UNIVERSITEIT GENT

FACULTY OF ENGINEERING AND ARCHITECTURE

Development of a one-Dimensional boiling model: Part I – A two-phase flow pattern map for a heavy hydrocarbon feedstock

Pieter Verhees, Abdul Akhras Rahman, Kevin M. Van Geem, Geraldine J. Heynderickx

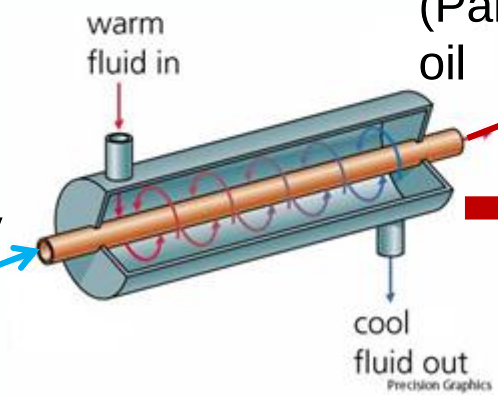
Laboratory for Chemical Technology, Ghent University

http://www.lct.UGent.be

CHISA, Prague, 28/08/2016

Fouling of heat exchangers

Liquid Heavy oil



(Partly) Evaporated oil

Tube wall temperature ↗

→ Fouling

Asphaltene precipitation

Heat transfer ↘

Pressure drop ↗

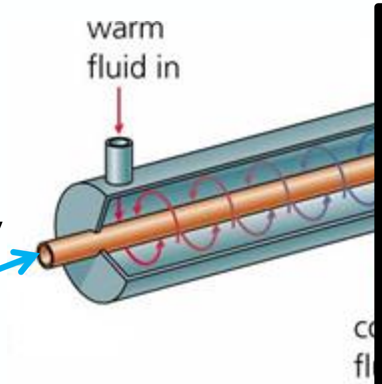
Cleaning needed

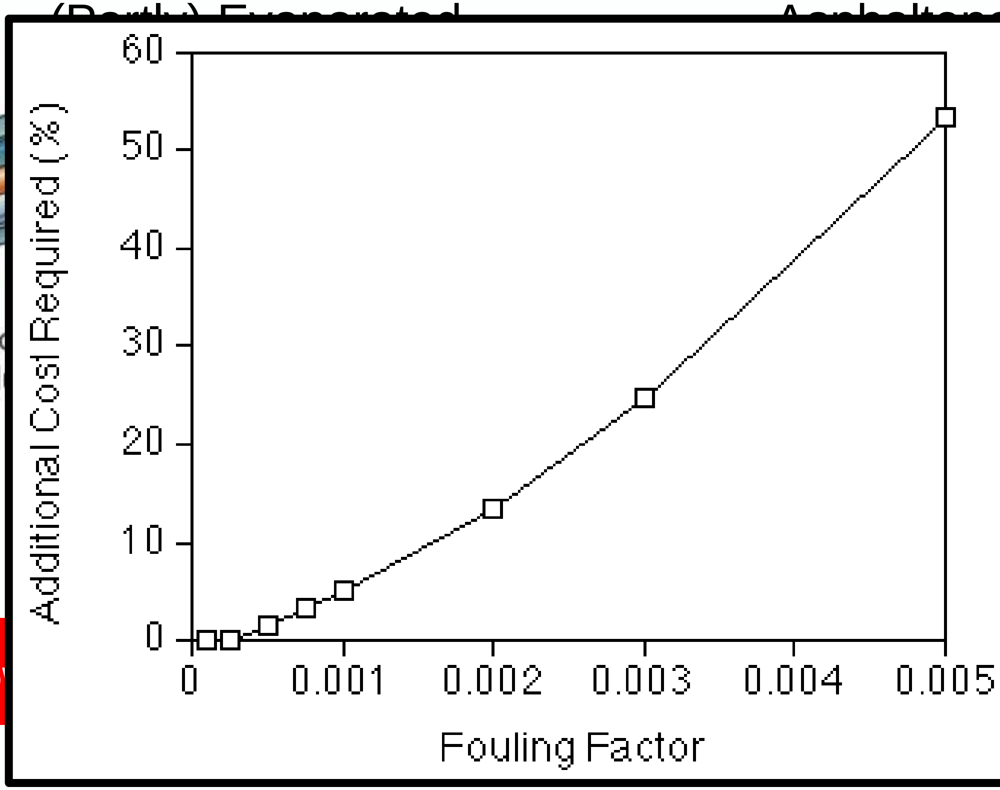
Shutdown

Huge cost

Fouling of heat exchangers

Liquid Heavy oil





precipitation

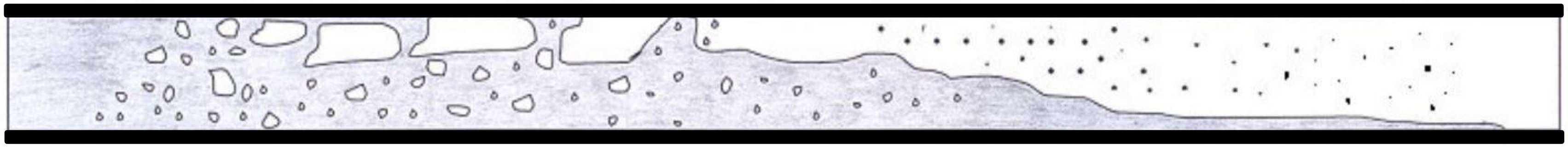
Shutdo

Huge cost

