Perfect Gases:

$pv = RT \qquad p\bar{v} = \bar{R}T$

$pV = mRT \qquad pV = n\bar{R}T$

where, $R = \bar{R}/M$

$$\bar{R} = \begin{cases} 8.314\ kJ/kmol \cdot K \\ 1.986\ Btu/lbmol \cdot {}^\circ R \\ 1545\ ft \cdot lbf/lbmol \cdot {}^\circ R \end{cases}$$

$pv = RT$

$u = u(T)$

$h = h(T) = u(T) + RT$

$c_p(T) = c_v(T) + R$

$\bar{c_p}(T) = \bar{c_v}(T) + \bar{R}$

$p_R = \dfrac{p}{p_c}$

$T_R = \dfrac{T}{T_c}$

$Z = \dfrac{pv}{RT}$

$c_v(T) = \frac{du}{dT}$ A-22 & A-23

$$u(T_2) - u(T_1) = \int_{T_1}^{T_2} c_v\,(T)dT$$

Constant Specific Heats

$u(T_2) - u(T_1) = c_v(T_2 - T_1)$

$c_p(T) = \frac{dh}{dT} \qquad k = \frac{c_p}{c_v}$

$$h(T_2) - h(T_1) = \int_{T_1}^{T_2} c_p\,(T)dT$$

Constant Specific Heats

$h(T_2) - h(T_1) = c_p(T_2 - T_1)$

Conservation of Mass:

$$\frac{dm_{cv}}{dt} = \sum_i \dot{m}_i - \sum_e \dot{m}_e$$

where, $\dot{m} = \int_A \rho\, V_n\, dA$

For 1-D flow:

$$\dot{m} = \rho AV = \frac{AV}{v}$$

For steady 1-D flow:

$$\sum_i \rho VA = \sum_e \rho VA$$

Steady, 1-D flow, 1 inlet/outlet:

$$\dot{m}_{in} = \dot{m}_{out}$$

Incompressible Substance Model:

$v = const. \qquad v \neq v(T, P)$

$u = u(T) \qquad h(T, p) = u(T) + pv$

$c = du/dt \qquad c_p = c_v = c$

$$u_2 - u_1 = \int_{T_1}^{T_2} c\,(T)dT$$

$$h_2 - h_1 = u_2 - u_1 + v(p_2 - p_1) = \int_{T_1}^{T_2} c\,(T)dT + v(p_2 - p_1)$$

If specific heat c is taken as constant;

$u_2 - u_1 = c(T_2 - T_1)$

$h_2 - h_1 = c(T_2 - T_1) + v(p_2 - p_1)$

Conservation of Energy (1st Law Open):

$$\frac{d}{dt}\int_V \rho\left(u + \frac{V^2}{2} + gz\right)dV = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \left(\int_A \left(h + \frac{V^2}{2} + gz\right)\rho V_n dA\right)_i - \sum_e \left(\int_A \left(h + \frac{V^2}{2} + gz\right)\rho V_n dA\right)_e$$

For 1-D flow:

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

For steady 1-D flow:

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

For steady, 1-D flow, 1 inlet/outlet:

$$\frac{1}{\dot{m}}(\dot{Q}_{in} - \dot{W}_{out}) = \left(h + \frac{V^2}{2} + gz\right)_2 - \left(h + \frac{V^2}{2} + gz\right)_1$$

2nd Law (Entropy Generation Concept):

$S_{gen} \geq 0$; $= 0$ Reversible , > 0 Irreversible ; $S_{gen} = S_2 - S_1 \geq 0$ Isolated System

$S_{gen} = S_2 - S_1 + \left(\sum \frac{Q_{out}}{T} - \sum \frac{Q_{in}}{T}\right) \geq 0$; $\dot{S}_{gen} = \frac{dS}{dt} + \sum \frac{\dot{Q}_{out}}{T} - \sum \frac{\dot{Q}_{in}}{T} \geq 0$ Closed System

Closed system undergoing reversible adiabatic (isentropic) process, $S_{gen} = S_2 - S_1 = 0$, $S_2 = S_1$

For closed system undergoing <u>cycle</u> $-\sum \frac{Q_{out}}{T} + \sum \frac{Q_{in}}{T} \leq 0$; $\oint \frac{dQ}{T} \leq 0$

Power cycles for reversible 2-T heat engine ; Refrigeration and heat pump cycles

$\eta = \frac{W_{cycle}}{Q_H} = 1 - \frac{Q_C}{Q_H}$, $\eta_{max} = 1 - \frac{T_C}{T_H}$, $COP_{max,refrig} = \frac{T_C}{T_H - T_C}$, $COP_{max,hp} = \frac{T_h}{T_H - T_C}$

$\dot{S}_{gen} = \frac{dS}{dt} + \left[\sum \dot{m}s + \sum \frac{\dot{Q}}{T}\right]_{out} - \left[\sum \dot{m}s + \sum \frac{\dot{Q}}{T}\right]_{in} \geq 0$ Open System

$\dot{S}_{gen} = \dot{m}(s_{out} - s_{in}) \geq 0$ 1- inlet & 1 outlet, adiabatic device, steady-state