Summary of Thermo

from: first_law_rev_2005.mcd, second_law_rev_2005.mcd, availability.mcd
ref: van Wylen & Sonntag (eqn #s) Woud (W nn.nn)

First Law

first law for cycle

$$\int 1\, dQ = \int 1\, dW \quad (5.2)$$

first law for system - change of state

$$Q_{1\_2} = E_2 - E_1 + W_{1\_2}$$

Q_{1_2} is the heat transferred TO system

E_1 E_2 are intial and final values of energy of system and ... (5.5)

W_{1_2} is work done BY the system

$$\delta Q = dE + \delta W = dU + dKE + dPE + \delta W \quad (5.4)$$

Closed System $\frac{d}{dt}U = Q\_dot - W\_dot$ $dU = \delta Q - \delta W$ $m\_dot_e = m\_dot_i = 0$ (W 2.3)

first law as a rate equation $\frac{d}{dt}Q = \frac{d}{dt}U + \frac{d}{dt}KE + \frac{d}{dt}PE + \frac{d}{dt}W = \frac{d}{dt}E + \frac{d}{dt}W$ (5.31 and 5.32)

first law as a rate equation - for a control volume

$H = U + p \cdot V$

$h = u + p \cdot v$

enthalpy defined - is a property (5.12)

$$\frac{d}{dt}Q_{c\_v} + \sum_n \left[m\_dot_i \cdot \left(h_i + \frac{V_i^2}{2} + g \cdot z_i\right)\right] = \frac{d}{dt}E_{c\_v} + \sum_n \left[m\_dot_e \cdot \left(h_e + \frac{V_e^2}{2} + g \cdot z_e\right)\right] + \frac{d}{dt}W_{c\_v} \quad (5.45)$$

Woud assuming energy $E = U + E_{kin} + E_{pot}$ and ... $E_{kin} = E_{pot} = 0$ $E = U$

$$\frac{d}{dt}U = Q\_dot - W\_dot + m\_dot_i \cdot \left(h_i + \frac{V_i^2}{2} + g \cdot z_i\right) - m\_dot_e \cdot \left(h_e + \frac{V_e^2}{2} + g \cdot z_e\right)$$

N.B. dot => rate not d( )/dt

W (2.1)

steady state, steady flow process ... open stationary

$$\sum_n m\_dot_{i_n} = \sum_n m\_dot_{e_n} \qquad m\_dot = flow\_rate \quad (5.46)$$

$$\frac{d}{dt}Q_{c\_v} + \sum_n \left[m\_dot_{i_n} \cdot \left(h_i + \frac{V_i^2}{2} + g \cdot z_i\right)\right] = \sum_n \left[m\_dot_{e_n} \cdot \left(h_e + \frac{V_e^2}{2} + g \cdot z_e\right)\right] + \frac{d}{dt}W_{c\_v} \quad (5.47), (W2.8)$$

steady state steady flow ... - single flow stream

$$q + h_i + \frac{V_i^2}{2} + g \cdot z_i = h_e + \frac{V_e^2}{2} + g \cdot z_e + w$$

this on per unit mass basis q = Q/m_dot (5.50)

uniform state, uniform flow process

$$Q_{c\_v} + \sum_n \left[m_{i_n} \cdot \left(h_i + \frac{V_i^2}{2} + g \cdot z_i \right) \right] = \sum_n \left[m_{e_n} \cdot \left(h_e + \frac{V_e^2}{2} + g \cdot z_e \right) \right] \dots$$

$$+ m_2 \cdot \left(u_2 + \frac{V_2^2}{2} + g \cdot z_2 \right) - m_1 \cdot \left(u_1 + \frac{V_1^2}{2} + g \cdot z_1 \right) + W_{c\_v} \qquad (5.54)$$

Second Law

Carnot cycle most efficient, and only function of temperature $\eta_{thermal} = 1 - \frac{T_L}{T_H}$

Entropy inequality of Clausius ... $\oint \frac{1}{T} dQ \le 0$ integrals are cyclic

=> for all reversible heat engines ... $\oint 1\, dQ = 0$ $\oint \frac{1}{T} dQ = 0$ => all irreversibles engines $\oint 1\, dQ \ge 0$ $\oint \frac{1}{T} dQ < 0$

$dS = \left(\frac{\delta Q_{rev}}{T} \right)$ reversible ... (7.2)

so as we did for energy E (e) in first law $\oint \frac{1}{T} dQ$ is independent of path in reversible process => is a porperty of the substance. entropy is an extensive property and entropy per unit mass is = s

$$\int_1^2 \frac{1}{T} dQ_{rev.} = S_2 - S_1 \qquad (7.3)$$

$$S_2 - S_1 \ge \int_1^2 \frac{1}{T} dQ$$

equality holds when reversible and when irreversible, the change of entrpy will be greater than the reversible

two relationships for simple compressible substance - Gibbs equations

appicable to rev & irrev processes

$T \cdot dS = dU + p \cdot \delta V$ (7.5) $T \cdot ds = du + p \cdot \delta v$

$T \cdot dS = dH - V \cdot dp$ (7.6) $T \cdot ds = dh - v \cdot dp$ (7.7)

second law for a control volume

$$\frac{d}{dt} S_{c\_v} + \sum_n (m\_dot_e \cdot s_e) - \sum_n (m\_dot_i \cdot s_i) \ge \sum_{c\_v} \frac{Q\_dot_{c\_v}}{T} \qquad (7.49)$$

