Thermodynamics:

Equation Sheets:

Chap 1: **number of moles**

$$n = \frac{m}{M} \qquad \bar{v} = \frac{v}{M}$$

Temperature Conversions:

$$R = 1.8K \qquad F = R - 459.67 \qquad C = K - 273.15 \qquad F = 1.8C + 32$$

Chap 2: **Energy balance of closed system** **Energy Rate balance of close system**

$$\Delta U + \Delta KE + \Delta PE = Q - W \qquad \frac{dE}{dt} = \dot{Q} - \dot{W}$$

Work due to action of a force **Work due to compression of a fluid**

$$W = \int_{r_1}^{r_2} \mathbf{F} \cdot d\mathbf{r} = \mathbf{F} \cdot \mathbf{V} \qquad W = \int_{V_1}^{V_2} p\,dV$$

Kinetic Energy **Gravitational Potential Energy**

$$KE = \frac{1}{2} m \mathrm{V}^2 \qquad PE = mgz$$

Energy Balance: Power Cycle **Power Cycle Efficiency**

$$W_{cycle} = Q_{in} - Q_{out} \qquad \eta = \frac{W_{cycle}}{Q_{in}}$$

Energy balance: Ref and Heat Pump **Refrigeration COP** **Heat Pump COP**

$$W_{cycle} + Q_{in} = Q_{out} \qquad \beta = \frac{Q_{in}}{W_{cycle}} \qquad \gamma = \frac{Q_{out}}{W_{cycle}}$$

Chap 3: **Quality** **Polytropic Process**

$$x = \frac{m_{vapor}}{m_{liquid} + m_{vapor}}$$

$$v = v_f + x(v_g - v_f)$$
$$u = u_f + x(u_g - u_f)$$
$$h = h_f + x(h_g - h_f)$$

$$pV^N = \text{constant}$$

Ideal Gas Model:

$$pv = RT \quad \textbf{or} \quad pV = mRT \quad \textbf{or} \quad pV = n\bar{R}T$$

$$\Delta U = m\int c_v\,dT \approx mc_v\Delta T \qquad \Delta H = m\int c_p\,dT \approx mc_p\Delta T$$

$$c_p = c_v + R \qquad c_p = \frac{kR}{k-1} \qquad c_v = \frac{R}{k-1}$$

Compressibility Model:

$$Z = \frac{p\bar{v}}{\bar{R}T} = \frac{pv}{RT} \qquad p_R = \frac{p}{p_c} \qquad T_R = \frac{T}{T_c} \qquad v'_R = \frac{\bar{v}}{\bar{R}T_c / p_c}$$

Chap 4: Continuity Equation: **Mass balance for CV:**

$$\dot{m} = \frac{AV}{v} = \frac{\dot{V}}{v} \qquad \frac{dm}{dt} = \sum_i \dot{m}_i - \sum_e \dot{m}_e$$

Energy Balance for CV

$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i (h_i + \frac{V_i^2}{2} + gz_i) - \sum_e \dot{m}_e (h_e + \frac{V_e^2}{2} + gz_e)$$

Simplified Nozzle/Diffuser model: **Simplified Turbine model:**

$$0 = \left(h_i + \frac{V_i^2}{2} \right) - \left(h_e + \frac{V_e^2}{2} \right) \qquad 0 = -\dot{W}_{cv} + \dot{m}(h_i - h_e)$$

Simplified Compressor/Pump model **Simplified Throttling model**

$$0 = -\dot{W}_{cv} + \dot{m}(h_i - h_e) \qquad 0 = h_i - h_e$$

Simplified Heat Exchanger model

$$0 = \sum_i \dot{m}_i - \sum_e \dot{m}_e \qquad 0 = \sum_i \dot{m}_i h_i - \sum_e \dot{m}_e h_e$$

Chap 5: 2nd Law Efficiency **2nd Law COP**

$$\eta_{\max} = 1 - \frac{T_C}{T_H} \qquad \beta_{\max} = \frac{T_C}{T_H - T_C} \qquad \gamma_{\max} = \frac{T_H}{T_H - T_C}$$

Clausius Inequality:

$$\oint \left(\frac{\delta Q}{T} \right)_b = -\sigma_{cycle}$$

Chap 6: Closed System Entropy Balance **Closed System Entropy Rate Balance**

$$S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T} \right)_b + \sigma_{cycle} \qquad \frac{dS}{dt} = \sum \frac{\dot{Q}}{T} + \dot{\sigma}$$

Control Volume Entropy Balance

$$\frac{dS}{dt} = \sum \frac{\dot{Q}}{T} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{\sigma}$$

Isentropic Efficiencies:

Turbine **Nozzle** **Compressor/Pump**

$$\eta_{turbine} = \frac{\dot{W}_{cv}/\dot{m}}{\left(\dot{W}_{cv}/\dot{m}\right)_s} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$

$$\eta_{nozzle} = \frac{V_2^{\,2}/2}{(V_2^{\,2}/2)_s}$$

$$\eta_{compress} = \frac{\left(-\dot{W}_{cv}/\dot{m}\right)_s}{-\dot{W}_{cv}/\dot{m}} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

Ideal Gas Model Relations:

$$s(T_2, v_2) - s(T_1, v_1) = c_v \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1}$$

$$s(T_2, p_2) - s(T_1, p_1) = c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}$$

or

$$s(T_2, p_2) - s(T_1, p_1) = s^o(T_2) - s^o(T_1) - R\ln\frac{p_2}{p_1}$$

Isentropic Ideal Gas relationships (when $s_1 = s_2$)

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{(k-1)/k} \qquad \frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1} \qquad \frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^{k}$$

$$\frac{p_2}{p_1} = \frac{p_{r2}}{p_{r1}} \qquad \frac{v_2}{v_1} = \frac{v_{r2}}{v_{r1}}$$
