

Unit Conversions - 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 $\text{Slug} = 32.174 \text{ lb}_{\text{mass}} = \text{lb}_{\text{mass}} \cdot \text{s}^2/\text{ft}$	Adiabatic: $\delta Q = \delta s = 0$ Isentropic: $\Delta s = 0$ 1st Law $\Delta E = \Delta KE + \Delta PE + \Delta U = {}_1Q_2 - {}_1W_2$ Rate Form: $\dot{E} = \dot{Q} - \dot{W}$ Mixtures $X = \frac{M_{\text{mix}}}{M} = \frac{x - x_f}{x_g - x_f} \quad (x = v, u, h)$ $\beta = (1 - X)\beta_f + X \cdot \beta_g$	Ideal Gas $P\bar{v} = \bar{R}T, \bar{R} \text{ is universal}$ $Pv = RT, \text{ where } R = \frac{\bar{R}}{M}$ $P = \rho RT$ $PV = mRT$ $\bar{R} = \begin{cases} 0.314 \frac{\text{kJ}}{\text{kmol} \cdot \text{K}} \\ 1.906 \frac{\text{Btu}}{\text{lbmol} \cdot \text{R}} \\ 1545 \frac{\text{ft} \cdot \text{lbf}}{\text{lbmol} \cdot \text{R}} \end{cases}$	Polytropic Ideal Gas $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{V_1}{V_2}\right)^{n-1}$ ${}_1W_2 = \begin{cases} \frac{mR(T_2 - T_1)}{(1-n)}, n \neq 1 \\ mRT \ln\left(\frac{P_2}{P_1}\right), n = 1 \end{cases}$ Compressed Liquid Approx. $s(T, P) = s_f(T), s = (v, u, h, s)$	Polytropic Process $P \cdot V^n = c \text{ or } P \cdot v^n = c$ - Volume expansion work ${}_1W_2 = \begin{cases} \frac{(P_2 V_2 - P_1 V_1)}{(1-n)}, n \neq 1 \\ P_1 V_1 \ln\left(\frac{P_2}{P_1}\right), n = 1 \end{cases}$ Real gas $z = \frac{Pv}{RT}, \text{ where } z = \text{compressibility factor}$
Specific Heat (heat capacity) 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 $C_p = \frac{C_p(T_1) + C_p(T_2)}{2}$ $C_p = C_v + R$	Enthalpy $H = U + P \cdot V$ $h = u + P \cdot v$	Energy Conservation $\frac{dE_{\text{cv}}}{dt} = \dot{Q}_{\text{cv}} - \dot{W}_{\text{cv}} + \sum_i \dot{m}_i \left(h_i + \frac{1}{2} V_i ^2 + g \cdot z_i \right) - \sum_e \dot{m}_e \left(h_e + \frac{1}{2} V_e ^2 + g \cdot z_e \right)$ 1 Inlet, 1 Exit: $0 = \dot{Q}_{\text{cv}} - \dot{W}_{\text{cv}} + \dot{m} \left[(h_i - h_e) + \frac{1}{2} (V_i ^2 - V_e ^2) + g(z_i - z_e) \right]$		
Mass Conservation $\frac{dM_{\text{cv}}}{dt} = \sum \dot{m}_i - \sum \dot{m}_e$ $\dot{m} = \rho A V = \frac{\rho Q}{v}$ Volumetric flow rate = $A V $ Flow work = $(P \cdot A) \cdot V $	Entropy $dS = \left(\frac{\delta Q}{T}\right)_{\text{rev}}, S = s \cdot m$ $S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b$ $T \cdot ds = du + P \cdot dv$ $T \cdot ds = dh - v \cdot dP$ Rev: ${}_1Q_2 = \int_1^2 T ds = mT(s_2 - s_1)$	Entropy Balance (Cycle) $\frac{dS_{\text{cv}}}{dt} = \sum \frac{\dot{Q}}{T} + \sum \dot{m}_i \cdot s_i - \sum \dot{m}_e \cdot s_e + \dot{s}_{\text{cv}}$ 1 in, 1 out: $0 = \sum \frac{\dot{Q}}{T} + \dot{m}(s_1 - s_2) + \dot{s}_{\text{cv}}$ $\Delta s = s_2 - s_1 = \frac{1}{m} (\sum \frac{\dot{Q}}{T} + \dot{s}_{\text{cv}})$	Entropy and Ideal Gas $\Delta s = s(T_2, P_2) - s(T_1, P_1) = \int_{T_1}^{T_2} \frac{C_p(T)}{T} dt + R \cdot \ln\left(\frac{P_2}{P_1}\right)$ $\Delta s = s(T_2, P_2) - s(T_2, P_1) = \int_{P_1}^{P_2} \frac{C_p(T)}{P} dP - R \cdot \ln\left(\frac{P_2}{P_1}\right)$ $\Delta s = s^*(T_2) - s^*(T_1) - R \cdot \ln\left(\frac{P_2}{P_1}\right)$	
Work and Power $W = \int F \cdot dr$ - Volume expansion work: $W = \int P dV$ $W = m \cdot \int P dv$ $\text{Power} = \frac{dW}{dt}$	Isentropic Efficiency Turbine: $\eta_1 = \frac{(h_1/m)_{\text{out}}}{(h_1/m)_{\text{in}}} = \frac{h_1 - h_{2s}}{h_1 - h_2} \leq 1$ Nozzle: $\eta_n = \frac{\frac{1}{2} m V_2^2}{\frac{1}{2} m (V_2^2)_{\text{is}}} \leq 1$ Compressor/Pump: $\eta_{c/p} = \frac{(h_1/m)_{\text{in}}}{(h_1/m)_{\text{out}}} \leq 1$	2nd Law and Cycle COP's $COP_{\text{refrigerator}} < COP_{\text{ref}} = COP_{\text{max}}$ $COP_{\text{refrigerator}} = COP_{\text{refrigerator}}$ 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: $\beta_{\text{ref}} = \frac{Q_{\text{in}}}{W} = \frac{Q_{\text{in}}}{Q_{\text{in}} - Q_{\text{out}}} = \frac{T_c}{T_h - T_c}$ Heat Pump: $\gamma_{\text{hp}} = \frac{Q_{\text{out}}}{W} = \frac{Q_{\text{out}}}{Q_{\text{out}} - Q_{\text{in}}} = \frac{T_h}{T_h - T_c}$		
Velocity² to kJ/kg $\frac{\text{m}^2}{\text{s}^2} \cdot \frac{\text{N} \cdot \text{s}^2}{\text{kg} \cdot \text{m}} \cdot \frac{1}{\text{N} \cdot \text{m}} \cdot \frac{\text{kJ}}{10^3 \text{ J}}$		Entropy Balance (Process) $S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b + \sigma$ $S_2 - S_1 = \sum \frac{\dot{Q}}{T} + \sigma$ $\frac{dS}{dt} = \sum \frac{\dot{Q}}{T} + \dot{\sigma}$	Energy $KE = \frac{1}{2} m v^2 \quad PE = m g z$	
			1st Law and Cycles Power: $Q_H - Q_C = W_{\text{cycle}}$ R+HP: $Q_{\text{out}} - Q_{\text{in}} = W_{\text{cycle}}$	

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Vladimir Karapetoff



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