Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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Equimolar Counter Diffusion & Convective Mass Transfer

- Course: Heat and Mass Transfer (DI05019071)
- Unit 5: Mass Transfer
- Lecture 45: Equimolar Counter Diffusion & Convective Mass Transfer

Lecture Agenda

- 1. What is Equimolar Counter Diffusion?
- 2. Derivation of Flux for Equimolar Counter Diffusion
- 3. Concentration Profile
- 4. Introduction to Convective Mass Transfer (Topic 5.6)
- 5. The Mass Transfer Coefficient
- 6. Dimensionless Numbers (Sh, Sc, Le)
- 7. Course Wrap-up

Equimolar Counter Diffusion: Concept

- Occurs in binary gas mixtures (A and B) where the molar fluxes of A and B are equal in magnitude but opposite in direction.
- Condition: N_A = - N_B
- Therefore, total molar flux N = N_A + N_B = 0.
- Physical example: Distillation processes, or two large tanks containing different ideal gases connected by a tube at constant pressure and temperature.

Governing Equation (Equimolar)

- Recall the total absolute molar flux equation:
- $N\_A = - D\_AB * (dC\_A / dx) + x\_A * (N\_A + N\_B)$
- Since $N\_A = -N\_B$, the bulk convective term $(N\_A + N\_B)$ is zero.
- Thus, $N\_A = - D\_AB * (dC\_A / dx)$
- Conclusion: In equimolar counter diffusion, the total absolute flux is exactly equal to the diffusion flux. The bulk mixture is strictly stationary (molar-average velocity $V = 0$).

Flux and Concentration Profile (Equimolar)

- Since N_A is constant (steady state), integrating Fick's law over length L gives:
- N_A = D_AB * (C_A1 - C_A2) / L
- For ideal gases, C_A = p_A / (Ru * T). Substituting this:
- N_A = D_AB * (p_A1 - p_A2) / (Ru * T * L)
- The concentration (and partial pressure) profile is linear across the diffusion path.

Convective Mass Transfer (Topic 5.6)

- When mass transfer occurs between a surface and a moving fluid, it involves both diffusion and bulk fluid motion.
- Analogous to convective heat transfer (Newton's Law of Cooling).
- The flow regime (laminar or turbulent) heavily influences the mass transfer rate.
- A concentration boundary layer develops over the surface.

The Mass Transfer Coefficient (h_m)

- Convective mass transfer rate is governed by an equation analogous to Newton's Law of Cooling.
- Rate equation: N_A = h_m * (C_A,surface - C_A,infinity)
- Where:
- - N_A = Molar convective flux (kmol/m^2·s)
- - h_m = Convective mass transfer coefficient (m/s)
- - C_A,surface = Concentration at the surface
- - C_A,infinity = Free stream concentration

Finding h_m: Dimensionless Numbers

- Like 'h' in heat transfer, 'h_m' is difficult to calculate analytically. We rely on empirical correlations using dimensionless numbers.
- In heat transfer, we used Nusselt (Nu) = f(Reynolds, Prandtl).
- In mass transfer, we use Sherwood (Sh) = f(Reynolds, Schmidt).

Sherwood and Schmidt Numbers

- **Sherwood Number (Sh)**: Ratio of convective mass transfer to mass diffusion.
- Sh = (h_m * L_c) / D_AB [Analogue to Nusselt Number]
- **Schmidt Number (Sc)**: Ratio of momentum diffusivity to mass diffusivity.
- Sc = ν / D_AB = μ / (ρ * D_AB) [Analogue to Prandtl Number]
- Typical Correlation: Sh = C * Re^m * Sc^n

The Lewis Number (Le)

- **Lewis Number (Le)**: Links heat and mass transfer. It is the ratio of thermal diffusivity to mass diffusivity.
- Le = α / D_AB = Sc / Pr
- Significance:
- - If Le = 1, thermal and concentration boundary layers grow at the exact same rate.
- - For many gas mixtures (like water vapor in air), Le is approximately 1, simplifying simultaneous heat and mass transfer analysis.

Summary of Mass Transfer

- Equimolar counter diffusion occurs when two species diffuse in opposite directions at equal molar rates (N_A = -N_B).
- Convective mass transfer is analogous to convective heat transfer.
- The mass transfer coefficient (h_m) is determined using the Sherwood and Schmidt dimensionless numbers.
- The heat and mass transfer analogy is a powerful engineering tool.

Course Conclusion

- This concludes the Heat and Mass Transfer course (DI05019071).
- We have covered:
- - Conduction (Fourier's Law)
- - Convection (Newton's Law of Cooling)
- - Radiation (Stefan-Boltzmann Law)
- - Heat Exchangers
- - Mass Transfer (Fick's Law)
- Best of luck with your final examinations!