ChE 243: Formula and Data Sheets

Property Relations

$V = m\,v$ (m^3) ; $U = m\,u$ (kJ) ; $H = m\,h$ (kJ) ; $S = m\,s$ (kJ/K)   [Note: V = volume]

$H \equiv U + PV$ (kJ) $\Rightarrow$ $h = u + Pv$ (kJ/kg)

$\mathrm{PE} = mgz$ (kJ) ; $\mathrm{pe} = gz$ (kJ/kg)

$\mathrm{KE} = \dfrac{1}{2} m \cdot \mathrm{vel}^2$ (kJ) ; $\mathrm{ke} = \dfrac{1}{2}\,\mathrm{vel}^2$ (kJ/kg)   [Note: vel = velocity]

$$c_v = \left(\frac{\partial u}{\partial T}\right)_v \ (\mathrm{kJ/kg\cdot K}) \ ; \quad c_P = \left(\frac{\partial h}{\partial T}\right)_P \ (\mathrm{kJ/kg\cdot K})$$

Saturated mixtures: $v_{\mathrm{mix}} = v_f + x(v_g - v_f)$; $u_{\mathrm{mix}} = u_f + x(u_g - u_f)$

$h_{\mathrm{mix}} = h_f + x(h_g - h_f)$; $s_{\mathrm{mix}} = s_f + x(s_g - s_f)$

Incompressible substances (i.e. solids and liquids): $c_v \approx c_P \equiv c$; $\Delta u \approx \Delta h \approx c\,\Delta T$

Ideal gases: $Pv = RT$; $c_{P0} = c_{v0} + R$ [Note: subscript "0" implies ideal gas]

$$\Delta u = \int_1^2 c_{v0}\,\mathrm{d}T \approx c_{v0}\,(T_2 - T_1) \ ; \quad \Delta h = \int_1^2 c_{P0}\,\mathrm{d}T \approx c_{P0}\,(T_2 - T_1)$$

First Law Relations

Closed system (control mass):

$$Q - W = m\left[\left(u_2 + \frac{1}{2}\,\mathrm{vel}_2^{\,2} + gz_2\right) - \left(u_1 + \frac{1}{2}\,\mathrm{vel}_1^{\,2} + gz_1\right)\right] \ ; \quad W = \int_1^2 P\,\mathrm{d}V \ \text{ for boundary work}$$

Open system (control volume or CV):

Steady flow

$$\dot{Q}_{\mathrm{CV}} - \dot{W}_{\mathrm{CV}} = \sum_{\text{exits}} \dot{m}_e\left(h_e + \frac{1}{2}\,\mathrm{vel}_e^{\,2} + gz_e\right) - \sum_{\text{inlets}} \dot{m}_i\left(h_i + \frac{1}{2}\,\mathrm{vel}_i^{\,2} + gz_i\right), \ \text{ where } \ \dot{m} = \frac{\mathrm{vel}\cdot A}{v}$$

For single stream steady flow, with $\dot{m}_e = \dot{m}_i \equiv \dot{m}$, define $q \equiv \dot{Q}/\dot{m}$; $w \equiv \dot{W}/\dot{m}$

$$\Rightarrow \quad q - w = \left(h_e + \frac{1}{2}\,\mathrm{vel}_e^{\,2} + gz_e\right) - \left(h_i + \frac{1}{2}\,\mathrm{vel}_i^{\,2} + gz_i\right)$$

Transient process (conditions uniform within CV & constant at inlets/exits; neglect changes in PE & KE)

$$Q_{\mathrm{CV}} - W_{\mathrm{CV}} = \sum_{\text{exits}} m_e h_e - \sum_{\text{inlets}} m_i h_i + (m_2 u_2 - m_1 u_1)_{\mathrm{CV}}$$

Second Law Relations (T in kelvin)

$$dS \equiv \frac{\delta Q_{\text{rev}}}{T} \quad \Rightarrow \quad Q_{\text{rev}} = \int_1^2 T\, dS$$

$$\Delta S_{\text{tot}} = \Delta S_{\text{system}} + \Delta S_{\text{surr}} = S_{\text{gen}} \geq 0$$

Incompressible substances (i.e. solids and liquids) with constant specific heats: $\Delta s = c \ln(T_2/T_1)$

Ideal gases (with constant specific heats):

$$\Delta s = \begin{cases} c_{v0} \ln(T_2/T_1) + R \ln(v_2/v_1) \\ c_{P0} \ln(T_2/T_1) - R \ln(P_2/P_1) \end{cases}$$

$$\Delta s = 0 \quad \Rightarrow \quad P_1 v_1^k = P_2 v_2^k \; ; \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} \; ; \quad \frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1} \; ; \quad \text{where } k = c_{P0}/c_{v0}$$

Closed system (control mass):

$$\Delta S = \sum \frac{Q}{T} + S_{\text{gen}} \; ; \quad S_{\text{gen}} \geq 0$$

