiency for any power cycle under the stated conditions is given by Eq. 5.8:

$$\eta_{MAX} = 1 - \frac{T_C}{T_H} = 1 - \frac{400\text{K}}{1000\text{K}} = 0.6\ (60\%)$$

Thus the second law is also satisfied. There is no apparent violation of the first and second laws.

(b) $Q_H = 400\text{ kJ}$, $W_{cycle} = 240\text{ kJ}$, $Q_C = 160\text{ kJ}$. These values satisfy the energy balance, and give

$$\eta = \frac{240\text{ kJ}}{400\text{ kJ}} = 0.6\ (60\%)$$

As $\eta = \eta_{MAX}$, this power cycle must be reversible. There is no apparent violation of the first and second laws.

(c) $Q_H = 400\text{ kJ}$, $W_{cycle} = 210\text{ kJ}$, $Q_C = 180\text{ kJ}$. With these values for Q_H and Q_C the energy balance gives

$$W_{cycle} = Q_H - Q_C = 400 - 180 = 220\text{ kJ}$$

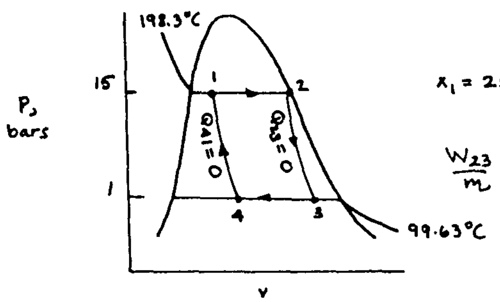
which does not agree with the given value. Accordingly, the conservation of energy principle is not satisfied. There is no need to consider the second law under such circumstances.

PROBLEM 5.61

KNOWN: 0.5 kg of water executes a Carnot cycle for which property data are provided.

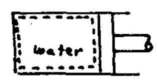
FIND: Sketch the cycle on p-v coordinates, evaluate the heat and work for each process, and evaluate the thermal efficiency.

SCHEMATIC AND GIVEN DATA:



$x_1 = 25\%$

$\frac{W_{23}}{m} = 403.8 \frac{kJ}{kg}$



Summary:

Process	Q	W
1-2	730.3	73.5
2-3	0	201.9
3-4	-578.3	-43.3
4-1	0	-79.9

ASSUMPTION: The system shown in the figure undergoes a Carnot cycle.

Process 1-2: $\frac{W_{12}}{m} = \int_1^2 p\,dv = p(v_2 - v_1)$. An energy balance gives $\frac{Q_{12}}{m} = u_2 - u_1 + \frac{W_{12}}{m}$. Thus

$$\frac{Q_{12}}{m} = (u_2 - u_1) + p(v_2 - v_1) = h_2 - h_1$$

With data from Table A-3. $v_2 = 0.1318\ m^3/kg$, $h_2 = 2792.2\ kJ/kg$, $u_2 = 2594.5\ kJ/kg$

$$v_1 = v_f + x(v_g - v_f) = 1.1539\times10^{-3} + 0.25(0.1318 - 1.1539\times10^{-3}) = 33.815\times10^{-3}\ m^3/kg$$

$$h_1 = h_f + x(h_g - h_f) = 844.84 + 0.25(1947.3) = 1331.67\ kJ/kg.$$

With these values, $Q_{12} = (0.5 kg)(2792.2 - 1331.67)\ kJ/kg = 730.3\ kJ$, and ← Q_{12}

$$W_{12} = (0.5 kg)(15\ bars)\left(10^5 \frac{N/m^2}{bar}\right)\left[(131.8 - 33.815)\times10^{-3}\frac{m^3}{kg}\right]\left(\frac{kJ}{10^3 N\cdot m}\right) = 73.5\ kJ$$ ← W_{12}

Process 2-3: $Q_{23} = 0$, $W_{23}/m = 403.8\ kJ/kg$. Thus $W_{23} = 201.9\ kJ$. ← Q_{23}, W_{23}
Using an energy balance and data from Table A-3, $u_3 = 2190.7\ kJ/kg$, giving $x_3 = 0.849$.