Prediction fouling → 1D modeling

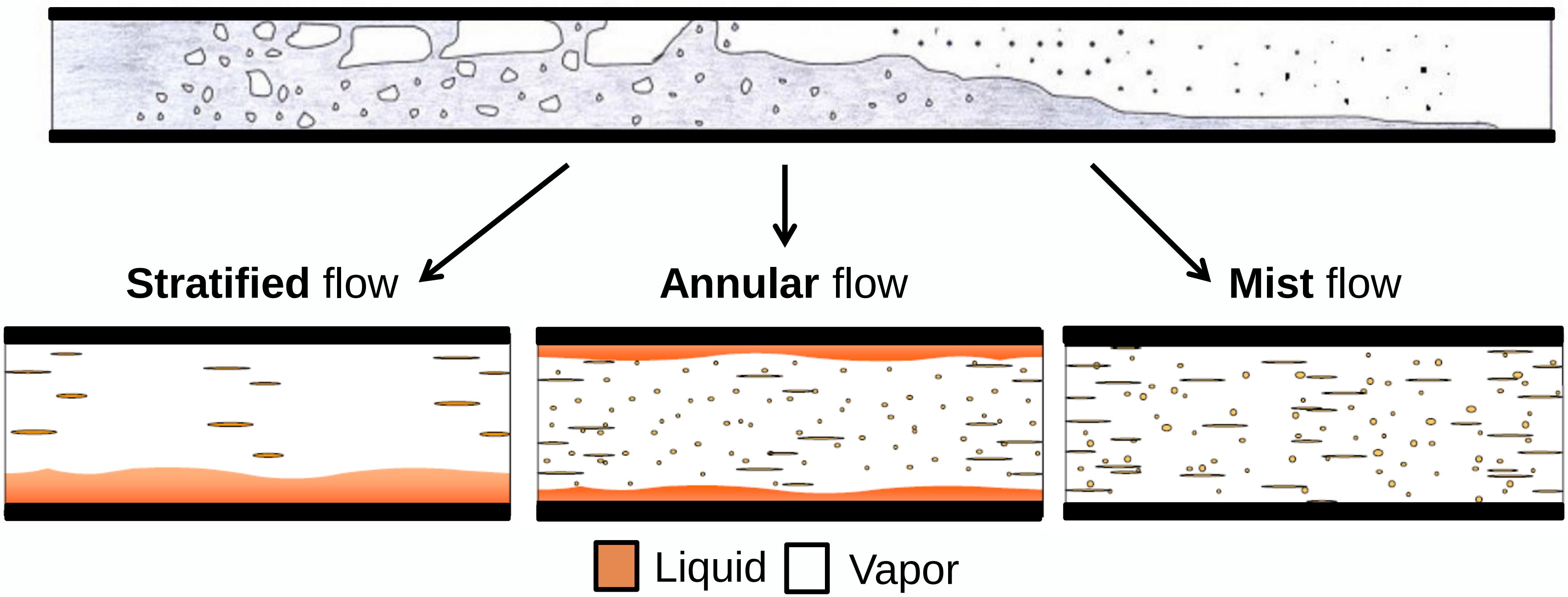
Fouling – Flow regime

Evaporating flow



Fouling – Flow regime

Evaporating flow



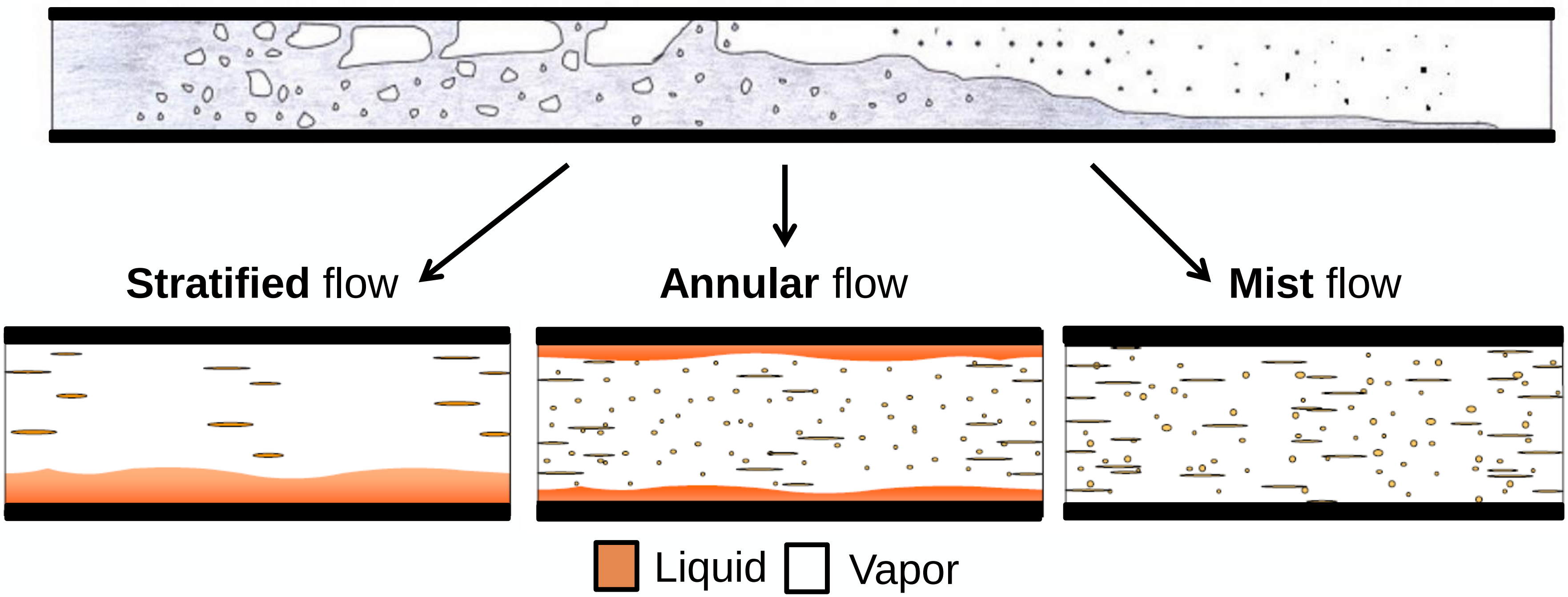
High tube temperature

Low tube temperature

Very high tube temperature

Fouling – Flow regime

Evaporating flow



High tube temperature

Low tube temperature

Very high tube temperature

Tube temperature ↑ → Fouling ↑

Flow regime!

