Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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LMTD for Condensers and Evaporators

- Course: Heat and Mass Transfer (DI05019071)
- Unit 4: Heat Exchanger
- Lecture 33: Condensers, Evaporators, and Cross-flow

Lecture Agenda

- 1. Concept of Phase Change in Exchangers
- 2. Temperature Profiles in Condensers
- 3. Temperature Profiles in Evaporators
- 4. LMTD for Phase Change
- 5. Cross-flow and Multipass Exchangers
- 6. The Correction Factor (F)

Phase Change in Heat Exchangers

- In many industrial processes, one fluid undergoes a phase change (boiling or condensation).
- During phase change at a constant pressure, the temperature of the fluid remains constant.
- Specific heat capacity (cp) is effectively infinite during phase change.
- Therefore, heat capacity rate ($C = m\ cp$) approaches infinity.

Temperature Distribution in Condensers

- Hot fluid (vapor) condenses into liquid at a constant temperature (Th).
- Cold fluid temperature (Tc) increases as it absorbs the latent heat.
- Th,in = Th,out = Th (constant line on the graph).
- Tc rises from Tc,in to Tc,out.

Temperature Distribution in Evaporators

- Cold fluid (liquid) boils into vapor at a constant temperature (Tc).
- Hot fluid temperature (Th) decreases as it provides the latent heat.
- Tc,in = Tc,out = Tc (constant line on the graph).
- Th drops from Th,in to Th,out.

LMTD for Condensers and Evaporators

- Because one temperature is constant, $\Delta T1$ and $\Delta T2$ are the same regardless of flow direction.
- Parallel flow and counter flow arrangements give the exact same LMTD.
- Condenser: $\Delta T1 = Th - Tc,in$; $\Delta T2 = Th - Tc,out$
- Evaporator: $\Delta T1 = Th,in - Tc$; $\Delta T2 = Th,out - Tc$
- $LMTD = (\Delta T1 - \Delta T2) / \ln(\Delta T1 / \Delta T2)$

Beyond Parallel and Counter Flow

- Pure parallel or counter flow is often impractical for large surface areas.
- Industry uses Cross-flow (fluids flow perpendicular to each other).
- Industry also uses Multipass shell-and-tube exchangers (e.g., 1 shell pass, 2 tube passes).
- The standard LMTD formula assumes pure parallel or counter flow.

The Correction Factor (F)

- For cross-flow and multipass exchangers, we modify the LMTD equation.
- q = U A F LMTD_cf
- Where LMTD_cf is the LMTD calculated assuming pure counter flow.
- F is a correction factor (0 ¡ F $\leq$ 1).
- If F ¡ 0.75, the heat exchanger design is generally considered uneconomical.

How to Find F

- F is found using published charts (Bowman, Mueller, and Nagle charts).
- The charts depend on two dimensionless temperature ratios: P and R.
- P (Capacity ratio) = $(t2 - t1) / (T1 - t1)$
- R (Temperature ratio) = $(T1 - T2) / (t2 - t1)$
- (Where T = shell side temps, t = tube side temps)

Correction Factor for Phase Change

- What happens to the Correction Factor (F) in a condenser or evaporator?
- Since one fluid temperature is constant, $R = 0$ or $R =$ infinity.
- Looking at the F-charts, for these values, $F = 1.0$ exactly.
- Conclusion: For phase change, $q = U\ A\ LMTD$ (no correction needed for cross/multipass).

Steps for LMTD Method

- 1. Calculate heat duty (q) if temperatures and mass flows are known.
- 2. Determine unknown inlet/outlet temperatures using energy balance.
- 3. Calculate LMTD for counter flow arrangement.
- 4. Find P and R, then read F from the appropriate chart (if cross/multipass).
- 5. Calculate Area A = q / (U F LMTD_cf).

Limitations of the LMTD Method

- LMTD is great for sizing problems (finding Area A when temps are known).
- LMTD is difficult for performance problems (finding outlet temps when A is known).
- If outlet temps are unknown, LMTD requires tedious trial-and-error iterations.
- To solve this, we will introduce the Effectiveness-NTU method in upcoming lectures.

Summary & Next Lecture

- Flow direction doesn't matter for condensers and evaporators.
- Cross-flow and multipass designs require a correction factor F.
- $F = 1$ for any phase change process.
- LMTD method requires iteration if outlet temperatures are unknown.
- Next Lecture: Overall Heat Transfer Coefficient and Fouling Factors.