Heat Transfer Relationships

Conduction, Convection and Radiation Laws of Heat Transfer

Fourier's Law of Conduction
$\dot{Q} = -k\ \nabla T A$

Newton's Law of Cooling
$\dot{Q} = hA(T_{\text{wall}} - T_{\text{fluid}})$

Stefan-Boltzmann Law of Radiation for Black Bodies
$\dot{Q} = \sigma A_1 (T_1^4 - T_2^4)$

Thermal Resistances

Thermal resistance is defined as $R \equiv \dfrac{(T_1 - T_2)}{\dot{Q}}$. The units are $\frac{K}{W}$.

Conduction Resistances

Plane wall: $R = \dfrac{L}{kA}$

Cylindrical shell: $R = \dfrac{\ln(b/a)}{2\pi Lk}$

Spherical shell: $R = (1/a - 1/b)/(4\pi k)$

Fins: $R = 1/\left[\sqrt{hPkA}\ \tanh(mL)\right], \qquad m = \sqrt{\dfrac{hP}{kA}}$

Fluid or Film Resistance

$R = \dfrac{1}{hA}$

Radiation Resistances

Grey Surface Resistance: $R = \dfrac{(1-\epsilon)}{A\epsilon}$

Spatial Resistance: $R = \dfrac{1}{A_1 F_{12}} = \dfrac{1}{A_2 F_{21}}$

Notes: Units of radiation resistances are $1/m^2$. F_{12} is the view factor between two surfaces: A_1 and A_2 is dimensionless and its range is $0 \leq F_{12} \leq 1$. The surface emissivity ϵ is a complex radiation parameter which is determined experimentally for real (grey) surfaces. It is dimensionless and its range is $0 \leq \epsilon \leq 1$. Smooth, highly polished metals such as aluminum have values as low as $\epsilon \approx 0.01 - 0.1$. Very rough, oxidized surfaces have values as high as $\epsilon \approx 0.8 - 0.95$. Black bodies are ideal bodies for which $\epsilon = 1$.

The total radiation resistance of a two surface enclosure which is bounded by two isothermal, grey surfaces is given by:

$$R_{\text{total}} = \frac{(1-\epsilon_1)}{A_1\epsilon_1} + \frac{1}{A_1 F_{12}} + \frac{(1-\epsilon_2)}{A_2\epsilon_2}$$

The radiation heat transfer rate between the two surfaces is given by

$$\dot{Q} = \frac{(e_{b1} - e_{b2})}{R_{\text{total}}} = \frac{\sigma(T_1^4 - T_2^4)}{R_{\text{total}}}$$