1D modeling evaporation

↓

Calculation heat transfer coefficient

↓

Step 1

Determination flow regime

Step 2

HTC calculation

Fouling prediction

↓

Step 1

Fouling model (~T)

Step 2

Determination flow regime

Step 3

Estimation wall temperature

Flow regime!

1D modeling evaporation | **Fouling prediction**

Ca

Step

Det

Step

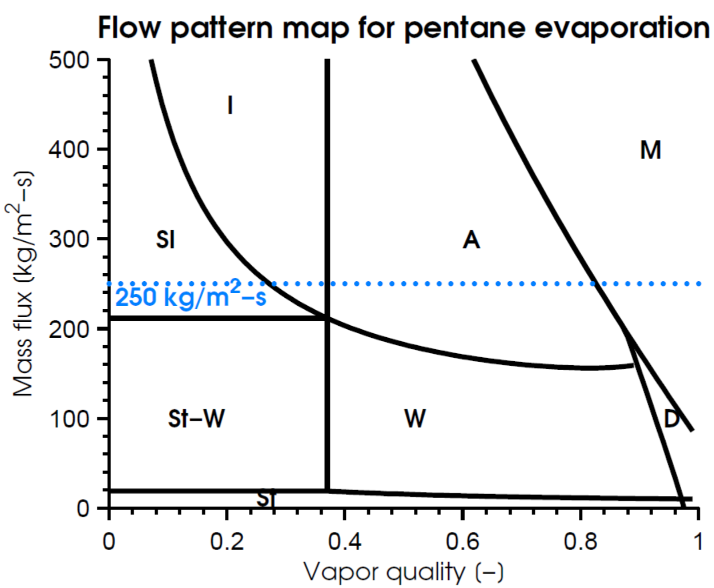
HTC

ime

ature

Accurate **flow regime prediction** is important

Flow regime map



This work

Regime maps in literature are developed based on experiments for

Water
Cooling fluids

In literature **correction is proposed to other fluids**

Valididation of the flow regime maps for heavy hydrocarbons

→ **CFD simulations**

Adiabatic flow regime map

Baker (1954) ◊

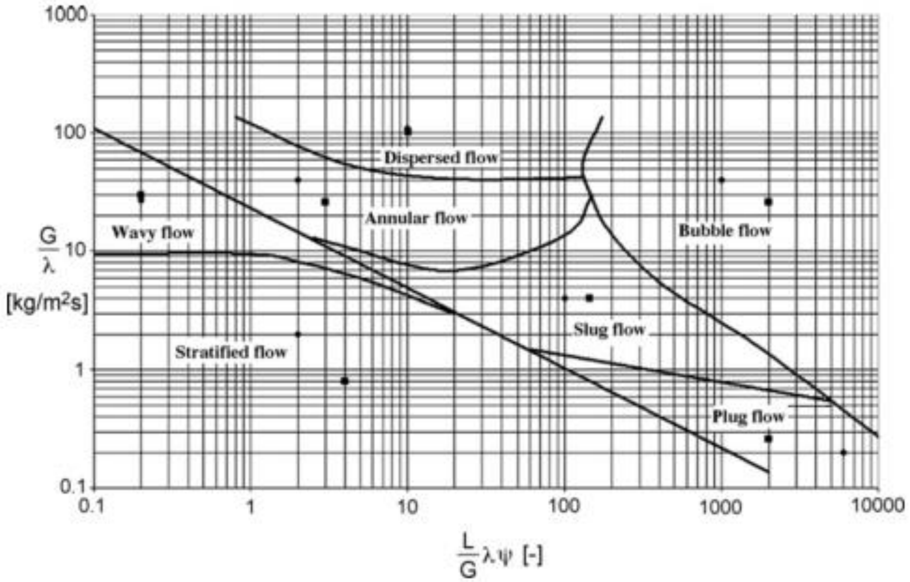
Based on experimental databases

Water + air

Generalization to other fluids by correction parameters

$$\lambda = \left[\left(\frac{\rho_g}{\rho_{air}}\right)\left(\frac{\rho_l}{\rho_{water}}\right)\right]^{0.5}$$

$$\psi = \frac{\sigma_{water}}{\sigma}\left[\left(\frac{\mu_l}{\mu_{water}}\right)\left(\frac{\rho_{water}}{\rho_l}\right)^2\right]^{1/3}$$



Valid for heavy hydrocarbons?

