Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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Fourier's Law

- Course: Heat and Mass Transfer (DI05019071)
- Unit 1: Conduction
- Lecture 1: Fourier's Law

Lecture Agenda

- 1. Introduction to Heat Transfer
- 2. Modes of Heat Transfer
- 3. Introduction to Conduction
- 4. Fourier's Law of Heat Conduction
- 5. Assumptions of Fourier's Law
- 6. Concept of Temperature Gradient

What is Heat Transfer?

- Heat Transfer is the science that deals with the rate of exchange of thermal energy between physical systems.
- Driving Force: Temperature Difference.
- Thermodynamics vs. Heat Transfer:
- - Thermodynamics deals with the amount of heat transferred and equilibrium states.
- - Heat Transfer deals with the rate of heat transfer and non-equilibrium phenomena.

Modes of Heat Transfer

- Thermal energy can be transferred in three distinct modes:
- 1. Conduction: Transfer of energy from more energetic particles to adjacent less energetic ones (requires a medium).
- 2. Convection: Transfer of energy between a solid surface and the adjacent fluid that is in motion.
- 3. Radiation: Transfer of energy due to the emission of electromagnetic waves (no medium required).

Focus on Conduction

- Conduction occurs in solids, liquids, and gases.
- In Gases and Liquids: Due to collisions and diffusion of molecules during their random motion.
- In Solids: Due to the combination of lattice vibrations of molecules and energy transport by free electrons.

Fourier's Law of Heat Conduction

- The fundamental law governing heat conduction is Fourier's Law, proposed by Joseph Fourier in 1822.
- Statement: The rate of heat conduction is proportional to the area measured normal to the direction of heat flow, and to the temperature gradient in that direction.

Mathematical Formulation

- Mathematically, Fourier's Law is expressed as:
- $$QnproptoAnfracdTdx$$
- $$Q = -kAnfracdTdx$$
- Where:
- - Q: Rate of heat transfer (W)
- - A: Cross-sectional area (m^2)
- - dT/dx: Temperature gradient (K/m or °C/m)
- - k: Thermal conductivity (W/m·K)

The Negative Sign in Fourier's Law

- Why is there a negative sign in $Q = -kA\frac{dT}{dx}$?
- - Heat always flows in the direction of decreasing temperature (from hot to cold).
- - Therefore, the temperature gradient dT/dx is inherently negative in the direction of positive heat flow (x).
- - The negative sign is inserted to make the heat transfer rate Q a positive quantity.

Assumptions of Fourier's Law

- Fourier's Law is based on several underlying assumptions:
- 1. Conduction of heat takes place under steady-state conditions.
- 2. The heat flow is unidirectional (1D).
- 3. The temperature gradient is constant, leading to a linear temperature profile.
- 4. There is no internal heat generation within the body.
- 5. The bounding surfaces are isothermal.

Temperature Gradient

- Temperature Gradient (dT/dx): The rate of change of temperature with respect to distance.
- For a plane wall of thickness L and surface temperatures T_1 and T_2:
- $$nfracdTdx = nfracT\_2 - T\_1L$$
- Since $T_1 > T_2$, dT/dx is negative.

Applications of Fourier's Law

- Fourier's Law is used to calculate:
- - Heat loss through building walls and roofs.
- - Heat transfer across heat exchanger tubes.
- - Thermal insulation required for pipes and furnaces.
- - Cooling rates of electronic components.

Summary

- Heat transfer is driven by temperature differences.
- Conduction is the transfer of heat through a stationary medium.
- Fourier's Law dictates that $Q = -kA(dT/dx)$.
- The negative sign ensures Q is positive as heat flows down the temperature gradient.

Next Lecture Preview

- Topic: Thermal Conductivity and Thermal Resistance
- Key questions to ponder:
- - What physical properties determine the value of 'k'?
- - How does temperature affect thermal conductivity?
- - Can we analyze heat transfer using electrical circuit concepts?