# Heat and Mass Transfer (DI05019071)

## Complete Lecture Deck

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# Overall Heat Transfer Coefficient

- Course: Heat and Mass Transfer (DI05019071)
- Unit 4: Heat Exchanger
- Lecture 30: Overall Heat Transfer Coefficient & Fouling

# Lecture Agenda

- 1. Heat Transfer Process in a Tube
- 2. Thermal Resistance Network
- 3. Overall Heat Transfer Coefficient (U)
- 4. U based on Inside vs. Outside Area
- 5. Introduction to the Fouling Factor
- 6. Design Considerations for Fouling

# Heat Transfer Process in a Tube

- Heat transfers from hot fluid to cold fluid through three mechanisms:
- 1. Convection from hot fluid to the inner wall.
- 2. Conduction through the solid tube wall.
- 3. Convection from the outer wall to the cold fluid.

# Thermal Resistance Network

- Total thermal resistance $R_{total} = R_{conv,i} + R_{wall} + R_{conv,o}$
- $R_{conv,i} = 1 / (h_i * A_i)$ (Inner convection resistance)
- $R_{wall} = \ln(r_o / r_i) / (2 * pi * k * L)$ (Cylindrical wall conduction resistance)
- $R_{conv,o} = 1 / (h_o * A_o)$ (Outer convection resistance)

# Overall Heat Transfer Coefficient (U)

- $Q = (T_h - T_c) / R_{total} = U * A * (T_h - T_c)$
- Therefore, $U * A = 1 / R_{total}$
- U is the overall heat transfer coefficient.
- It represents the total ability of the system to transfer heat.

# U based on Inside vs. Outside Area

- Since the inner area ($A_i$) and outer area ($A_o$) of a tube are different, U depends on which area is used.
- $U_i * A_i = U_o * A_o = 1 / R_{total}$
- $1 / (U_i * A_i) = 1/(h_i*A_i) + R_{wall} + 1/(h_o*A_o)$
- When specifying U, one must specify if it is $U_i$ or $U_o$.

# Simplifying U for Thin-Walled Tubes

- If the tube wall is very thin and highly conductive, R_wall approaches 0.
- Also, A_i is approximately equal to A_o.
- The equation simplifies to: $1/U = 1/h\_i + 1/h\_o$
- U is dominated by the smaller convection coefficient (the larger resistance).

# The Fouling Factor (Rf)

- Over time, surfaces accumulate deposits (scale, rust, algae).
- These deposits act as additional insulation, reducing heat transfer.
- The effect of these deposits is represented by a fouling factor, R_f.
- R_f has units of m^2 K / W.

# Impact of Fouling on Heat Transfer

- Fouling adds additional thermal resistances to our network.
- New equation for U based on outer area:
- $1 / U_o = (A_o/A_i)(1/h_i) + (A_o/A_i)R_{f,i} + A_o{*}R_{wall} + R_{f,o} + 1/h_o$
- As $R_f$ increases, U decreases, and Q drops.

# Typical Values of Fouling Factors

- Distilled water: R_f = 0.0001 m^2 K/W
- City water: R_f = 0.0002 m^2 K/W
- River water: R_f = 0.001 m^2 K/W
- Fuel oil: R_f = 0.0009 m^2 K/W
- Notice that dirtier fluids have much higher fouling factors.

# Design Considerations for Fouling

- Engineers must oversize heat exchangers to account for future fouling.
- A heat exchanger designed with a clean U value will fail to meet requirements after a few months.
- Periodic cleaning schedules must be planned to restore U to design levels.

# Summary

- U incorporates all convective and conductive resistances.
- U must be referenced to a specific area (inside or outside).
- Fouling adds thermal resistance and degrades performance over time.
- Heat exchangers must be oversized to compensate for fouling.

# Next Lecture Preview

- Topic: Effectiveness of Heat Exchanger (NTU Method)
- - What to do when outlet temperatures are unknown
- - Definition of heat exchanger effectiveness
- - The Number of Transfer Units (NTU)