Customized Balance Equations (Prof. S. Bhattacharjee, SDSU)

Closed Steady Systems (Wall, Light bulb, Laptop adapter, Gear box, closed cycles)

Mass: $m = \text{constant}$; (1)

Energy: $0 = \dot{Q} - \dot{W}_{\text{ext}} \quad [\text{kW}]$

where, $\dot{W}_{\text{ext}} = \dot{W}_B + \dot{W}_{\text{sh}} + \dot{W}_{\text{el}}$ (2)

Entropy: $0 = \dfrac{\dot{Q}}{T_B} + \dot{S}_{\text{gen}} \left[\dfrac{\text{kW}}{\text{K}}\right]$ where, $\dot{S}_{\text{gen}} \geq 0$ (3)

SingleFlow Open Steady Systems (pumps, turbines, nozzles, valves, pipes, etc.)

Mass: $\dot{m}_e = \dot{m}_i = \dot{m} \quad \left[\dfrac{\text{kg}}{\text{s}}\right]$; (1)

Energy: $\dot{m}j_e = \dot{m}j_i + \dot{Q} - \dot{W}_{\text{ext}} \quad [\text{kW}]$

where, $j = h + \text{ke} + \text{pe} = h + \dfrac{V^2}{2000} + \dfrac{gz}{1000} \quad [\text{kJ/kg}]$, $\dot{W}_{\text{ext}} = \dot{W}_B + \dot{W}_{\text{sh}} + \dot{W}_{\text{el}} \quad [\text{kW}]$ (2)

Entropy: $\dot{m}s_e = \dot{m}s_i + \dfrac{\dot{Q}}{T_B} + \dot{S}_{\text{gen}} \left[\dfrac{\text{kW}}{\text{K}}\right]$ where, $\dot{S}_{\text{gen}} \geq 0$ (3)

Closed Process (Heating water in a tank, piston-cylinder compression)

Mass: $m = \text{constant} \ [\text{kg}]$; (1)

Energy: $\Delta E = E_f - E_b = Q - W_{\text{ext}} \quad [\text{kJ}]$

where, $e = u + \text{ke} + \text{pe} = u + \dfrac{V^2}{2000} + \dfrac{gz}{1000} \quad [\text{kJ/kg}]$; $W_{\text{ext}} = W_B + W_{\text{sh}} + W_{\text{el}} \quad [\text{kJ}]$ (2)

Entropy: $\Delta S = S_f - S_b = Q/T_B + S_{\text{gen}} \quad [\text{kJ/K}]$ where, $S_{\text{gen}} \geq 0$ (3)

Open Process (Filling an evacuated tank, filling a propane cylinder, discharge from a tank)

Mass: $\Delta m = m_f - m_b = m_i - m_e \quad [\text{kg}]$ (1)

Energy: $\Delta E = E_f - E_b = m_i j_i - m_e j_e + Q - W_{\text{ext}} \quad [\text{kJ}]$

where, $e = u + \text{ke} + \text{pe} = u + \dfrac{V^2}{2000} + \dfrac{gz}{1000}$, $j = h + \text{ke} + \text{pe} = h + \dfrac{V^2}{2000} + \dfrac{gz}{1000} \quad [\text{kJ/kg}]$ (2)

and $W_{\text{ext}} = W_B + W_{\text{sh}} + W_{\text{el}} \quad [\text{kJ}]$

Entropy: $\Delta S = S_f - S_b = m_i s_i - m_e s_e + Q/T_B + S_{\text{gen}}$ where, $S_{\text{gen}} \geq 0$ (3)

Manual State Evaluation – V 2.0

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General State Related Equations (applies to any substance):

$$m = \rho \cancel{V};\ \rho = \frac{1}{v};\ \text{ke} = \frac{V^2}{2000};\ \text{pe} = \frac{gz}{1000};\ \ e \equiv u + ke + pe;\ j \equiv h + ke + pe;\ h \equiv u + pv \tag{1}$$

$$E = me;;\ \ S = ms;\ KE = m(\text{ke});\ PE = m(\text{pe}) \tag{2}$$

$$\dot{m} = \rho AV\ ;\ \dot{\cancel{V}} = AV\ ;\ \dot{E} = \dot{m}e\ ;\ \ \dot{S} = \dot{m}s\ ; \tag{3}$$

$$Tds = du + pdv = dh - vdp;\ \ \ c_v \equiv (\partial u / \partial T)_v;\ c_p \equiv (\partial h / \partial T)_p \tag{4}$$

