Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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Newton's law of cooling

- Course: Heat and Mass Transfer (DI05019071)
- Unit 2: Convection
- Lecture 16: Newton's Law of Cooling

Lecture Agenda

- 1. Introduction to Convection
- 2. Mechanism of Convective Heat Transfer
- 3. Types of Convection
- 4. Newton's Law of Cooling
- 5. Convection Heat Transfer Coefficient
- 6. Factors Affecting the Heat Transfer Coefficient

Introduction to Convection

- Convection is the mode of heat transfer between a solid surface and the adjacent liquid or gas that is in motion.
- It involves the combined effects of:
- 1. Conduction (at the surface)
- 2. Fluid motion (macroscopic movement of fluid parcels)
- Without fluid motion, heat transfer between a solid surface and an adjacent fluid is purely by conduction.

Mechanism of Convection

- Near the solid surface, fluid velocity is zero (no-slip condition).
- Heat is first transferred to this stationary fluid layer by conduction.
- This heat is then carried away by the macroscopic motion of the fluid away from the surface.
- Therefore, convection is essentially conduction combined with fluid advection.

Types of Convection

- Convection is broadly classified based on how the fluid motion is initiated:
- 1. Forced Convection: Fluid is forced to flow over the surface by external means (pump, fan, wind).
- 2. Free (Natural) Convection: Fluid motion is caused by buoyancy forces due to density differences induced by temperature gradients.

Newton's Law of Cooling

- Governs the rate of convection heat transfer.
- Statement: The rate of heat transfer is directly proportional to the surface area and the temperature difference between the surface and the fluid.
- Equation: q = h * A * (T_s - T_\infty)
- Where:
- - q: Rate of heat transfer (W)
- - h: Convection heat transfer coefficient (W/m^2K)
- - A: Surface area (m^2)

Understanding the Equation

- Equation details: q = h * A * (T_s - T_\infty)
- T_s: Temperature of the surface.
- T_\infty: Temperature of the fluid sufficiently far from the surface (free-stream temperature).
- The direction of heat transfer depends on which temperature is higher. If T_s ¿ T_\infty, heat flows from the surface to the fluid.

Convection Heat Transfer Coefficient (h)

- It is not a property of the fluid.
- It is an experimentally determined parameter whose value depends on all the variables influencing convection.
- Units: Watts per square meter Kelvin ($W/m^2{\cdot}K$) or $W/m^2{\cdot}^\circ C$.
- It characterizes how effectively heat is transferred by convection.

Factors Affecting 'h'

- The convection heat transfer coefficient depends heavily on:
- 1. Fluid properties (dynamic viscosity, thermal conductivity, density, specific heat).
- 2. Surface geometry (flat plate, cylinder, sphere).
- 3. Surface roughness.
- 4. Fluid velocity (flow type: laminar vs. turbulent).

Typical Values of 'h'

- Free Convection (Gases): 2 - 25 W/m^2·K
- Free Convection (Liquids): 50 - 1,000 W/m^2·K
- Forced Convection (Gases): 25 - 250 W/m^2·K
- Forced Convection (Liquids): 50 - 20,000 W/m^2·K
- Boiling and Condensation: 2,500 - 100,000 W/m^2·K

Comparison: Conduction vs. Convection

- Conduction:
- - Mechanism: Molecular vibration/electron drift.
- - Medium: Solid (mostly), stationary fluid.
- - Law: Fourier's Law ($q = -kA(dT/dx)$).
- Convection:
- - Mechanism: Macroscopic fluid motion + conduction.
- - Medium: Moving fluid.
- - Law: Newton's Law of Cooling ($q = hA(\Delta T)$).

Summary

- Convection combines conduction with fluid motion.
- Newton's Law of Cooling is q = h * A * (T_s - T_\infty).
- The convection heat transfer coefficient 'h' is an empirical parameter, not a material property.
- 'h' depends on fluid properties, flow conditions, and surface geometry.

Next Lecture Preview

- Topic: Concept of forced and free convection
- Key questions:
- - How do buoyancy forces create fluid motion in free convection?
- - When does forced convection transition from laminar to turbulent flow?