Agenda

In this presentation we introduce the wall boiling models in ANSYS CFD, share theory, usage, validations and some of the best practices.

These models are available with Eulerian multiphase model.

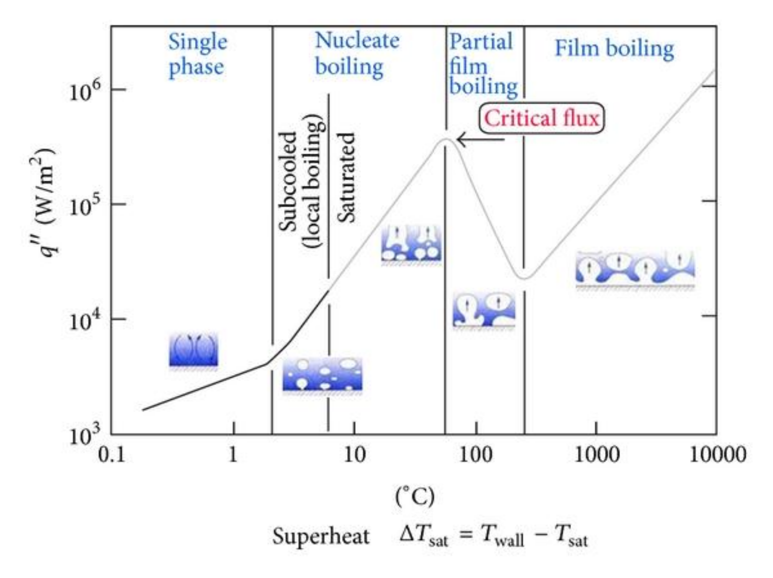
Wall boiling models are mechanistic models, in which several mechanisms and underlying sub-mechanisms of wall boiling process are used to build the model. Empirical correlations are used for each mechanism to close the model.

Outline

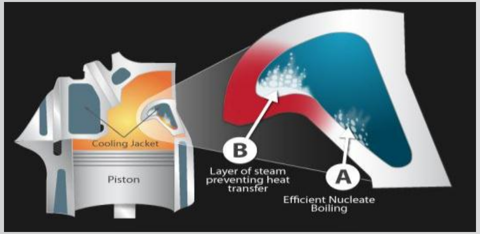
- Introduction
- Theory
- Usage
- Validation Studies
- Best Practices
- Appendix

What is Boiling

- Boiling occurs in many industrial applications and is characterized by large heat transfer coefficients
- This efficient heat transfer mechanism is limited by the critical heat flux where the heat transfer coefficient decreases leading to a rapid temperature rise potentially leading to system melting and destruction
- Traditionally, empirical correlations for critical heat flux are used to develop an understanding of the process dynamics
- But these correlations are valid only in the limited specified region of fluid conditions and fluid properties and hold for a defined geometry



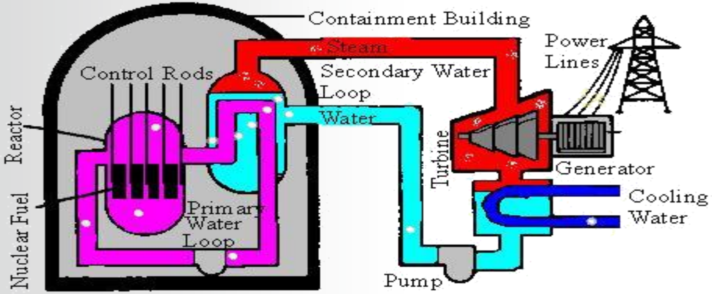
Need of boiling simulation



Engine jacket cooling

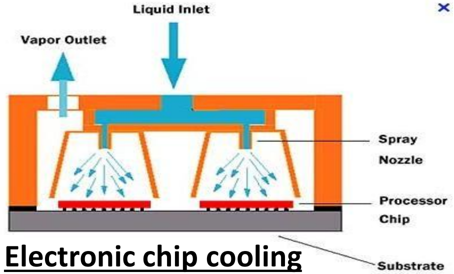
Quenching process

- Auto Industry
  - Engine cooling
  - Heat treatment
- Power Industry
  - Boiling in tubes or fuel rods
  - Burn out simulation
- Electronics
  - Electronic chip cooling
  - Micro channel boiling

