Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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Compact Heat Exchangers

- Course: Heat and Mass Transfer (DI05019071)
- Unit 4: Heat exchanger
- Lecture 38: Compact Heat Exchangers

Lecture Agenda

- 1. Introduction and Definition
- 2. Why Use Compact Heat Exchangers?
- 3. Classification and Types
- 4. Plate-Fin Heat Exchangers
- 5. Tube-and-Fin Heat Exchangers
- 6. Pressure Drop Considerations
- 7. Applications

Definition of a Compact Heat Exchanger

- A compact heat exchanger is defined by a high area density (ratio of heat transfer surface area to its volume, denoted by β).
- General criteria:
- $\beta =$ Area / Volume ¿ 700 m^2/m^3 (for gas-to-fluid).
- β ¿ 400 m^2/m^3 (for liquid or phase-change applications).
- They incorporate extended surfaces (fins) to achieve this high density.

Why Use Compact Heat Exchangers?

- Gas flows have low convection heat transfer coefficients (h).
- To achieve a desired heat transfer rate ($Q = h * A * \Delta T$), a large area (A) is required.
- Space and weight are often severely constrained (e.g., aerospace, automotive).
- Compact designs provide massive area within a small footprint, compensating for the low 'h' of gases.

Classification and Types

- Compact heat exchangers are typically cross-flow types and are classified mainly by their construction:
- 1. Plate-Fin Heat Exchangers (PFHE)
- 2. Tube-and-Fin Heat Exchangers
- 3. Printed Circuit Heat Exchangers (PCHE)
- 4. Regenerators (Rotary matrix)

Plate-Fin Heat Exchangers (PFHE)

- Constructed from alternating layers of corrugated fins and flat separator plates.
- Fluids flow through the passages created by the fins.
- Allows for multiple fluid streams (3 or more) in a single unit.
- Primarily made of brazed aluminum for lightweight and good conductivity.

Types of Fins in PFHE

- Fin geometry dictates heat transfer enhancement and flow friction.
- 1. Plain Fins: Straight channels, low friction, lower heat transfer.
- 2. Wavy Fins: Induce swirling, better heat transfer.
- 3. Offset Strip / Serrated Fins: Break boundary layers, very high heat transfer, high pressure drop.
- 4. Louvered Fins: Slices in the fin direct flow, very common in radiators.

Tube-and-Fin Heat Exchangers

- Consist of round or flat tubes with continuous fins attached to the outside.
- Typically used when one fluid is a liquid (in the tube) and the other is a gas (across the fins).
- Flat tubes offer less aerodynamic drag on the gas side compared to round tubes.

Pressure Drop and Pumping Power

- Trade-off: Increasing surface density and boundary layer interruption increases heat transfer but also increases flow friction.
- Higher pressure drop means a larger fan or pump is required.
- Pumping power costs can exceed the material costs of the exchanger over its lifetime.
- Optimization is required to balance Colburn j-factor (heat transfer) and Friction factor (f).

Applications: Automotive & HVAC

- Automotive: Radiators, charge air coolers (intercoolers), oil coolers, AC condensers.
- HVAC: Air conditioning evaporator and condenser coils, heat recovery wheels.
- Electronics: CPU/GPU heatsinks (fin arrays).

Applications: Aerospace & Cryogenics

- Aerospace: Environmental control systems, engine oil coolers.
- Cryogenics: Air separation plants, liquefaction of natural gas (LNG).
- Cryogenic PFHEs can achieve temperature approaches of less than $2^{\circ}C$ between streams.

Summary

- Compact heat exchangers have area densities ¿ 700 m^2/m^3.
- They are essential for gas-flow applications where 'h' is low.
- Plate-fin and tube-fin are the most common configurations.
- Design requires a careful balance between heat transfer performance and pressure drop.

Next Lecture Preview

- Topic: Numerical Examples on Heat Exchangers (Part 1)
- Key questions to ponder:
- - How do we apply the LMTD method to solve real-world problems?
- - What are the step-by-step procedures for parallel and counter-flow designs?