1. Introduction

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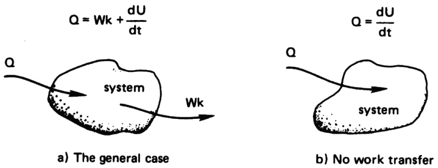
1.1 Relation of heat transfer to thermodynamics

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

$$Q = Wk + \frac{dU}{dt}$$



When the substance undergoing the process is incompressible :

$$Q = \frac{dU}{dt} = m\ c\ \frac{dT}{dt}$$

1.2 Three principle modes of heat transfer

Convection : primarily in solids but also laminar flows

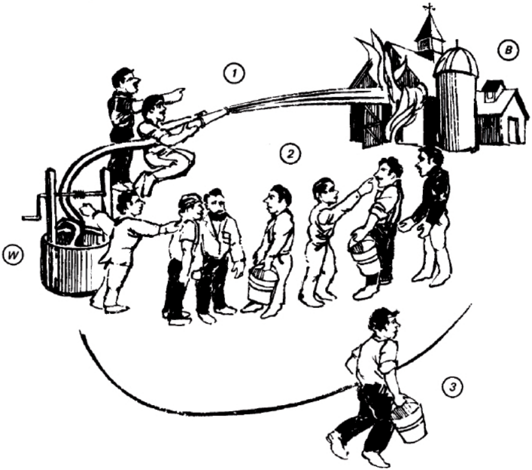
Convection : in liquids and gases

Thermal radiation : through vacuum, gases and liquids

Let the water be analogous to heat, and let the people be analogous to the heat tranfer 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, lubrification, ...)
- 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.

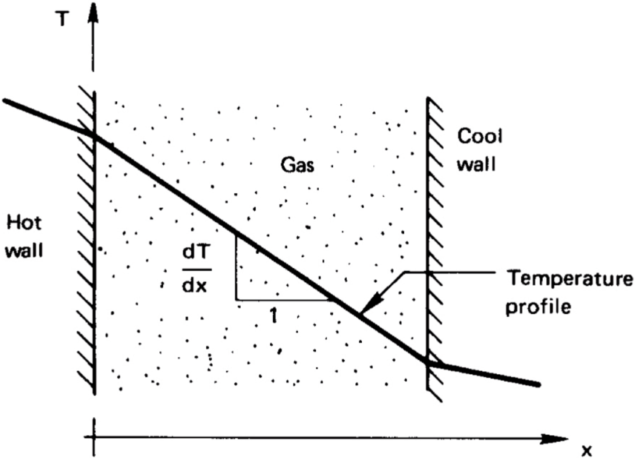
1.3 Conduction

Conduction :

- Occurs at the molecular level : transfer of energy from more energetic particles to less energetic particles (i.e. from hotter to colded 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

$$q = -k\frac{dT}{dx}$$


T
Gas
Cool
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Hot
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dT
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Temperature
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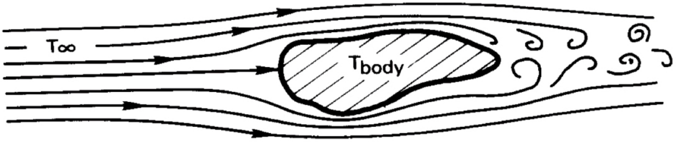
1.4 Convection

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.



$$q = \overline{h}\left(T_{body} - T_{\infty}\right)$$

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, σ , is $5.6704 \cdot 10^{-8}\ W/m^2K^4$ and T is the absolute temperature.

1.5 Radiation

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, ϵ $(0 \leq \epsilon \leq 1)$, which qualifies how effect the grey body is relative to the black body $(\epsilon = 1)$.