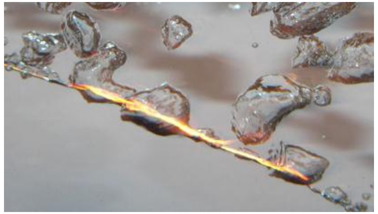


Nuclear Power Plant

Phase change in micro channels

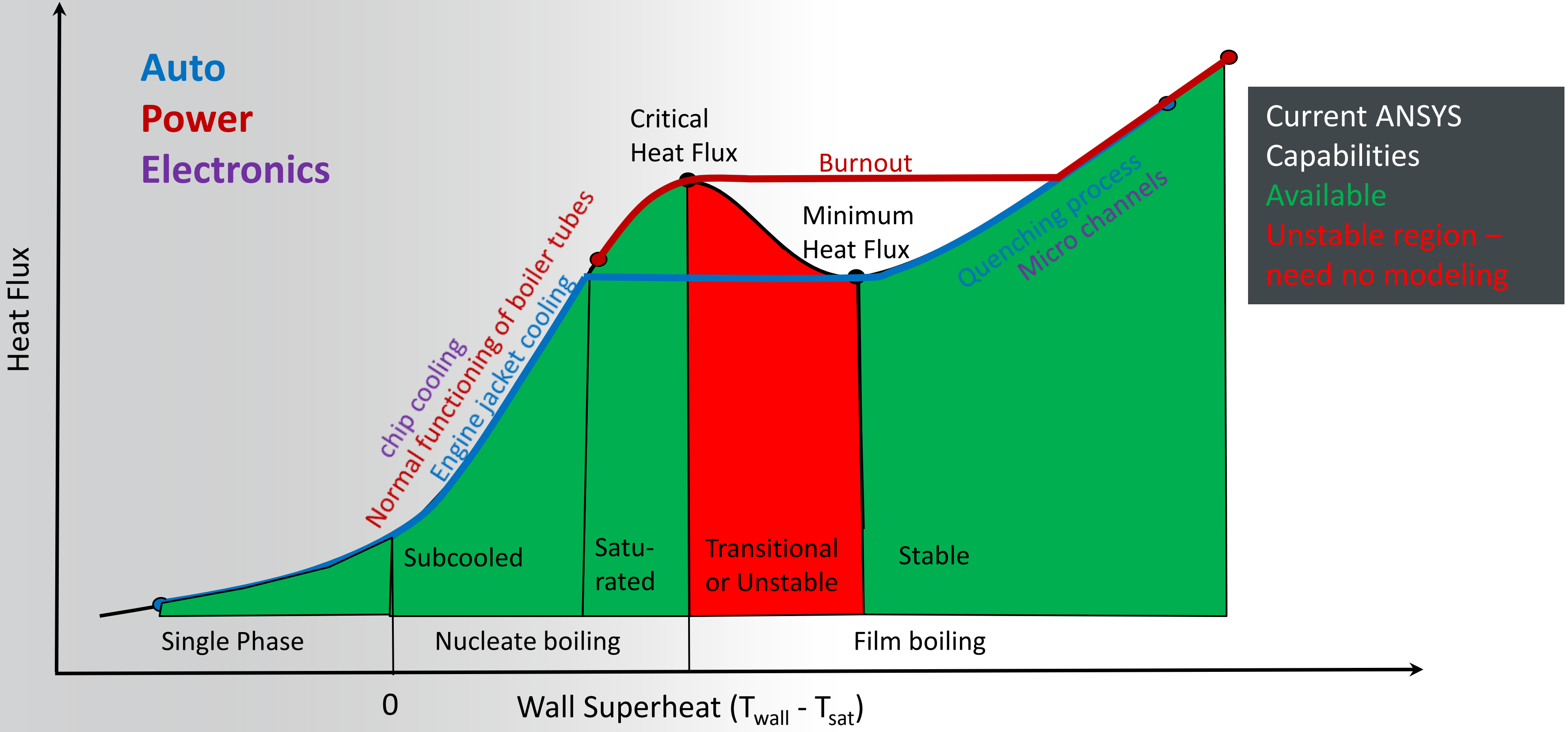


Electronic chip cooling

