6. Heat Transfer & Refrigeration

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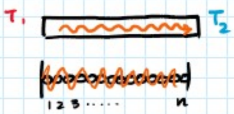
Heat → energy in transit
- → effect quantified by temperature
- → transfer of heat energy occurs when there is a difference in temperature

MODES OF HEAT TRANSFER

Conduction

- Medium: solid



- Vibration in place transfers heat
- No movement of molecules

= FOURIER'S LAW =

Rate of heat flow by conduction in a given direction

$\propto$

Area normal to direction of heat flow AND gradient of temp. in that direction

$$Q \propto A \frac{dt}{dx}$$

$$\boxed{Q = -\underbrace{k}_{\text{thermal conductivity of material}} A \frac{dt}{dx}}$$

thermal conductivity of material
- only depends on material
- max value: 2300 W/mK (diamond)

$$\boxed{\underbrace{q}_{\text{heat flux}} = \frac{Q}{A} = -k\frac{dt}{dx}}$$

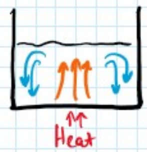
For a plane slab in steady state:

$$Q = -kA\frac{(T_2 - T_1)}{L} \quad [W]$$

$$q = -k\frac{(T_2 - T_1)}{L} \quad [W/m^2]$$

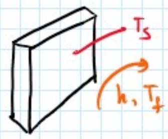
Convection

- Medium: Fluids



- Continuous movement of molecules
- Two types:
  - → Natural: movement w/o external agents
  - → Forced: movement w/ external agents

= NEWTON'S LAW OF COOLING =



$$Q = hA(T_s - T_f) \quad [W]$$

$$q = h(T_s - T_f) \quad [W/m^2]$$

Q: rate of heat transfer from solid to liquid

h: convective heat transfer coefficient

Radiation

- Medium: NONE
- All objects above 0 K temperature emit radiation in the form of EM waves
  ↓
  Maxwell's wave theory
- Radiation w/ $\lambda \in [0.1\mu m, 100\mu m]$
  ↓
  thermal radiation
  (converted to heat when absorbed)

= STEFAN-BOLTZMANN LAW =

$$\boxed{E_b = \sigma T^4 \quad [W/m^2]}$$

- T → temp. in K
- σ → Stefan-Boltzmann constant $5.6697 \times 10^{-8}\ W/(m^2K^4)$
- E_b → black body emissive power

Note: Above defines emissive power of a blackbody (ideal emitter, absorber)

But what if we want radiation from a real body?

$$\boxed{E = \varepsilon E_b = \varepsilon \sigma T^4 \quad [W/m^2]}$$

ε → emissivity $\in [0,1]$
↓
depends on material, surface finish, temp., λ of radiation

What about absorption of a real body?

$$\boxed{q_{abs} = \alpha\, q_{inc} \quad [W/m^2]}$$

- q_{abs} → absorbed energy
- q_{inc} → incident energy
- α → absorptivity $\in [0,1]$

$$q = \frac{-k(T_2 - T_1)}{L} \quad [W/m^2]$$

absorbed energy

incident energy

absorptivity $\in [0,1]$

k values

Cast iron

copper

silver

water

air

ice

aluminium

highest/lowest

NUMERICALS

① Asbestos layer of 10 mm thickness ($k = 0.116$ W/mK) is used as insulation over a boiler wall. Consider an area of 0.5 m^2 and find out the rate of heat flow as well as the heat flux over this area if the temperatures on either side of this insulation are 300°C and 30°C.

Soln $L = 10\text{ mm} = 0.01\text{ m}$

$k = 0.116$ W/mK

$A = 0.5\, m^2$

$T_1 = 300°C$, $T_2 = 30°C$

$$Q = \frac{-kA(T_1 - T_2)}{L} = 1566 \text{ W}$$

$$q = \frac{Q}{A} = 3132 \text{ W/m}^2$$