3

3.1 (a) System = Ball (1) + Water (2)

Energy balance: $M_1\hat{U}_1^f + M_2\hat{U}_2^f - M_1\hat{U}_1^i - M_2\hat{U}_2^i = 0$

$\Rightarrow M_1C_{V,1}\left(T_1^f - T_1^i\right) + M_2C_{V,2}\left(T_2^f - T_2^i\right) = 0$; also $T_1^f - T_2^f$. Thus

$$T^f = \frac{M_1C_{V,1}T_1^i + M_2C_{V,2}T_2^i}{M_1C_{V,1} + M_2C_{V,2}} = \frac{5\times10^3\times0.5\times75 + 12\times10^3\times4.2\times5}{5\times10^3\times0.5 + 12\times10^3\times4.2}$$

$= 8.31°\text{C}$

[Note: Since only ΔT's are involved, $°\text{C}$ were used instead of K)].

(b) For solids and liquids we have (eqn. 3.4-6). That $\Delta S = M\int C_P \frac{dT}{T} = MC_P \ln\frac{T_2}{T_1}$ for the case in which C_P is a constant. Thus

$$\text{Ball:}\quad \Delta S = 5\times10^3\ \text{g}\times0.5\frac{\text{J}}{\text{g}\cdot\text{K}}\times\ln\left\{\frac{8.31+273.15}{75+273.15}\right\} = -531.61\frac{\text{J}}{\text{K}}$$

$$= -531.61\ \text{s}$$

$$\text{Water:}\quad \Delta S = 12\times10^3\ \text{g}\times4.2\frac{\text{J}}{\text{g}\cdot\text{K}}\times\ln\left\{\frac{8.31+273.15}{5+273.15}\right\} = +596.22\frac{\text{J}}{\text{K}}$$

and

$$\Delta S(\text{Ball}+\text{Water}) = 596.22 - 531.61\frac{\text{J}}{\text{K}} = 64.61\frac{\text{J}}{\text{K}}$$

Note that the system Ball + Water is isolated. Therefore

$$\Delta S = S_{\text{gen}} = 64.61\frac{\text{J}}{\text{K}}$$

3.2 Energy balance on the combined system of casting and the oil bath

$M_cC_{V,c}\left(T^f - T_c^i\right) + M_oC_{V,o}\left(T^f - T_o^i\right) = 0$ since there is a common final temperature.

$$20\ \text{kg}\times0.5\frac{\text{kJ}}{\text{kg}\cdot\text{K}}\left(T^f - 450\right)\text{K} + 150\ \text{kg}\times2.6\frac{\text{kJ}}{\text{kg}\cdot\text{K}}\left(T^f - 450\right)\text{K} = 0$$

This has the solution $T^f = 60°\text{C} = 313.15$ K

Since the final temperature is known, the change in entropy of this system can be calculated from $\Delta S = 20\times0.5\times\ln\left(\frac{273.15+60}{273.15+450}\right) + 150\times2.6\times\ln\left(\frac{273.15+60}{273.15+50}\right) = 4.135\frac{\text{kJ}}{\text{K}}$

3.3 Closed system energy and entropy balances

$$\frac{dU}{dt} = \dot{Q} + \dot{W}_s - P\frac{dV}{dt};\quad \frac{dS}{dt} = \frac{\dot{Q}}{T} + \dot{S}_{\text{gen}};$$

Thus, in general $\dot{Q} = T\frac{dS}{dt} - T\dot{S}_{\text{gen}}$ and

$$\dot{W}_s = \frac{dU}{dt} - \dot{Q} + P\frac{dV}{dt} = \frac{dU}{dt} - T\frac{dS}{dt} + T\dot{S}_{gen} + P\frac{dV}{dt}$$

Reversible work: $\dot{W}_s^{\mathrm{Rev}} = \dot{W}_s^{\mathrm{Rev}}\left(\dot{S}_{\mathrm{gen}} = 0\right) = \dfrac{dU}{dt} - T\dfrac{dS}{dt} + P\dfrac{dV}{dt}$

(a) System at constant U & V $\Rightarrow \dfrac{dU}{dt} = 0$ and $\dfrac{dV}{dt} = 0$

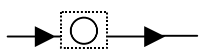
$$\dot{W}_s\left(\dot{S}_{gen} = 0\right) = \dot{W}_S^{\mathrm{Rev}} = -T\frac{dS}{dt}$$

(b) System at constant S & P $\Rightarrow \dfrac{dS}{dt} = 0$ and $\dfrac{dP}{dt} = 0 \Rightarrow P\dfrac{dV}{dt} = \dfrac{d}{dt}(PV)$

so that

$$\dot{W}_s\left(\dot{S}_{gen} = 0\right) = \dot{W}_S^{\mathrm{rev}} = \frac{dU}{dt} + \frac{d}{dt}(PV) = \frac{d}{dt}(U + PV) = \frac{dH}{dt}$$

3.4

700 bar, 600°C  10 bar, $T = ?$

Steady-state balance equations

$$\frac{dM}{dt} = 0 = \dot{M}_1 + \dot{M}_2$$

$$\frac{dU}{dt} = 0 = \dot{M}_1\hat{H}_1 + \dot{M}_2\hat{H}_2 + \cancel{\dot{Q}}^{0} + \cancel{\dot{W}_s}^{0} - P\cancel{\frac{dV}{dt}}^{0} = \dot{M}_1\hat{H}_1 + \dot{M}_2\hat{H}_2$$

or $\hat{H}_1 = \hat{H}_2$

Drawing a line of constant enthalpy on Mollier Diagram we find, at $P = 10$ bar, $T \cong 308°\mathrm{C}$

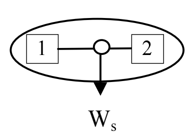
At 700 bar and 600°C	At 10 bar and 308°C
$\hat{V} = 0.003973\ \mathrm{m^3/kg}$	$\hat{V} \approx 0.2618\ \mathrm{m^3/kg}$
$\hat{H} = 3063\ \mathrm{kJ/kg}$	$\hat{H} \approx 3063\ \mathrm{kJ/kg}$
$\hat{S} = 5.522\ \mathrm{kJ/kg\ K}$	$\hat{S} = 7.145\ \mathrm{kJ/kg\ K}$

Also

$$\frac{dS}{dt} = 0 = \dot{M}_1\hat{S}_1 + \dot{M}_2\hat{S}_2 + \frac{\cancel{\dot{Q}}^{0}}{T} + \dot{S}_{\mathrm{gen}} = 0$$

$$\Rightarrow \dot{S}_{\mathrm{gen}} = \dot{M}_1\left(\hat{S}_2 - \hat{S}_1\right) \textbf{ or } \frac{\dot{S}_{\mathrm{gen}}}{\dot{M}_1} = \hat{S}_2 - \hat{S}_1 = 7.145 - 5.522 = 1.623\frac{\mathrm{kJ}}{\mathrm{kg \cdot K}}$$

3.5

System 

Energy balance

$$\Delta U = \left(U_2^f - U_2^i\right) + \left(U_1^f - U_1^i\right) = \cancel{\dot{Q}}^{\text{adiabatic}} + W_S - \cancel{\int PdV}^{\text{constant volume}}$$