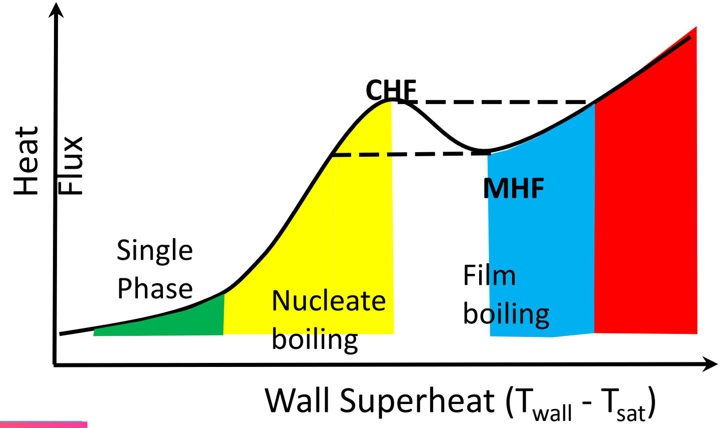


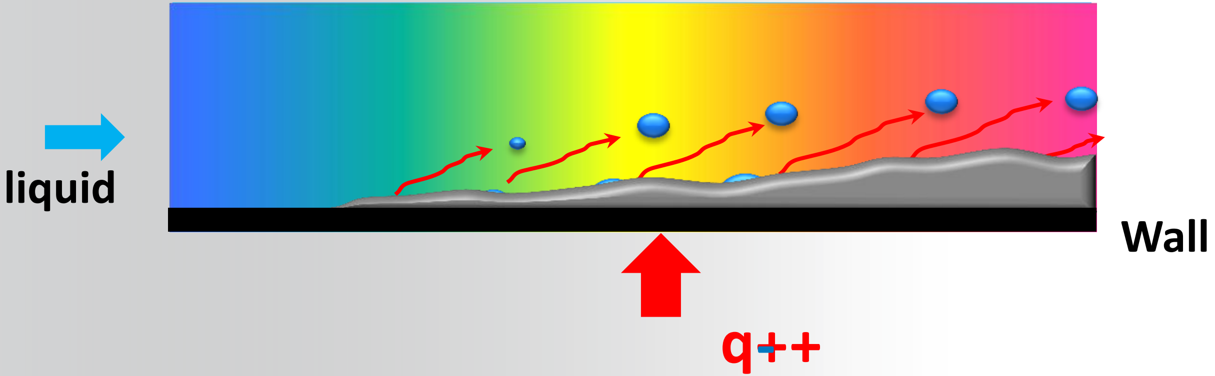
Burn out of electrically heated wire

Boiling curve, applications & ANSYS capabilities



What happens at the wall?





