Heat Transfer Overview

Conduction

- Energy transfer from more to less energetic particles due to particle interactions – diffusion of energy due to molecular activity
  - Examples
  - Usually involves solids
  - Rate = f( )
  - What is the driving potential?

Fourier's Law of Heat Conduction

$q_x = -kA\frac{dT}{dx}$ Total heat transfer in x direction

$q_x^{"} = \frac{q_x}{A} = -k\frac{dT}{dx}$ Heat transfer per unit area in x direction

k=thermal conductivity (W/m°C or Btu/h ft °F)

-- a measure of how fast heat flows through a material

-- k(T), but we usually use the value at the average temperature

q can have x, y, and z components; it's a vector quantity

Special Case

- If T(x) is linear, Fourier's Law for the 1-D case becomes

$$q_x^{"} = -k\frac{\Delta T}{\Delta x} - k\frac{T_2 - T_1}{x_2 - x_1} = -k\frac{T_2 - T_1}{L}$$

- When will this happen?
- Example

Conduction Definitions

- Heat capacity = ρc_p (J/m^3°C)
  - Amount of heat needed to raise a unit volume of material one degree
- Thermal diffusivity = $\alpha = k/\rho c_p$ (m^2/s)
  - How fast heat diffuses through a material

Convection

- Energy transfer due to both
  - molecular motion (diffusion, like conduction) and
  - bulk motion of fluid (motion of gas or liquid)
    - Advection
- Convection=diffusion+advection
- Three kinds
  - Forced convection – external fluid motion
  - Natural (free) convection – motion due to buoyancy effects
  - Latent heat exchange – due to phase change – condensation, boiling (covered in ME 211 but not ME 114)

Newton's Law of Cooling

$$q = hA(T_s - T_\infty)$$

$$q'' = h(T_s - T_\infty)$$

- h=heat transfer coefficient (W/m²°C)
- T_s=solid surface temperature
- T_∞ =temperature of fluid far from surface
- h=f( )

Boundary Layer

Example

- A 0.4 cm x 2 cm computer chip must dissipate 5 W of heat. Air with a heat transfer coefficient of 80 W/m²K and a temperature of 20°C blows over the chip. The chip is in danger of overheating if it reaches 90°C. Is the chip in danger? Should you attach a heat sink?

Thermal Radiation

- Emitted by all matter above 0 Kelvin
- Due to changes in electron configurations
- Requires no medium
- Emissive power of a blackbody (ideal radiator)

$$E_b = \sigma T_s^4$$

  - T_s=surface temp in Kelvin
  - σ=Stefan-Boltzmann Constant 5.67×10^{-8} W/m²K⁴

Thermal Radiation, Cont.

- ε=emissivity: how efficiently a surface emits compared to a blackbody
- α=absorptivity: percent of incident flux absorbed
- ε,α =f(temp, wavelength, surface condition)

$$E = \varepsilon\sigma T_s^4 \qquad G_{absorbed} = \alpha G_{incident}$$

Thermal Radiation, cont.

- Special case: ε=α if surface temperatures of all surfaces in an enclosure are close
- Special case: surface completely surrounded by another isothermal surface, no intervening medium

$$q''_{rad} = emitted - absorbed = \varepsilon\sigma T_s^4 - \alpha\sigma T_{surr}^4$$

$$= \varepsilon\sigma\left(T_s^4 - T_{surr}^4\right) \neq \varepsilon\sigma\left(T_s - T_{surr}\right)^4$$

Total Heat Transfer

- Only conduction, convection, or radiation can occur or else a combination can occur simultaneously
- $Q_{conv}+Q_{rad}$ or $Q_{cond}+Q_{rad}$