Formulas

$$\Delta s = c_p \ln\left(\frac{T_2}{T_1}\right) - R_{sp}\left(\frac{P_2}{P_1}\right)$$

Remove if solid or liquid

$$\Delta s = c_v \ln\left(\frac{T_2}{T_1}\right) + R_{sp}\left(\frac{v_1}{v_2}\right)$$

$$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = \left(\frac{v_1}{v_2}\right)^{k-1}$$

$$\left(\frac{P_2}{P_1}\right) = \left(\frac{v_1}{v_2}\right)^{k}$$

$P_x = \sqrt{P_1 P_2}$ → minimum compressor work

$$\Delta S = \frac{Q}{T_{reservoir}}$$

$c_p = mf_1 c_{p_1} + \ldots + mf_n c_{p_n} = \sum mf_i c_{p_i}$

$$COP = \eta_{th} = \frac{\text{Desired output}}{\text{Required input}}$$

Pumps:

$$\eta_p = \frac{v(P_2 - P_1)}{h_{2a} - h_1}$$

Nozzles:

$$h_1 - h_{2a} = \frac{V_{2a}^2}{2}$$

$$\eta_N = \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

$$w_{iso} = -R_{sp} T \ln\left(\frac{P_2}{P_1}\right)$$

$w_{rev} = -v(P_2 - P_1)$ → incompressible fluids

$Pv = R_{sp}T$

↳ 0.287 for air

$$h_a = c_p T + \omega h_g$$

$$\Delta h = c_p(T_2 - T_1) + \omega(h_{g_2} - h_{g_1})$$

$\omega = \dfrac{m_a}{m_w}$ $\quad P_v = \phi P_g = \phi P_{sat@T}$ $\quad T_{dp} = T_{sat@P_v}$

Adiabatic mixing of airstreams:

$$\frac{\dot{m}_{a1}}{\dot{m}_{a2}} = \frac{h_2 - h_3}{h_3 - h_1} = \frac{\omega_2 - \omega_3}{\omega_3 - \omega_1}$$

$$R_{wall} = \frac{L}{kA}$$

$$R_{cylinder} = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi k l}$$

$$R_{conv} = \frac{1}{h_{conv} A_s}$$ → exposed surface area

$$h_r = \varepsilon \sigma (T_h^2 + T_c^2)(T_h + T_c)$$

$$R_{rad} = \frac{1}{h_r A_s}$$

$$Q = \frac{T_2 - T_1}{R}$$

$$L_c = \frac{V}{A_s}$$

$$Bi = \frac{hL_c}{k}$$ $Bi \leq 0.1$ for lumped system to be valid

$$\tau = \frac{\rho V c}{h A_s} = \frac{\rho c L_c}{h}$$

$$t = -\tau \ln\left[\frac{T - T_\infty}{T_i - T_\infty}\right]$$

$$\dot{m} = \rho \dot{V} = \rho v A$$

$$\dot{Q} = \dot{m} c_p (T_2 - T_1)$$

$$\dot{Q} = \dot{q} A_s$$

$$\dot{Q}_{conv} = h A_s (T_s - T_\infty)$$

$$\dot{Q}_{rad} = \sigma \varepsilon A_s (T_s^4 - T_{surr}^4), \quad \sigma = 5.67 \times 10^{-8}\, W m^{-2} K^{-4}$$

External forced convection

$T_f = \frac{1}{2}(T_s + T_\infty) \rightarrow$ Film temperature

$Re_x = \frac{\rho U_\infty x}{\mu} = \frac{U_\infty x}{\nu} \rightarrow$ Reynold's number for flat plates

$Re < 5 \times 10^5$ for laminar flow in exposed flat plates

$5 \times 10^5 \leq Re \leq 10^7$ for turbulent flow in exposed flat plates

$Re = \frac{\rho U_\infty D}{\mu} = \frac{U_\infty D}{\nu} \rightarrow$ Reynold's number for flow past objects

$Re < 2 \times 10^5$ for laminar flow past objects

$Re > 2 \times 10^6$ for turbulent flow past objects

$Nu_x = \frac{h_x k}{x} \rightarrow$ Nusselt number

$$h_x = \frac{Nu_x x}{k}$$

$$\bar{h}_L = \frac{1}{L}\left(\int_0^{x_{cr}} h_{x,\text{laminar}}\, dx + \int_{x_{cr}}^{L} h_{x,\text{turbulent}}\, dx\right)$$

$$\overline{Nu}_L = \frac{\bar{h}_L L}{k}$$

$$\bar{C}_f = \frac{1}{L}\left(\int_0^{x_{cr}} C_{f,x,\text{laminar}}\, dx + \int_{x_{cr}}^{L} C_{f,x,\text{turbulent}}\, dx\right)$$

$F_D = \frac{1}{2}\bar{C}_f \rho V^2 A \rightarrow$ Convective drag force

Internal forced convection

$T_b = \frac{1}{2}(T_{m,o} + T_{m,i}) \rightarrow$ Bulk fluid temperature

$\dot{Q} = \dot{q}A \rightarrow$ Heat flow rate for constant heat flux

$\Delta T_{ln} = \frac{\Delta T_2 - \Delta T_1}{\ln\Delta T_2 - \ln\Delta T_1} \rightarrow$ Log mean temperature difference

$\dot{Q} = \dot{m}c_p \Delta T_{ln} \rightarrow$ Heat flow rate for constant surface temperature

$D_h = \frac{4A_c}{p} \rightarrow$ hydraulic diameter

$D_h = D$ for circular pipes

$D_h = a$ for square ducts

$Re_x = \frac{\rho V_{avg} D_h}{\mu} = \frac{V_{avg} D_h}{\nu} \rightarrow$ Reynold's number

$Re < 2300$ for laminar flow in pipes

$Re > 2300$ for turbulent flow in pipes

when $x > 10D_h$, flow can be assumed to be fully developed

$NTU = \frac{h_L A_s}{\dot{m}c_p}$

Radiation

$A_i F_{i\to j} = A_j F_{j\to i}$ → Reciprocity rule

$F_{1\to 1} + F_{1\to 2} + F_{1\to 3} + \dots + F_{1\to N} = \sum_{j=1}^{N} F_{i\to j} = 1$ → Summation rule

$F_{i\to j} = F_{i\to j1} + F_{i\to j2} + \dots + F_{1\to jN}$ ⇒ Superposition rule

$F_{i\to j} = F_{i\to k}$ → Symmetry rule

$\dot{Q}_{i\to j} = A_i F_{i\to j} \sigma (T_i^4 - T_j^4)$, $\sigma = 5.67 \times 10^{-8}\, Wm^{-2}K^{-4}$