Open system (control volume or CV):

Steady flow

$$\frac{\dot{Q}_{\text{CV}}}{T} + \dot{S}_{\text{gen}} = \sum_{\text{exits}} \dot{m}_e s_e - \sum_{\text{inlets}} \dot{m}_i s_i \; ; \quad \dot{S}_{\text{gen}} \geq 0$$

Transient process (conditions uniform within CV and constant at inlets/exits)

$$\frac{Q_{\text{CV}}}{T} + S_{\text{gen}} = \sum_{\text{exits}} m_e s_e - \sum_{\text{inlets}} m_i s_i + (m_2 s_2 - m_1 s_1)_{\text{CV}} \; ; \quad S_{\text{gen}} \geq 0$$

Power and refrigeration devices:

$$\eta_{\text{th}} \equiv \frac{W_{\text{net,out}}}{Q_{\text{H}}} = \frac{Q_{\text{H}} - Q_{\text{L}}}{Q_{\text{H}}} \; ; \quad \text{COP}_{\text{Re}} \equiv \frac{Q_{\text{L}}}{W_{\text{net,in}}} = \frac{Q_{\text{L}}}{Q_{\text{H}} - Q_{\text{L}}} \; ; \quad \text{COP}_{\text{HP}} \equiv \frac{Q_{\text{H}}}{W_{\text{net,in}}} = \frac{Q_{\text{H}}}{Q_{\text{H}} - Q_{\text{L}}}$$

$$\eta_{\text{th,Carnot}} = \frac{T_{\text{H}} - T_{\text{L}}}{T_{\text{H}}} \; ; \quad \text{COP}_{\text{Re,Carnot}} = \frac{T_{\text{L}}}{T_{\text{H}} - T_{\text{L}}} \; ; \quad \text{COP}_{\text{HP,Carnot}} = \frac{T_{\text{H}}}{T_{\text{H}} - T_{\text{L}}}$$

$$\eta_{\text{turbine}} \equiv \frac{w_{\text{actual}}}{w_s} = \frac{h_1 - h_{2,\text{actual}}}{h_1 - h_{2s}} \; ; \quad \eta_{\text{compressor}} \equiv \frac{w_s}{w_{\text{actual}}} = \frac{h_{2s} - h_1}{h_{2,\text{actual}} - h_1}$$

Incompressible steady flow: reversible work (neglecting changes in PE & KE) is $w_{\text{CV}} = -v \int_{\text{in}}^{\text{out}} dP$

Generalized Charts

$$T_R \equiv \frac{T}{T_{\text{cr}}} \; ; \quad P_R \equiv \frac{P}{P_{\text{cr}}}$$

$$Z \equiv \frac{Pv}{RT} \; ; \quad Z_h \equiv \frac{h^* - h}{RT_{\text{cr}}} \; ; \quad Z_s \equiv \frac{s^* - s}{R}$$

$$h_2 - h_1 = (h_2 - h_2^*) + (h_2^* - h_1^*) + (h_1^* - h_1) \; ; \qquad \Delta h^* = \int_1^2 c_{P0} \, \mathrm{d}T \; \approx \; c_{P0}(T_2 - T_1)$$

$$s_2 - s_1 = (s_2 - s_2^*) + (s_2^* - s_1^*) + (s_1^* - s_1) \; ; \qquad \Delta s^* = c_{P0} \ln(T_2/T_1) - R \ln(P_2/P_1)$$

Dimensions and Units

Dimension	Unit
length	metre (m)
mass	kilogram (kg)
amount	mole (mol)
temperature	kelvin (K)
time	second (s)

Dimension	Unit
force	newton (N)
pressure	pascal (Pa)
heat, work	joule (J)
power	watt (W)
volume	cubic metre (m^3)

Constants and Conversion Factors

$1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$

$1\ \text{J} = 1\ \text{N} \cdot \text{m}$

$1\ \text{W} = 1\ \text{J/s}$

$1\ \text{Pa} = 1\ \text{N/m}^2$

$1\ \text{m}^3 = 10^3\ \text{L} = 10^6\ \text{mL}$

$1\ \text{tonne} = 1000\ \text{kg}$

$1\ \text{bar} = 10^5\ \text{Pa} = 100\ \text{kPa}$

$1\ \text{atm} = 101.325\ \text{kPa}$

$1\ \text{psi} = 6.894\ 757\ \text{kPa}$

$R_\text{u} = 8.314\ 47\ \text{kJ/(kmol} \cdot \text{K)}$

$R = R_\text{u}/M$ (M = molar mass)

$g = 9.806\ 65\ \text{m/s}^2$

$0°\text{C} = 273.15\ \text{K}$

Linear interpolation

$$y = y_1 + \left(\frac{x - x_1}{x_2 - x_1}\right) \cdot (y_2 - y_1)$$

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