Heat and Mass Transfer (DI05019071)

Complete Lecture Deck

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Boiling and Condensation

- Course: Heat and Mass Transfer (DI05019071)
- Unit 2: Convection
- Lecture 21: Boiling Regimes and Condensation

Lecture Agenda

- 1. Convection with Phase Change
- 2. Pool Boiling vs. Flow Boiling
- 3. The Boiling Curve (Nukiyama Curve)
- 4. Natural Convection Boiling Regime
- 5. Nucleate Boiling Regime
- 6. Transition and Film Boiling Regimes
- 7. Critical Heat Flux (Burnout Point)
- 8. General Aspects of Condensation
- 9. Filmwise vs. Dropwise Condensation

Convection with Phase Change

- Boiling and condensation are forms of convection associated with a change in phase (liquid to gas, or gas to liquid).
- Latent heat of vaporization plays a massive role.
- Heat transfer coefficients (h) for phase change are typically orders of magnitude higher than single-phase forced convection.
- Examples: Power plant boilers, steam condensers, refrigeration systems.

Pool Boiling vs. Flow Boiling

- Pool Boiling: Boiling occurs in a quiescent (still) fluid. Fluid motion is due entirely to natural convection currents and bubble motion. (e.g., boiling water in a pan).
- Flow Boiling: Fluid is forced to move over a heated surface by external means (pump) while boiling occurs. (e.g., water flowing through a reactor core).
- We will focus primarily on Pool Boiling to understand the regimes.

The Boiling Curve

- Plots Heat Flux (q") on the y-axis vs. Excess Temperature (ΔT_excess = T_surface - T_saturation) on the x-axis.
- Log-log scale is usually used.
- Discovered by Nukiyama in 1934.
- Identifies four distinct boiling regimes as surface temperature increases.

1. Natural Convection Boiling

- Occurs at low excess temperatures (ΔT_excess ¡ 5°C for water).
- Fluid near the surface is superheated slightly.
- Heat is transferred by free convection to the liquid surface where evaporation occurs.
- No bubbles form on the heating surface yet.

2. Nucleate Boiling

- Occurs at 5°C ¡ ΔT_excess ¡ 30°C.
- Bubbles begin to form at nucleation sites (scratches, pits) on the surface.
- Bubbles detach, rise, and cause intense fluid mixing.
- Extremely high heat transfer rates. This is the most desirable operating regime for industrial boilers.

Critical Heat Flux (Burnout Point)

- The peak of the nucleate boiling curve (around ΔT_excess $\approx$ 30°C for water).
- Also known as Critical Heat Flux (CHF) or Departure from Nucleate Boiling (DNB).
- At this point, bubble formation is so rapid that bubbles start to merge before detaching.
- Maximum possible heat transfer rate in nucleate boiling.

3 & 4. Transition & Film Boiling

- Transition Boiling (30°C ¡ ΔT ¡ 120°C): Bubbles merge to form an unstable vapor film. Heat flux actually drops as T_surface increases because vapor is a poor conductor.
- Film Boiling (ΔT ¿ 120°C): A stable, continuous vapor film completely covers the surface. (Leidenfrost effect).
- Radiation becomes a significant mode of heat transfer across the vapor film.

General Aspects of Condensation

- Occurs when vapor comes into contact with a surface whose temperature is below the saturation temperature of the vapor.
- Latent heat is released to the surface.
- Two main types of condensation on solid surfaces:
- 1. Filmwise Condensation
- 2. Dropwise Condensation

Filmwise vs. Dropwise Condensation

- Filmwise: The liquid wets the surface completely, forming a continuous liquid film. The film acts as a thermal resistance.
- Dropwise: The liquid does NOT wet the surface. Vapor condenses in discrete drops which roll off, leaving bare surface exposed.
- Dropwise condensation achieves heat transfer rates up to 10 times higher than filmwise condensation.

Summary

- Boiling and condensation offer very high heat transfer rates due to phase change.
- The boiling curve maps regimes: Natural convection, Nucleate (desired), Transition, and Film (dangerous).
- Critical Heat Flux is a dangerous limit where a vapor blanket forms.
- Dropwise condensation is much more efficient than filmwise condensation.

Unit 3 Preview

- Unit 3: Radiation
- Key questions:
- - How does heat travel through a vacuum like space?
- - What is electromagnetic thermal radiation?
- - What makes a body 'black', 'white', or 'grey' in heat transfer?