Process 3-4: As for process 1-2, $W_{34}/m = p(v_4 - v_3)$, $Q_{34}/m = (h_4 - h_3)$. Also, since the system undergoes a reversible cycle while communicating with reservoirs at $T_H = 471\ K$, $T_C = 373\ K$, Eq. 5.6 is applicable

$$\frac{|Q_{34}|}{Q_{12}} = \frac{373}{471} \Rightarrow h_3 - h_4 = \frac{373}{471}(1460.53) = 1156.6\ \frac{kJ}{kg}$$

Thus, $h_4 = h_3 - 1156.6 = (417.46 + 0.849(2258)) - 1156.6 = 1177.9\ kJ/kg$. Using this value,
$x_4 = (1177.9 - 417.46)/2258 = 0.337$. Then, $v_4 = 1.0432\times10^{-3} + 0.337[1.694 - 1.0432\times10^{-3}] = 0.5716\ m^3/kg$,
$u_4 = 417.36 + 0.337(2506.1 - 417.36) = 1121.27\ kJ/kg$. Also, $v_3 = 1.438\ m^3/kg$.
Finally, $Q_{34} = -578.3\ kJ$, $W_{34} = -43.3\ kJ$. ← Q_{34}, W_{34}

Process 4-1: $Q_{41} = 0$. $W_{41}/m = u_4 - u_1 = 1121.27 - (843.16 + 0.25(1751.34)) = -159.73\ kJ/kg$.
So, $W_{41} = -79.9\ kJ$. ← Q_{41}, W_{41}

Thermal Efficiency.

Method #1: $$\eta = \frac{W_{cycle}}{Q_{in}} = \frac{73.5 + 201.9 - 43.3 - 79.9}{730.3} = 0.208\ (20.8\%)$$

Method #2: Equation 5.8

$$\eta_{MAX} = 1 - \frac{T_C}{T_H} = 1 - \frac{(99.63 + 273.15)}{(198.3 + 273.15)} = 1 - \frac{372.78}{471.45} = 0.208\ (20.8\%)$$

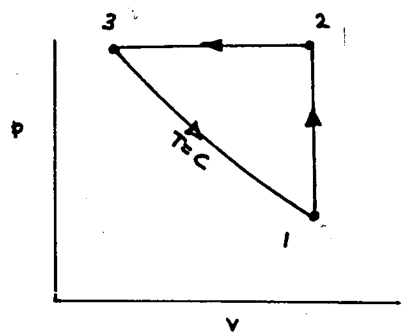
PROBLEM 6.21

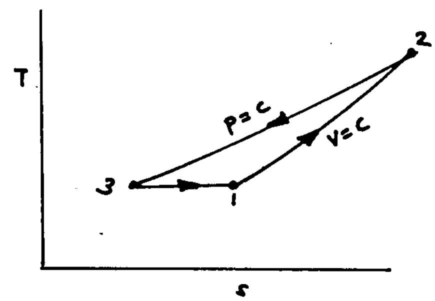
KNOWN: A quantity of air undergoes a thermodynamic cycle consisting of three processes.

FIND: Evaluate the change in entropy for each process and sketch the cycle on p-v coordinates.

SCHEMATIC & GIVEN DATA:

$P_1 = 0.1$ MPa
$T_1 = 15°C$
$V_1 = 0.02$ m^3
$P_2 = 0.42$ MPa





ASSUMPTIONS: (1) As shown in the accompanying figure, the system consists of the quantity of air. (2) The air behaves as an ideal gas with $c_p = 1$ kJ/kg·K.

ANALYSIS: The entropy changes can be evaluated using Eqs. 6.26 and 6.27. First, some preliminary results are calculated. Using the ideal gas equation of state

$$m = \frac{P_1 V_1}{R T_1} = \frac{(0.1 \times 10^6 \text{ N/m}^2)(0.02 \text{ m}^3)}{\left(\frac{8314}{28.97} \frac{\text{N·m}}{\text{kg·K}}\right)(288 \text{ K})} = 0.024 \text{ kg}$$

Also, since $V_1 = V_2$

$$\left.\begin{array}{l} P_1 V = m R T_1 \\ P_2 V = m R T_2 \end{array}\right\} \Rightarrow \quad T_2 = \frac{P_2}{P_1} T_1 = \left(\frac{0.42}{0.10}\right)(288) = 1210 \text{ K}$$

With Eq. 3.44

$$c_v = c_p - R = 1 \frac{\text{kJ}}{\text{kg·K}} - \frac{8.314}{28.97} \frac{\text{kJ}}{\text{kg·K}} = 0.713 \text{ kJ/kg·K}$$

