Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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- Course: Heat and Mass Transfer (DI05019071)
- Unit 5: Mass Transfer
- Lecture 42: Concentrations, Velocities and Fluxes

Lecture Agenda

- 1. Mixture Composition
- 2. Mass Concentration (Density)
- 3. Molar Concentration
- 4. Mass and Mole Fractions
- 5. Mixture Velocities
- 6. Mass and Molar Fluxes

Mixture Composition: An Overview

- To describe mass transfer mathematically, we must quantify the composition of a mixture.
- A mixture consists of two or more chemical species (e.g., Species A, Species B, Species C, ...).
- The concentration of a species can be expressed in two primary ways:
- 1. On a mass basis (Mass Concentration)
- 2. On a molar basis (Molar Concentration)

Mass Concentration (Partial Density)

- Mass concentration (ρ_A) of species A is the mass of species A per unit volume of the mixture.
- ρ_A = m_A / V (Unit: kg/m^3)
- The total mass density (ρ) of the mixture is the sum of the mass concentrations of all species:
- $\rho = \rho$_A + ρ_B + ... + ρ_n = Σ(ρ_i)

Molar Concentration

- Molar concentration (C_A) of species A is the number of moles of species A per unit volume.
- $C_A = n_A / V$ (Unit: $kmol/m^3$ or mol/L)
- The total molar concentration (C) of the mixture is the sum of the molar concentrations of all species:
- $C = C_A + C_B + ... + C_n = \Sigma(C_i)$
- Relation between mass and molar concentration: $\rho_A = C_A * M_A$ (where M_A is molecular weight).

Mass and Mole Fractions

- Mass Fraction (m_A): The ratio of the mass concentration of species A to the total density.
- m_A = ρ_A / ρ (Note: Σ(m_i) = 1)
- Mole Fraction (x_A or y_A): The ratio of the molar concentration of species A to the total molar concentration.
- x_A = C_A / C (Note: Σ(x_i) = 1)
- Note: x_A is typically used for liquids/solids, y_A for gases.

Mixture Velocity

- In a moving mixture, each species may have its own absolute velocity (v_i).
- The overall velocity of the mixture can be defined in two ways:
- 1. Mass-average velocity (v)
- 2. Molar-average velocity (V)
- This is important because mass transfer involves movement relative to the bulk fluid motion.

Mass and Molar Average Velocities

- **Mass-Average Velocity (v)**:
- $v = \Sigma(\rho\_i * v\_i) / \rho$
- It is the velocity based on the momentum of the mixture.
- **Molar-Average Velocity (V)**:
- $V = \Sigma(C\_i * v\_i) / C$
- It is the velocity based on the molar flow of the mixture.

Concept of Diffusion Velocity

- The velocity of a species relative to the bulk mixture velocity is its **diffusion velocity**.
- Mass diffusion velocity of species A = (v_A - v)
- Molar diffusion velocity of species A = (v_A - V)
- Diffusion velocity tells us how fast a species is moving purely due to concentration gradients, independent of the bulk flow.

Mass and Molar Fluxes

- **Flux** is the amount of species transferred per unit area per unit time.
- **Absolute Mass Flux (n_A)** = $\rho_A * v_A$ ($kg/m^2 \cdot s$)
- **Mass Diffusion Flux (j_A)** = $\rho_A * (v_A - v)$
- **Absolute Molar Flux (N_A)** = $C_A * v_A$ ($kmol/m^2 \cdot s$)
- **Molar Diffusion Flux (J_A)** = $C_A * (v_A - V)$
- Relationship: $n_A = j_A + \rho_A * v$

Summary

- Concentration can be expressed by mass (ρ_A) or by moles (C_A).
- Mass fractions (m_A) and mole fractions (x_A) sum to 1.
- A mixture has a mass-average velocity and a molar-average velocity.
- Fluxes can be defined based on absolute velocity or diffusion velocity.
- Total flux = Diffusion flux + Convective (Bulk) flux.

Next Lecture Preview

- Topic: Fick's Law of Diffusion
- Key questions to ponder:
- - How is diffusion flux mathematically related to the concentration gradient?
- - What is the physical significance of the diffusion coefficient (diffusivity)?
- - How does Fick's Law compare to Fourier's Law of heat conduction?