SL Model: (Assumptions: $\rho = \text{constant}$. c_v =constant)

$$\Delta u \equiv u_2 - u_1 = c(T_2 - T_1); \qquad c_v = c_p = c; \tag{5}$$

$$\Delta h \equiv h_2 - h_1 = \Delta(u + pv) = \Delta u + \Delta(pv) = c(T_2 - T_1) + v(p_2 - p_1) \tag{6}$$

$$\Delta s = c_p \ln \frac{T_2}{T_1} \tag{7}$$

PG Model: (Assumptions: $p = \rho RT$; c_v =constant)

$$p = \rho RT = \frac{RT}{v} = \frac{m}{\cancel{V}} RT = \frac{m}{\cancel{V}} \frac{\bar{R}}{M} T = \frac{m}{M} \bar{R} \frac{T}{\cancel{V}} = n\bar{R} \frac{T}{\cancel{V}}, \qquad \text{where } R \equiv \frac{\bar{R}}{\bar{M}} \tag{8}$$

$$\Delta u \equiv u_2 - u_1 = c_v(T_2 - T_1),\ \ \Delta h \equiv h_2 - h_1 = c_p(T_2 - T_1), \quad \text{where} \quad c_p = (c_v + R) \tag{9}$$

$$\Delta s = c_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1};\ \ \Delta s = c_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1};\ \text{also, } k \equiv \frac{c_p}{c_v},\ c_p = \frac{kR}{k-1}; \quad \text{and} \quad c_v = \frac{R}{k-1} \tag{10}$$

For isentropic process: $$\frac{p_2}{p_1} = \left(\frac{\rho_2}{\rho_1}\right)^k = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} \qquad \frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = \left(\frac{\rho_2}{\rho_1}\right)^k = \left(\frac{v_1}{v_2}\right)^k = \left(\frac{\cancel{V}_1}{\cancel{V}_2}\right)^k \tag{11}$$

For polytropic process replace k with n

IG Model: (Assumptions: $p = \rho RT$; c_v is function of T).

$$p = \rho RT = \frac{RT}{v} = \frac{m}{\cancel{V}} RT = \frac{m}{\cancel{V}} \frac{\bar{R}}{M} T = \frac{m}{M} \bar{R} \frac{T}{\cancel{V}} = n\bar{R} \frac{T}{\cancel{V}} \tag{12}$$

$$h = h(T),\ u = u(T)\ \ s = s(p,T).\ \text{(use look up tables)};\ \ c_p = c_v + R \tag{13}$$

The temperature dependent part of entropy is separated from the pressure dependent part:

$$\Delta s = \int_{T_1}^{T_2} c_p \frac{dT}{T} - R \ln \frac{p_2}{p_1} = s^o(T_2) - s^o(T_1) - R \ln \frac{p_2}{p_1},\ \text{where } s^0(T) \text{ is tabulated against } T. \tag{14}$$

PC Model: Determine the phase, L, V or M, of the fluid. For vapor use superheated Table. For mixture, use saturation table (if the quality is not known, your goal should be to evaluate the quality first which is the key to finding all specific properties of a mixture). For liquid use the **CL sub-model**.

CL Sub-Model: v, u and s depend on T only. Therefore, use the temperature-sorted saturation table to obtain $v = v_{f@T}$, $u = u_{f@T}$ or $s = s_{f@T}$. To find h, use $h = u + pv = u_{f@T} + pv_{f@T}$.

RG Model: $p = Z(p_r, T_r)\rho RT$ where Z, the compressibility factor, is obtained from a chart. p_r and T_r are pressure and temperature normalized by the corresponding critical properties. Just like entropy in the PG or IG model, h and u also have two parts, one temperature dependent and another pressure dependent, in the RG model. The departure of these values from the corresponding IG values are tabulated in the enthalpy and entropy departure charts as functions of p_r and T_r. Therefore, the complete state can be evaluated if p_r and T_r are given.