◊Baker, O., Design of pipe lines for simultaneous flow of oil and gas. *Oil and Gas Journal* **1954,** 26

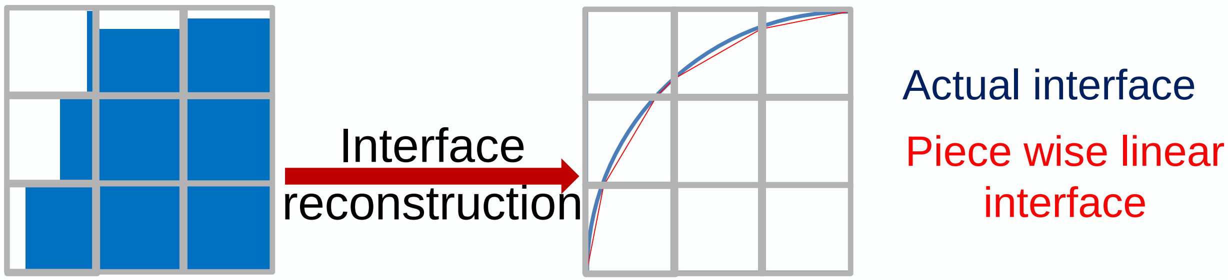
CFD Model

ANSYS FLUENT 13.0

Multiphase model: Volume of Fluid

$$\frac{\partial}{\partial t}(\alpha_l \rho_l) + \nabla.(\alpha_l \rho_l \vec{v}) = m_{vl} - m_{lv} \qquad \alpha_v = 1 - \alpha_l$$

Interface tracking: Geo-reconstruct



Accurate when mesh size is an order of magnitude smaller than radius of curvature