= when reversible

steady state, steady flow process

$$\frac{d}{dt} S_{c\_v} = 0 \qquad (7.50)$$

$$\sum_n (m\_dot_e \cdot s_e) - \sum_n (m\_dot_i \cdot s_i) \ge \sum_{c\_v} \frac{Q\_dot_{c\_v}}{T} \qquad (7.51)$$

= when reversible

uniform state, uniform flow process

$$m_2 \cdot s_2 - m_1 \cdot s_1 + \sum_n (m_e \cdot s_e) - \sum_n (m_i \cdot s_i) \ge \int_0^t \frac{Q\_dot_{c\_v}}{T} dt \qquad (7.56)$$

= when reversible

Availability

reversible work (maximum) of a control volume that exchanges heat with the surroundings at To

$$W_{rev} = \sum_n \left[m_{i_n} \cdot \left(h_i - T_o \cdot s_i + \frac{V_i^{\,2}}{2} + g \cdot z_i \right) \right] - \left[\sum_n \left[m_{e_n} \cdot \left(h_e - T_o \cdot s_e + \frac{V_e^{\,2}}{2} + g \cdot z_e \right) \right] \right. + \left. \left[m_2 \cdot \left(u_2 - T_o \cdot s_2 + \frac{V_2^{\,2}}{2} + g \cdot z_2 \right) - m_1 \cdot \left(u_1 - T_o \cdot s_1 + \frac{V_1^{\,2}}{2} + g \cdot z_1 \right) \right] \right] \quad (8.7)$$

latter [..] is total for c.v.

system (fixed mass

$$\frac{W_{rev\_1\_2}}{m} = w_{rev\_1\_2} = \left(u_1 - T_o \cdot s_1 + \frac{V_1^{\,2}}{2} + g \cdot z_1 \right) - \left(u_2 - T_o \cdot s_2 + \frac{V_2^{\,2}}{2} + g \cdot z_2 \right) \quad (8.8)$$

steady-state, steady flow process - rate form

$$W\_dot_{rev} = \sum_n \left[m_{i_n} \cdot \left(h_i - T_o \cdot s_i + \frac{V_i^{\,2}}{2} + g \cdot z_i \right) \right] - \left[\sum_n \left[m_{e_n} \cdot \left(h_e - T_o \cdot s_e + \frac{V_e^{\,2}}{2} + g \cdot z_e \right) \right] \right] \quad (8.9)$$

single flow of fluid $$\frac{W\_dot_{rev}}{m\_dot} = w_{rev} = h_i - T_o \cdot s_i + \frac{V_i^{\,2}}{2} + g \cdot z_i - \left(h_e - T_o \cdot s_e + \frac{V_e^{\,2}}{2} + g \cdot z_e \right) \quad (8.10)$$

availablity

steady state, steady flow **process** ***...(e.g. single flow ...availability (per unit mass flow)***

$$\psi = h - T_o \cdot s + \frac{V_i^{\,2}}{2} + g \cdot z - \left(h_o - T_o \cdot s_o + \frac{V_o^{\,2}}{2} + g \cdot z_o \right) \quad (8.16)$$

reversible work between any two states = decrease in availablity between them

$$w_{rev} = \psi_i - \psi_e = h_1 - T_o \cdot s_1 - h_2 + T_o \cdot s_2 = h_1 - T_o \cdot s_1 - h_2 + T_o \cdot s_2 = \left(h_1 - h_2 \right) - T_o \cdot \left(s_1 - s_2 \right) \quad \text{(8.17) extended}$$

can be written for more than one flow ...

$$W - dot_{rev} = \sum_n \left(m_{i_n} \cdot \psi_{i_n} \right) - \sum_n \left(m_{e_n} \cdot \psi_{e_n} \right) \quad (8.18)$$

availability w/o KE and PE per unit mass of **system**

$$\phi = \left(u + p_o \cdot v - T_o \cdot s\right) - \left(u_o + p_o \cdot v_o - T_o \cdot s_o\right) = u - u_o + p_o \cdot \left(v - v_o\right) - T_o \cdot \left(s - s_o\right) \qquad (8.21)$$

and reversible work maximum between states 1 and 2 is ...

$$w_{rev\_1\_2} = \phi_1 - \phi_2 - p_o \cdot \left(v_1 - v_2\right) + \frac{V_1^{\,2} - V_2^{\,2}}{2} + g \cdot \left(z_1 - z_2\right) \qquad (8.22)$$