Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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Effectiveness of Heat Exchanger and NTU Method

- Course: Heat and Mass Transfer (DI05019071)
- Unit 4: Heat Exchanger
- Lecture 35: Effectiveness-NTU Method (Part 1)

Lecture Agenda

- 1. Why not use LMTD?
- 2. Heat Capacity Rate (C)
- 3. Maximum Possible Heat Transfer (q_max)
- 4. Heat Exchanger Effectiveness (ε)
- 5. The Number of Transfer Units (NTU)
- 6. Capacity Ratio (c)

The Limitation of LMTD

- LMTD is excellent for 'Sizing' problems:
- - You know inlet and outlet temps, you find LMTD, then find Area.
- LMTD is terrible for 'Performance' problems:
- - You have a specific heat exchanger (Area known).
- - You know inlet temps, but NOT outlet temps.
- - Finding outlet temps requires guessing them, calculating LMTD, and iterating until things match.

Heat Capacity Rate (C)

- First, we define the Heat Capacity Rate, C.
- C = mass flow rate (m) * specific heat (cp)
- Ch = m_h * cp_h (Hot fluid capacity rate)
- Cc = m_c * cp_c (Cold fluid capacity rate)
- Units: W/K or J/s·K

Identifying C_min and C_max

- Calculate both Ch and Cc.
- The smaller value is designated as C_min.
- The larger value is designated as C_max.
- The fluid with C_min will experience the LARGER temperature change (ΔT) in the heat exchanger.
- Since $q = C * \Delta T$, if C is small, ΔT must be large for the same q.

Maximum Possible Heat Transfer (q_{max})

- What is the theoretical maximum heat transfer possible?
- It happens in an infinitely long counter-flow heat exchanger.
- The fluid with C_{min} will reach the inlet temperature of the other fluid.
- $q_{max} = C_{min} * (T_{h,in} - T_{c,in})$
- The max temperature difference is $(T_{h,in} - T_{c,in})$.

Defining Effectiveness (ε)

- Effectiveness (ε) is the ratio of actual heat transfer to maximum possible heat transfer.
- $\varepsilon =$ q_actual / q_max
- Effectiveness is dimensionless and $0 \leq \varepsilon \leq 1$.
- q_actual $= \varepsilon$ * C_min * (Th,in - Tc,in)

Calculating Actual Heat Transfer

- Once q_actual is found via effectiveness, outlet temps are easy:
- q_actual = Ch * (Th,in - Th,out)
- Th,out = Th,in - (q_actual / Ch)
- q_actual = Cc * (Tc,out - Tc,in)
- Tc,out = Tc,in + (q_actual / Cc)

How to find Effectiveness?

- Effectiveness depends on the geometry of the heat exchanger and two dimensionless groups.
- ε = function(NTU, c, flow arrangement)
- We need to define NTU and c to use the formulas and charts.

Number of Transfer Units (NTU)

- NTU is a dimensionless parameter indicating the 'size' or heat transfer capability.
- NTU = (U * A) / C_min
- Higher NTU means a larger heat exchanger (more Area or better U).
- Practically, for NTU ¿ 3, the size of the heat exchanger grows massively for very small gains in effectiveness.

Capacity Ratio (c)

- Capacity ratio 'c' is the ratio of the minimum to maximum heat capacity rates.
- $c = C\_min / C\_max$
- Since $C\_min \leq C\_max$, the ratio c must be: $0 \leq c \leq 1$.
- If $c = 0$, one fluid is undergoing phase change ($C\_max =$ infinity).
- If $c = 1$, both fluids have the same capacity rate (balanced flow).

Effectiveness Formulas Preview

- Parallel Flow: $\varepsilon =$ [1 - exp(-NTU*(1+c))] / (1+c)
- Counter Flow (c¡1): $\varepsilon =$ [1 - exp(-NTU*(1-c))] / [1 - c*exp(-NTU*(1-c))]
- Counter Flow (c=1): $\varepsilon =$ NTU / (1 + NTU)
- These are standard formulas provided in data books.

Summary & Next Lecture

- LMTD requires iteration for performance problems.
- q_{max} occurs when the C_{min} fluid reaches the opposite inlet temperature.
- Effectiveness $\varepsilon = q_{actual} / q_{max}$.
- ε depends on NTU (UA/Cmin) and c (Cmin/Cmax).
- Next Lecture: Using Effectiveness charts and solving numerical problems.