Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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July 23, 2026

Numerical examples on Heat Exchangers (Part 2)

- Course: Heat and Mass Transfer (DI05019071)
- Unit 4: Heat exchanger
- Lecture 40: Numerical examples (NTU Method & Cross-Flow)

Lecture Agenda

- 1. When to use LMTD vs. NTU Method
- 2. Recap of Effectiveness-NTU Formulas
- 3. Example 3: Performance Prediction (NTU Method)
- 4. Recap of Multipass Correction Factor (F)
- 5. Example 4: Shell and Tube Exchanger with 'F' Factor

LMTD vs. Effectiveness-NTU Method

- LMTD Method is best for SIZING problems:
- - You know inlet and outlet temperatures.
- - You need to find the required Surface Area (A).
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- Effectiveness-NTU Method is best for RATING/PERFORMANCE problems:
- - You know the Surface Area (A) and inlet temperatures.
- - You need to predict outlet temperatures and Heat Transfer Rate (Q).

Recap: Effectiveness-NTU Formulas

- Heat Capacity Rates: C_h = m_h * Cp_h, C_c = m_c * Cp_c
- Identify C_min (the smaller of C_h and C_c) and C_max.
- Capacity Ratio: c = C_min / C_max
- Maximum possible heat transfer: Q_max = C_min * (T_h,in - T_c,in)
- Number of Transfer Units (NTU) = (U * A) / C_min
- Effectiveness (ε) = Q_actual / Q_max
- ε is found from charts or formulas based on NTU, c, and flow arrangement.

Example 3: Problem Statement (NTU Method)

- A counter-flow heat exchanger has a surface area of 10 m^2 and $U = 200\ W/m^2.K$.
- Hot fluid ($Cp = 2.0\ kJ/kg.K$) enters at $120^\circ C$ at 1.0 kg/s.
- Cold fluid ($Cp = 4.18\ kJ/kg.K$) enters at $20^\circ C$ at 0.5 kg/s.
- Find: The rate of heat transfer and the outlet temperatures.

Example 3: Capacity Rates and NTU

- Step 1: Calculate Capacity Rates
- C_h = 1.0 kg/s * 2000 J/kg.K = 2000 W/K
- C_c = 0.5 kg/s * 4180 J/kg.K = 2090 W/K
- Therefore, C_min = C_h = 2000 W/K.
- Capacity ratio (c) = C_min / C_max = 2000 / 2090 = 0.957
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- Step 2: Calculate NTU
- NTU = (U * A) / C_min = (200 * 10) / 2000 = 2000 / 2000 = 1.0

Example 3: Effectiveness and Q_actual

- Step 3: Find Effectiveness (ε) for Counter Flow
- Formula for Counter Flow: ε = [1 - exp(-NTU*(1-c))] / [1 - c*exp(-NTU*(1-c))]
- ε = [1 - exp(-1*(1-0.957))] / [1 - 0.957*exp(-1*(1-0.957))]
- ε = [1 - exp(-0.043)] / [1 - 0.957*exp(-0.043)]
- ε = [1 - 0.9579] / [1 - 0.957(0.9579)] = 0.0421 / (1 - 0.9167) = 0.505 (or 50.5%)
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- Step 4: Calculate Q_max and Q_actual
- Q_max = C_min * (T_h,in - T_c,in) = 2000 * (120 - 20) = 200,000 W = 200 kW
- Q_actual = ε * Q_max = 0.505 * 200 kW = 101 kW

Example 3: Outlet Temperatures

- Step 5: Calculate Outlet Temperatures
- From Q = C_h * (T_h,in - T_h,out)
- 101,000 = 2000 * (120 - T_h,out)
- 50.5 = 120 - T_h,out =¿ T_h,out = 69.5°C
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- From Q = C_c * (T_c,out - T_c,in)
- 101,000 = 2090 * (T_c,out - 20)
- 48.33 = T_c,out - 20 =¿ T_c,out = 68.33°C

Recap: Multipass Correction Factor (F)

- For Cross-Flow and Multipass Shell-and-Tube exchangers, the flow is neither pure parallel nor pure counter-flow.
- We calculate LMTD assuming pure counter-flow, then apply a correction factor (F).
- $Q = U * A * F * \Delta T\_lm,CF$
- F is obtained from charts based on parameters P and R:
- - P = (t2 - t1) / (T1 - t1) (Effectiveness parameter)
- - R = (T1 - T2) / (t2 - t1) (Capacity ratio parameter)

Example 4: Problem Statement (Shell & Tube)

- A 1-shell pass, 2-tube pass heat exchanger is used to heat water in tubes from 20°C to 70°C.
- Hot oil in the shell cools from 140°C to 90°C.
- Total heat transfer rate Q = 150 kW.
- $U = 400\ W/m^2.K$.
- Find the required surface area.

Example 4: Solution

- Step 1: Calculate LMTD for Counter Flow
- $\Delta T1 = 140 - 70 = 70^\circ C$, $\Delta T2 = 90 - 20 = 70^\circ C$
- Since $\Delta T1 = \Delta T2$, LMTD $= 70^\circ C$.
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- Step 2: Find P and R parameters
- Let tube fluid be lower case (t), shell fluid be upper case (T).
- $P = (70 - 20) / (140 - 20) = 50 / 120 = 0.417$
- $R = (140 - 90) / (70 - 20) = 50 / 50 = 1.0$
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- Step 3: From chart for 1-2 exchanger, at P=0.417, R=1.0, F ≈ 0.85

Example 4: Final Area Calculation

- Step 4: Calculate Area
- Formula: Q = U * A * F * ΔT_lm
- 150,000 W = 400 $W/m^2.K$ * A * 0.85 * 70 K
- 150,000 = A * (400 * 0.85 * 70)
- 150,000 = A * 23,800
- Area = 150,000 / 23,800 = 6.30 m^2

Summary & Unit 4 Conclusion

- NTU Method is essential when outlet temperatures are unknown (rating/performance problems).
- Correction factor (F) is mandatory for multipass and cross-flow designs when using LMTD.
- This concludes Unit 4: Heat Exchangers. You should now be able to analyze and size various heat transfer equipment.