Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

Milav Dabgar

Lecturer, GP Palanpur

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Overall Heat Transfer Coefficient

- Course: Heat and Mass Transfer (DI05019071)
- Unit 2: Convection
- Lecture 18: Overall Heat Transfer Coefficient

Lecture Agenda

- 1. Real-world Heat Transfer Scenarios
- 2. The Thermal Resistance Concept Revisited
- 3. Defining Convection Resistance
- 4. Heat Transfer through a Plane Wall (Convection on both sides)
- 5. The Overall Heat Transfer Coefficient (U)
- 6. U for Cylindrical Geometries (Pipes)
- 7. Fouling and Thermal Contact Resistance

Real-world Scenarios

- In most engineering problems, heat transfer involves multiple modes in series.
- Example 1: Heat lost from a room through a wall to the cold outside air. (Inner convection -¿ Wall conduction -¿ Outer convection).
- Example 2: Heat exchanger tube. Hot fluid inside, cold fluid outside. (Inner convection -¿ Tube wall conduction -¿ Outer convection).

Thermal Resistance Revisited

- Recall from Unit 1: Heat transfer can be modeled analogously to electrical current.
- Current (I) -¿ Heat transfer rate (q)
- Voltage Difference (ΔV) -¿ Temperature Difference (ΔT)
- Electrical Resistance (R_e) -¿ Thermal Resistance (R_t)
- q = ΔT / R_total

Convection Resistance

- Newton's Law of Cooling: q = h * A * (T_s - T_\infty)
- Rearranging into the resistance format (q = ΔT / R):
- q = (T_s - T_\infty) / (1 / (h*A))
- Therefore, Convection Thermal Resistance is:
- R_conv = 1 / (h * A)

Heat Transfer through a Plane Wall

- Consider a wall of thickness 'L', thermal conductivity 'k', area 'A'.
- Hot fluid (T_h, h_1) on one side, cold fluid (T_c, h_2) on the other.
- Thermal circuit consists of three resistances in series:
- 1. R_conv1 = 1 / (h_1 * A)
- 2. R_cond = L / (k * A)
- 3. R_conv2 = 1 / (h_2 * A)

The Overall Heat Transfer Coefficient (U)

- To simplify calculations, we define the Overall Heat Transfer Coefficient (U).
- Equation: q = U * A * ΔT_overall
- Where ΔT_overall = T_hot_fluid - T_cold_fluid.
- Comparing with q = ΔT / R_total, we get:
- U * A = 1 / R_total =¿ U = 1 / (R_total * A)

U for a Plane Wall

- For our plane wall with convection on both sides:
- $R_{total} = (1 / h_1 A) + (L / k A) + (1 / h_2 A)$
- Since $U = 1 / (R_{total} * A)$, we can factor out 'A':
- $U = 1 / [(1/h_1) + (L/k) + (1/h_2)]$
- Units for U are $W/m^2 \cdot K$ (same as h).

U for Cylindrical Geometries

- For pipes, the inner area ($A\_i = 2\pi r\_i\ L$) is different from the outer area ($A\_o = 2\pi r\_o\ L$).
- Because A is not constant, U depends on which area it is based on:
- $U\_i * A\_i = U\_o * A\_o = 1 / R\_total$
- $U\_i = 1 / [\ (1/h\_i) + (A\_i*\ln(r\_o/r\_i)/(2\pi kL)) + (A\_i/(A\_o*h\_o))\ ]$

Fouling Factor (R_f)

- Over time, surfaces accumulate deposits (scale, rust, algae).
- These deposits act as additional thermal insulation, reducing heat transfer.
- This added resistance is called the Fouling Factor (R_f).
- $R\_total = R\_conv1 + R\_f1 + R\_cond + R\_f2 + R\_conv2$

Impact of Fouling on U

- Fouling always increases the total thermal resistance.
- Therefore, fouling always decreases the Overall Heat Transfer Coefficient (U).
- Equipment must be designed with extra capacity (a clean U value vs a dirty U value) to allow for fouling over its operational life.

Summary

- Convection thermal resistance is R_conv = 1 / (hA).
- The Overall Heat Transfer Coefficient (U) combines all series resistances: U*A = 1/R_total.
- For pipes, U must be specified relative to the inner or outer area.
- Fouling adds thermal resistance and degrades performance over time.

Next Lecture Preview

- Topic: Dimensionless numbers and their physical significance
- Key questions:
- - How do we simplify complex convection problems?
- - What are the Reynolds, Prandtl, and Nusselt numbers?