Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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Dimensionless Numbers in Convection

- Course: Heat and Mass Transfer (DI05019071)
- Unit 2: Convection
- Lecture 19: Dimensionless Numbers (Re, Pr, Nu)

Lecture Agenda

- 1. The Challenge of Finding 'h'
- 2. What is Dimensional Analysis?
- 3. Reynold's Number (Re): Definition & Significance
- 4. Prandtl Number (Pr): Definition & Significance
- 5. Nusselt Number (Nu): Definition & Significance
- 6. Empirical Correlations (Nu = f(Re, Pr))

The Challenge of Finding 'h'

- As we learned, 'h' depends on many variables:
- Fluid velocity (V), density (ρ), viscosity (μ), specific heat (Cp), thermal conductivity (k), and characteristic length (L).
- Mathematically: h = f(V, ρ, μ, Cp, k, L)
- Performing experiments by varying one parameter at a time while holding the others constant is practically impossible and very expensive.

Dimensional Analysis

- Dimensional analysis groups these many variables into a few dimensionless groups.
- Benefits:
- 1. Drastically reduces the number of variables (e.g., from 7 variables to 3 dimensionless groups).
- 2. Makes experimental data generalizable (scale models can be used to predict real-world behavior).
- Buckingham Pi Theorem is often used to derive these groups.

Reynold's Number (Re)

- Definition: Re = (ρ * V * L) / μ
- Where:
- - ρ = fluid density (kg/m^3)
- - V = fluid velocity (m/s)
- - L = characteristic length (m)
- - μ = dynamic viscosity (kg/m·s)

Significance of Reynold's Number

- Physical Significance: Re is the ratio of Inertia forces to Viscous forces.
- Re = (Inertia Forces) / (Viscous Forces)
- - High Re (Inertia dominates): Turbulent flow, chaotic mixing.
- - Low Re (Viscosity dominates): Laminar flow, smooth layers.
- Re is used to determine if a flow is laminar or turbulent.

Prandtl Number (Pr)

- Definition: Pr = (μ * Cp) / k = ν / α
- Where:
- - μ = dynamic viscosity, Cp = specific heat, k = thermal conductivity.
- - ν = kinematic viscosity (μ/ρ) = momentum diffusivity.
- - α = thermal diffusivity (k/(ρ*Cp)).

Significance of Prandtl Number

- Physical Significance: Pr is the ratio of Molecular Momentum Diffusivity to Thermal Diffusivity.
- Pr $= \nu$ / α
- It describes the relative thickness of the velocity boundary layer compared to the thermal boundary layer.
- - Liquid metals: Pr ¡¡ 1 (heat diffuses faster than momentum).
- - Gases: Pr $\approx$ 1 (similar boundary layers).
- - Oils: Pr ¿¿ 1 (momentum diffuses faster than heat).

Nusselt Number (Nu)

- Definition: Nu = (h * L) / k_fluid
- Where:
- - h = convection heat transfer coefficient.
- - L = characteristic length.
- - k_fluid = thermal conductivity of the fluid.

Significance of Nusselt Number

- Physical Significance: Nu is the ratio of Convection heat transfer to Conduction heat transfer in the fluid layer.
- Nu = (q_convection) / (q_conduction_if_fluid_was_stationary)
- Nu = 1 means heat transfer is purely by conduction.
- Higher Nu means more effective convection.
- Nu is the parameter we want to solve for to find 'h'.

Empirical Correlations

- Through dimensional analysis, we find that Nu is a function of Re and Pr for forced convection.
- General form: Nu = C * Re^m * Pr^n
- Engineers perform experiments to find the constants C, m, and n for different geometries (flat plate, pipe, sphere) and flow types (laminar, turbulent).
- Workflow: Calculate Re and Pr -¿ Use correlation to find Nu -¿ Calculate h from Nu.

Summary

- Dimensional analysis simplifies convection by grouping variables.
- Re (Inertia/Viscous) determines flow regime (laminar vs turbulent).
- Pr (Momentum diff/Thermal diff) is a fluid property relating boundary layers.
- Nu (Convection/Conduction) is the dimensionless heat transfer coefficient.
- Convection problems are solved using Nu $=$ f(Re, Pr) correlations.

Next Lecture Preview

- Topic: Boundary layer definition and characteristics
- Key questions:
- - What happens to the fluid exactly at the solid surface?
- - How do the velocity and thermal boundary layers develop?