Process 1-2: With $v_2 = v_1$, Eq. 6.26 reduces so

$$S_2 - S_1 = m c_v \ln \frac{T_2}{T_1} = (0.024 \text{kg})\left(0.713 \frac{\text{kJ}}{\text{kg·K}}\right) \ln \frac{1210}{288}$$

$$= 0.0246 \text{ kJ/K} \longleftarrow S_2 - S_1$$

Process 2-3: With $p_3 = P_2$, Eq. 6.27 reduces so

$$S_3 - S_2 = m c_p \ln \frac{T_3}{T_2} = m c_p \ln \frac{T_1}{T_2}$$

$$= (0.024 \text{kg})\left(1.0 \frac{\text{kJ}}{\text{kg·K}}\right) \ln \frac{288}{1210}$$

$$= -0.0344 \text{ kJ/K} \longleftarrow S_3 - S_2$$

Process 3-1: Since $T_3 = T_1$, Eq. 6.27 reduces so

$$S_1 - S_3 = -m R \ln \frac{P_1}{P_3} = -m R \ln \frac{P_1}{P_2}$$

$$= -(0.024)\left(\frac{8.314}{28.97}\right) \ln \frac{0.1}{0.42}$$

$$= 0.0099 \text{ kJ/K} \longleftarrow S_1 - S_3$$

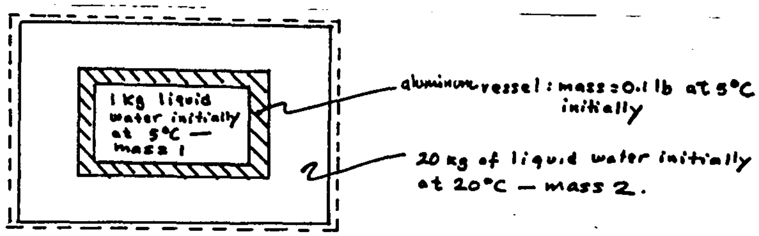
COMMENT: The cycle is also sketched on T-s coordinates using the result of Problem 6.22a.

PROBLEM 6.72

KNOWN: Data are provided on an isolated system consisting of an aluminum vessel and two quantities of liquid water.

FIND: Determine (a) the final temperature when the system has come to equilibrium, (b) the entropy change for the aluminum vessel and each of the liquid masses, (c) the amount of entropy produced.

SCHEMATIC & GIVEN DATA:



ASSUMPTIONS: (1) The system shown in the accompanying figure is isolated. (2) The aluminum vessel and each of the liquid masses can be modeled as incompressible with constant specific heat.

ANALYSIS: From Table A-19, the specific heat of aluminum is $c = 0.9\ kJ/kg \cdot K$ and of liquid water $c_w = 4.18\ kJ/kg \cdot K$.

(a) With assumption 1, $Q = W = 0$ and an energy balance reduces to

$$\Delta U = \cancel{Q}^{0} - \cancel{W}^{0}$$

$$(\Delta U)_1 + (\Delta U)_2 + (\Delta U)_{copper} = 0$$

With assumption 2

$$m_1 c_w [T_f - T_1] + m_2 c_w [T_f - T_2] + mc [T_f - T_1] = 0$$

where m_1 and T_1 are the mass and initial temperature of liquid mass 1, m_2 and T_2 are the mass and initial temperature of liquid mass 2, and m is the mass of the vessel.

Solving for the final temperature, T_f

$$T_f = \frac{m_1 c_w T_1 + m_2 c_w T_2 + mc\, T_1}{m_1 c_w + m_2 c_w + mc}$$

$$= \frac{(1)(4.18)(278) + (20)(4.18)(293) + (0.1)(0.9)(278)}{(1)(4.18) + (20)(4.18) + (0.1)(0.9)} = 292.3\ K\ (19°C) \longleftarrow T_f$$

(b) Entropy changes. Using Eq. 6.24 (assumption 2)

$$(\Delta S)_1 = m_1 c_w \ln \frac{T_f}{T_1} = (1)(4.18) \ln \frac{292.3}{278} = 0.20967\ \frac{kJ}{K}$$

$$(\Delta S)_2 = m_2 c_w \ln \frac{T_f}{T_2} = (20)(4.18) \ln \frac{292.3}{293} = -0.19996\ \frac{kJ}{K} \longleftarrow \Delta S$$

$$(\Delta S)_{copper} = mc \ln \frac{T_f}{T_1} = (0.1)(0.9) \ln \frac{292.3}{278} = 0.00451\ \frac{kJ}{K}$$

(c) Since there is no heat transfer to or from the system an entropy balance gives

$$\Delta S = \cancel{\int_1^2 \left(\frac{\delta Q}{T}\right)_b} + \sigma \Rightarrow \sigma = (\Delta S)_1 + (\Delta S)_2 + (\Delta S)_{Aluminum}$$

$$= 0.0142\ \frac{kJ}{K} \longleftarrow \sigma$$