

<b>Unit Conversions</b> - Temperature $T(^{\circ}\text{C}) = T(\text{K}) - 273.15$ $T(^{\circ}\text{F}) = 1.8 \cdot T(^{\circ}\text{C}) + 32$ $T(\text{R}) = T(^{\circ}\text{F}) + 459.67$ - Pressure $1 \text{ bar} = 10^5 \text{ Pa} = 100 \text{ kPa}$ $P_{\text{atm}} = 101 \text{ kPa} = 14.7 \text{ lbf/in}^2$ $6895 \text{ Pa} = 1 \text{ psi}$ - Energy + Power $1 \text{ Btu} = 778 \text{ ft} \cdot \text{lbf}$ $1 \text{ hp} = 550 \text{ ft} \cdot \text{lbf/s} = 2545 \text{ Btu/hr}$ $N = \text{kg} \cdot \text{m/s}^2$ - Volume $1 \text{ m} = 3.28084 \text{ ft}$ - Fluids $\rho_{\text{H}_2\text{O}} = 1000 \text{ kg/m}^3 = 1.94 \text{ slug/ft}^3$ $\gamma_{\text{H}_2\text{O}} = 9800 \text{ N/m}^3 = 62.4 \text{ lbf/ft}^3$ $\gamma_{\text{Hg}} = 133,200 \text{ N/m}^3$ - Mass $\text{Slug} = 32.174 \text{ lb}_{\text{mass}} = \text{lb}_{\text{mass}} \cdot \text{s}^2/\text{ft}$	<b>Adiabatic:</b> $\delta Q = \delta s = 0$ <b>Isentropic:</b> $\Delta s = 0$ <b>1<sup>st</sup> Law</b> $\Delta E = \Delta KE + \Delta PE + \Delta U = {}_1Q_2 - {}_1W_2$ Rate Form: $\dot{E} = \dot{Q} - \dot{W}$ <b>Mixtures</b> $X = \frac{M_{\text{ring}}}{M} = \frac{x - x_f}{x_g - x_f} \quad (x = v, u, h)$ $\beta = (1 - X)\beta_f + X \cdot \beta_g$	<b>Ideal Gas</b> $P\hat{v} = \hat{R}T, \hat{R} \text{ is universal}$ $Pv = RT, \text{ where } R = \frac{\hat{R}}{M_u}$ $P = \rho RT$ $PV = mRT$ $\hat{R} = \begin{cases} 0.314 \frac{\text{kJ}}{\text{kmol} \cdot \text{K}} \\ 1.906 \frac{\text{Btu}}{\text{lbmol} \cdot \text{R}} \\ 1545 \frac{\text{ft} \cdot \text{lbf}}{\text{lbmol} \cdot \text{R}} \end{cases}$	<b>Polytropic Ideal Gas</b> $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{V_1}{V_2}\right)^{n-1}$ ${}_1W_2 = \begin{cases} \frac{mR(T_2 - T_1)}{(1-n)}, n \neq 1 \\ mRT \ln\left(\frac{P_2}{P_1}\right), n = 1 \end{cases}$ <b>Compressed Liquid Approx.</b> $s(T, P) = s_f(T), s = (v, u, h, s)$	<b>Polytropic Process</b> $P \cdot V^n = c \text{ or } P \cdot v^n = c$ - Volume expansion work ${}_1W_2 = \begin{cases} \frac{(P_2 V_2 - P_1 V_1)}{(1-n)}, n \neq 1 \\ P_1 V_1 \ln\left(\frac{P_2}{P_1}\right), n = 1 \end{cases}$ <b>Real gas</b> $z = \frac{Pv}{RT}, \text{ where } z = \text{compressibility factor}$
<b>Specific Heat (heat capacity)</b> $C$ used when incompressible, otherwise $C_p$ and $C_v$ $\Delta u = \int_{T_1}^{T_2} C_v(T) dT$ $\Delta h = \int_{T_1}^{T_2} C_p(T) dT + v(P_2 - P_1)$ Constant $C$ , approximation $C_v = \frac{C_p(T_1) + C_p(T_2)}{2}$ $C_p = C_v + R$	<b>Enthalpy</b> $H = U + P \cdot V$ $h = u + P \cdot v$ <b>Entropy Balance (Cycle)</b> $\frac{dS_{\text{cycle}}}{dt} = \sum \frac{\dot{Q}}{T} + \sum \dot{m}_1 \cdot s_1 - \sum \dot{m}_2 \cdot s_2 + \dot{d}_{\text{cv}}$ $1 \text{ in, } 1 \text{ out: } 0 = \sum \frac{\dot{Q}}{T} + \dot{m}(s_1 - s_2) + \dot{d}_{\text{cv}}$ $\Delta s = s_2 - s_1 = \frac{1}{\dot{m}} \left( \sum \frac{\dot{Q}}{T} + \dot{d}_{\text{cv}} \right)$	<b>Energy Conservation</b> $\frac{dE_{\text{cv}}}{dt} = \dot{Q}_{\text{cv}} - \dot{W}_{\text{cv}} + \sum \dot{m}_i \left( h_i + \frac{1}{2} V_i ^2 + g \cdot z_i \right) - \sum \dot{m}_e \left( h_e + \frac{1}{2} V_e ^2 + g \cdot z_e \right)$ $1 \text{ Inlet, } 1 \text{ Exit: } 0 = \dot{Q}_{\text{cv}} - \dot{W}_{\text{cv}} + \dot{m} \left[ (h_1 - h_2) + \frac{1}{2}( V_1 ^2 -  V_2 ^2) + g(z_1 - z_2) \right]$ <b>Entropy and Ideal Gas</b> $\Delta s = s(T_2, P_2) - s(T_1, P_1) = \int_{T_1}^{T_2} \frac{C_p(T)}{T} dt + R \cdot \ln\left(\frac{P_1}{P_2}\right)$ $\Delta s = s(T_2, P_2) - s(T_2, P_1) = \int_{P_1}^{P_2} \frac{C_p(T)}{P} dP - R \cdot \ln\left(\frac{P_2}{P_1}\right)$ $\Delta s = s^*(T_2) - s^*(T_1) - R \cdot \ln\left(\frac{P_2}{P_1}\right)$	<b>2<sup>nd</sup> Law and Cycle COP's</b> $\text{COP}_{\text{refrigerator}} < \text{COP}_{\text{ref}} = \text{COP}_{\text{max}}$ $\text{COP}_{\text{refrigerator}} = \text{COP}_{\text{refrigerator}}$ Power: $\eta_{\text{ref}} = \frac{W}{Q_{\text{in}}} = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}} = 1 - \frac{T_c}{T_h}$ Refrig: $\beta_{\text{ref}} = \frac{Q_{\text{out}}}{W} = \frac{Q_{\text{out}}}{Q_{\text{in}} - Q_{\text{out}}} = \frac{T_c}{T_h - T_c}$ Heat Pump: $\gamma_{\text{ref}} = \frac{Q_{\text{out}}}{W} = \frac{Q_{\text{out}}}{Q_{\text{in}} - Q_{\text{out}}} = \frac{T_h}{T_h - T_c}$	
<b>Mass Conservation</b> $\frac{dM_{\text{control}}}{dt} = \sum \dot{m}_i - \sum \dot{m}_e$ $\dot{m} = \rho A  V  = \frac{\rho Q}{v}$ Volumetric flow rate = $A V $ Flow work = $(P \cdot A) \cdot  V $	<b>Entropy</b> $dS = \left(\frac{\delta Q}{T}\right)_{\text{rev}}, S = s \cdot m$ $S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b$ $T \cdot ds = du + P \cdot dv$ $T \cdot ds = dh - v \cdot dP$ Rev: ${}_1Q_2 = \int_1^2 T ds = mT(s_2 - s_1)$	<b>2<sup>nd</sup> Law and Entropy</b> $\oint_{\text{cycle}} \left(\frac{\delta Q}{T}\right)_b \leq 0$ $S$ production: $\sigma = -\oint \left(\frac{\delta Q}{T}\right)_b \geq 0$ $\sigma > 0$ : irreversible cycle $\sigma = 0$ : reversible cycle $\sigma < 0$ : impossible	<b>Isentropic Efficiency</b> Turbine: $\eta_t = \frac{W_t/m}{(W_t/m)_s} = \frac{h_1 - h_2}{h_1 - h_{2s}} \leq 1$ Nozzle: $\eta_n = \frac{\frac{1}{2}V_2^2}{\frac{1}{2}(V_2^2)_s} \leq 1$ Compressor/Pump: $\eta_{c/p} = \frac{(W_c/m)_s}{(W_c/m)_a} \leq 1$	
<b>Work and Power</b> $W = \int F \cdot dr$ - Volume expansion work: $W = \int P dV$ $W = m \cdot \int P dv$ $\text{Power} = \frac{dW}{dt}$	<b>Entropy Balance (Process)</b> $S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b + \sigma$ $S_2 - S_1 = \sum \frac{\dot{Q}}{T} + \sigma$ $\frac{dS}{dt} = \sum \frac{\dot{Q}}{T} + \dot{\sigma}$	<b>Energy</b> $KE = \frac{1}{2} m v^2 \quad PE = m g z$ <b>1<sup>st</sup> Law and Cycles</b> Power: $Q_H - Q_C = W_{\text{cycle}}$ R+HP: $Q_{\text{out}} - Q_{\text{in}} = W_{\text{cycle}}$		
<b>Velocity<sup>2</sup> to kJ/kg</b> $\frac{m^2}{s^2} \cdot \frac{\text{N} \cdot \text{s}^2}{\text{kg} \cdot \text{m}} \cdot \frac{1}{\text{N} \cdot \text{m}} \cdot \frac{\text{kJ}}{10^3 \text{ J}}$				

# Engineering Thermodynamics Equation Sheet

**Frank A Di Bella**



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