1. Introduction

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1.1 Relation of heat transfer to thermodynamics

The First Law of Thermodynamics for a closed system takes the following form on a rate basis:

\[ Q = W_k + \frac{dU}{dt} \]

When the substance undergoing the process is incompressible:

\[ Q = \frac{dU}{dt} = m \cdot c \cdot \frac{dT}{dt} \]
1.2 Three principle modes of heat transfer

**Convection**: primarily in solids but also laminar flows

**Convection**: in liquids and gases

**Thermal radiation**: through vacuum, gases and liquids

Let the water be analogous to heat, and let the people be analogous to the heat transfer medium. Then:

- **Case 1**: The hose directs water from W to B independently of the medium. This is analogous to *thermal radiation*.
- **Case 2**: In the bucket brigade, water goes from W to B through the medium. This is analogous to *conduction*.
- **Case 3**: A single runner, representing the medium, carries water from W to B. This is analogous to *convection*. 
1.2 Three principle modes of heat transfer
1.2 Heat and mass transfer applications

Plays an important role in many industrial and environmental processes and problems.

- **Power generation** (boilers, condensers, cooling towers, ...)
- **Refrigeration** (air-conditioning, refrigeration, heat pumps, ...)
- **Motors** (cooling of pumps, compressors, engines, ...)
- **Turbomachinery** (cooling on blades, lubrication, ...)
- **Chemical processing** (heating and cooling, phase change, ...)
- **Electronics** (cooling of computer chips, avionics, ...)
- **Aerospace** (cooling of rocket engines, spacecraft, ...)
- **Food processing** (numerous processes)

**Heat exchangers**: device to transfer heat from one fluid to another.
1.3 Conduction

Conduction:

- Occurs at the molecular level: transfer of energy from more energetic particles to less energetic particles (i.e. from hotter to colder particles).
- Higher gas temperature is associated with higher molecular energy.
- There is random motion of molecules and molecules are very closely spaced.
- Energy transfer is via lattice waves induced by atomic motion.
- Also, energy transfer by the free electrons (if any; none in a nonelectrically conducting substances).

Empirical law: The heat flux, \( q(W/m^2) \), resulting from thermal conduction is proportional to the magnitude of the temperature gradient and opposite to it in sign. If we call the constant of proportionality, \( k \), then

\[
q = -k \frac{dT}{dx}
\]
1.3 Conduction

Heat transfer - Introduction
1.4 Convection

Convective heat transfer is conveyed by two modes

- Diffusion (random molecular motion)
- Bulk or Macroscopic motion

Energy transport is typically with superposition of these two modes.

\[ q = \overline{h} (T_{body} - T_\infty) \]
1.5 Radiation

All bodies constantly emit energy by a process of electromagnetic radiation. The intensity of such energy flux depends upon the temperature of the body and the nature of its surface.

The stefan-Boltzmann law: The flux of energy radiating from a body is commonly designated \( e(T) \, W/m^2 \).

\[
e(T) \equiv E(\infty, T) = \int_{0}^{\infty} e_\lambda(\lambda, T) \, d\lambda
\]

The Stefan-Boltzmann law is

\[
e_b(T) = \sigma T^4
\]

where the Stephan-Boltzmann constant, \( \sigma \), is \( 5.6704 \times 10^{-8} \, W/m^2K^4 \) and \( T \) is the absolute temperature.
The maximum emission rate is from an ideal surface called a black body that emits the maximum at all wavelengths. Another ideal surface is a grey body, which emits less radiant energy than a black body. It is characterized by its emissivity, $\epsilon$ ($0 \leq \epsilon \leq 1$), which qualifies how effect the grey body is relative to the black body ($\epsilon = 1$).