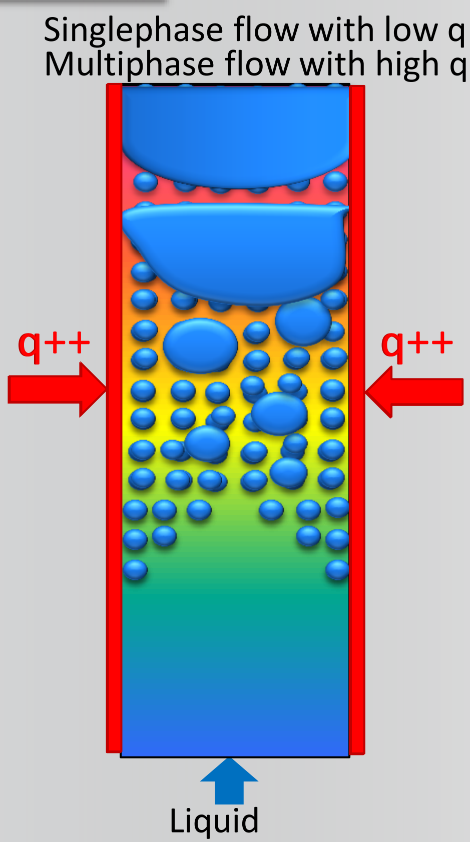
Types of Boiling

- **Subcooled boiling:**
  - Subcooled boiling occurs when the heat flux applied to the wall is too high to be transferred to the bulk of liquid by the single phase convective and conductive processes. The term "subcooled" means, that the saturation temperature is exceeded only in a local vicinity of the wall, whereas the average temperature in the bulk remains below saturation.
- **Saturated Boiling**
  - When the bulk of the liquid approaches saturation temperature, the boiling process becomes violent, with very high bubble departure diameter. This is called "saturated" boiling.
- **Departure from Nucleate Boiling (DNB)**
  - When the core of the pipe still has liquid as continuous phase but the near wall volume fraction is so high that the vapor bubbles coalesce and form a film, it is called Departure from Nucleate Boiling (DNB).
- **Critical Heat Flux (CHF)/ Burn out**
  - When the core of the pipe has droplet flow regime with vapor as continuous phase and the liquid film on the wall dries out, it is called Critical Heat Flux (CHF)/ Burn Out.

Physical Model

- The conventional approach for modelling boiling process with significant volume fractions of both phases is the Eulerian multiphase model
- Phase distributions are calculated by solving phase specific continuity equations for volume fractions and separate set of momentum equations
- For the steam-water flow an energy equation is solved for water, while vapour is assumed to be saturated
  - Optionally, solve energy equation for vapour as well
- The exchange of mass, momentum and heat between phases are modelled using the appropriate empirical models for interfacial forces
  - Drag, lift, turbulent dispersion and wall lubrication

RPI wall boiling algorithm and its extension



Flow regime	Treatment at the wall	Treatment in the domain
Single Phase	Heat flux to liquid	No special treatment
Multiphase •subcooled nucleate boiling	Heat flux to liquid Evaporation heat flux	Mono Disperse flow •Euler model
Multiphase •saturated boiling, •slug-flow, •annular, •droplet flow	Heat flux to liquid Evaporation heat flux Heat flux to vapor	Poly disperse flow •Population balance •Interfacial area concentration

With ANSYS CFD, it is possible to model

- Subcooled nucleate boiling using RPI wall boiling model (CFX and Fluent)
- Saturated boiling using Non-equilibrium wall boiling model (Fluent)
- Critical Heat Flux (CHF)/Departure from Nucleate Boiling (DNB)/Burn Out conditions using CHF wall boiling model (Fluent)

Subcooled Boiling

- Subcooled boiling occurs when the heat flux applied to the wall is too high to be transferred to the bulk of liquid by the single phase convective and conductive processes

- The term “subcooled” means, that the saturation temperature is exceeded only in a local vicinity of the wall, whereas the average temperature in the bulk remains below saturation

- Steam bubbles are generated at the heated surface at nucleation sites, with the surface density of these sites depending various factors including the superheat ΔT_{sat}

- The attached bubbles grow and then leave the wall at certain critical size
  - Depends on surface tension and flow regime of surrounding fluids
- Heat transfer from the wall is then described as being carried by turbulent convection of liquid, by transient conduction due to the departing bubbles, and by evaporation

Subcooled Boiling: RPI Model

- The overall heat balance at the wall, the so called heat partitioning is usually written as

$$q_W = \underbrace{q_C}_{Convective} + \underbrace{q_Q}_{Quenching} + \underbrace{q_E}_{Evaporative}$$

- The quenching heat flux represents the effects of transient conduction through the patches of the fresh bulk liquid, coming to the wall to replace each departing steam bubble

- Distribution of the entire wall heat flux between these mechanisms can be calculated by modelling each mechanism in terms of:
  - the nucleation site density,
  - the size of departing bubble and their detachment frequency
  - Waiting time for the next bubble to appear on the site