Validated with Water + Air simulations

CFD simulations

Feed

Gasoil is complex hydrocarbon mixture

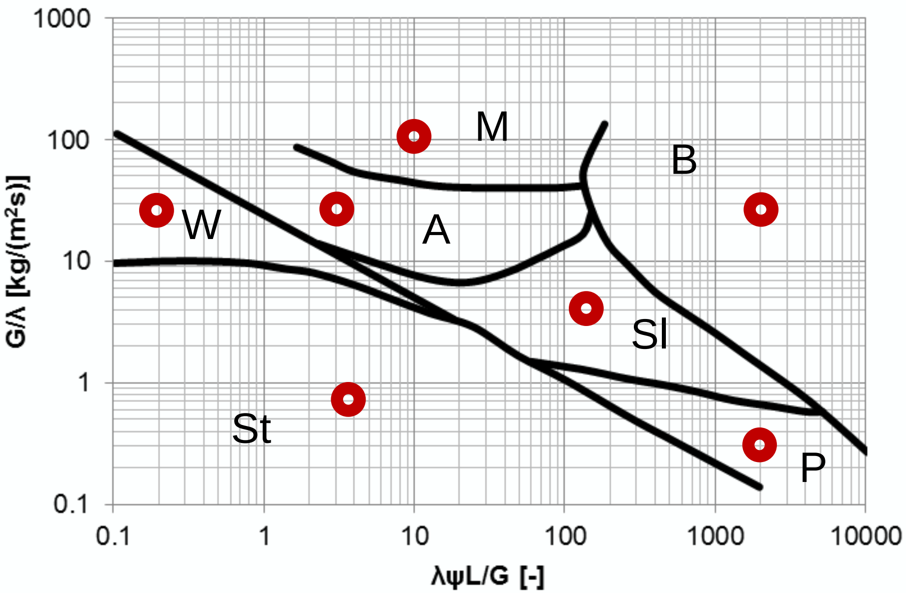
➡ Represented by 1 pseudocomponent

Simulation conditions

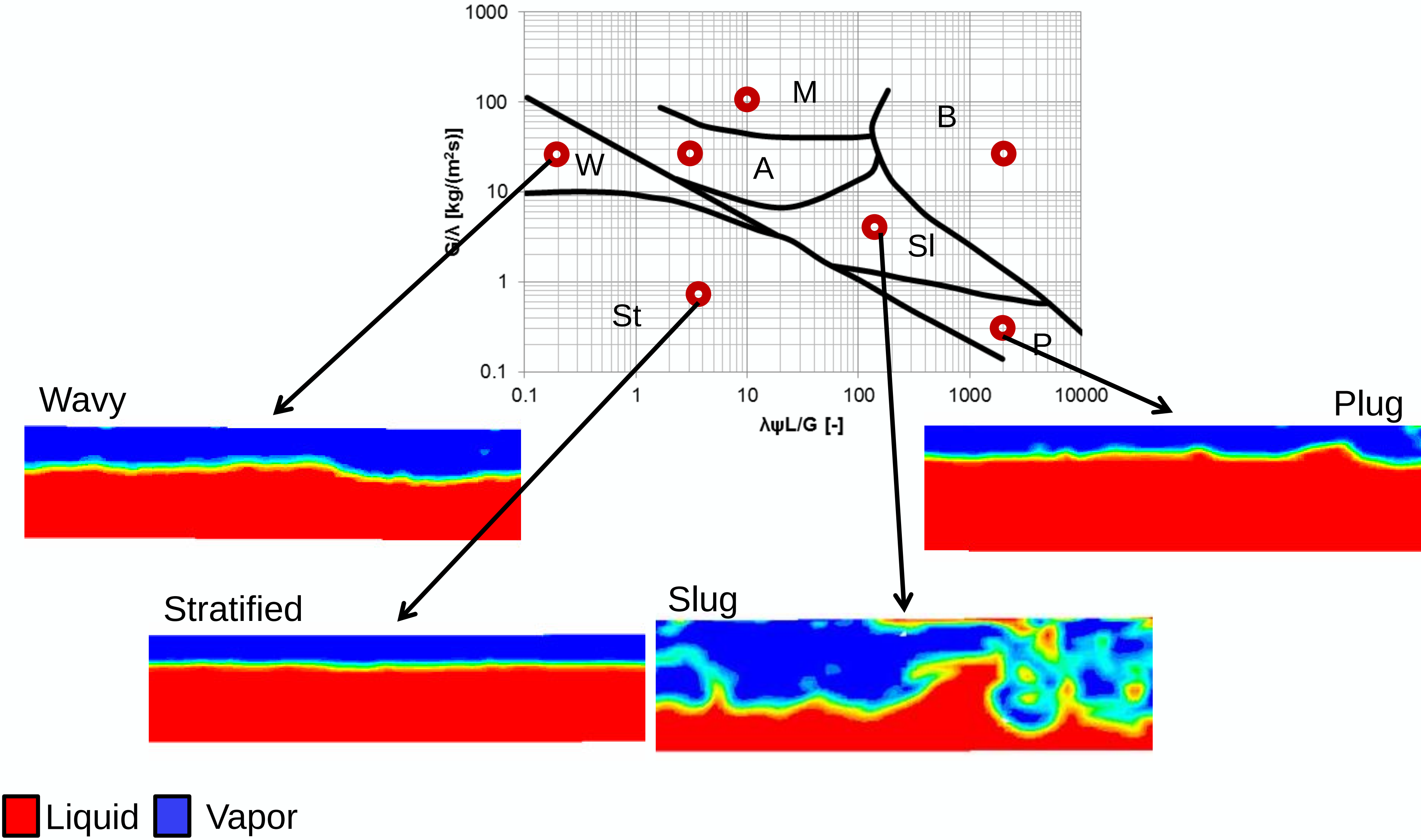
7 simulations are performed

Operating conditions

➡ All seven regimes are observed

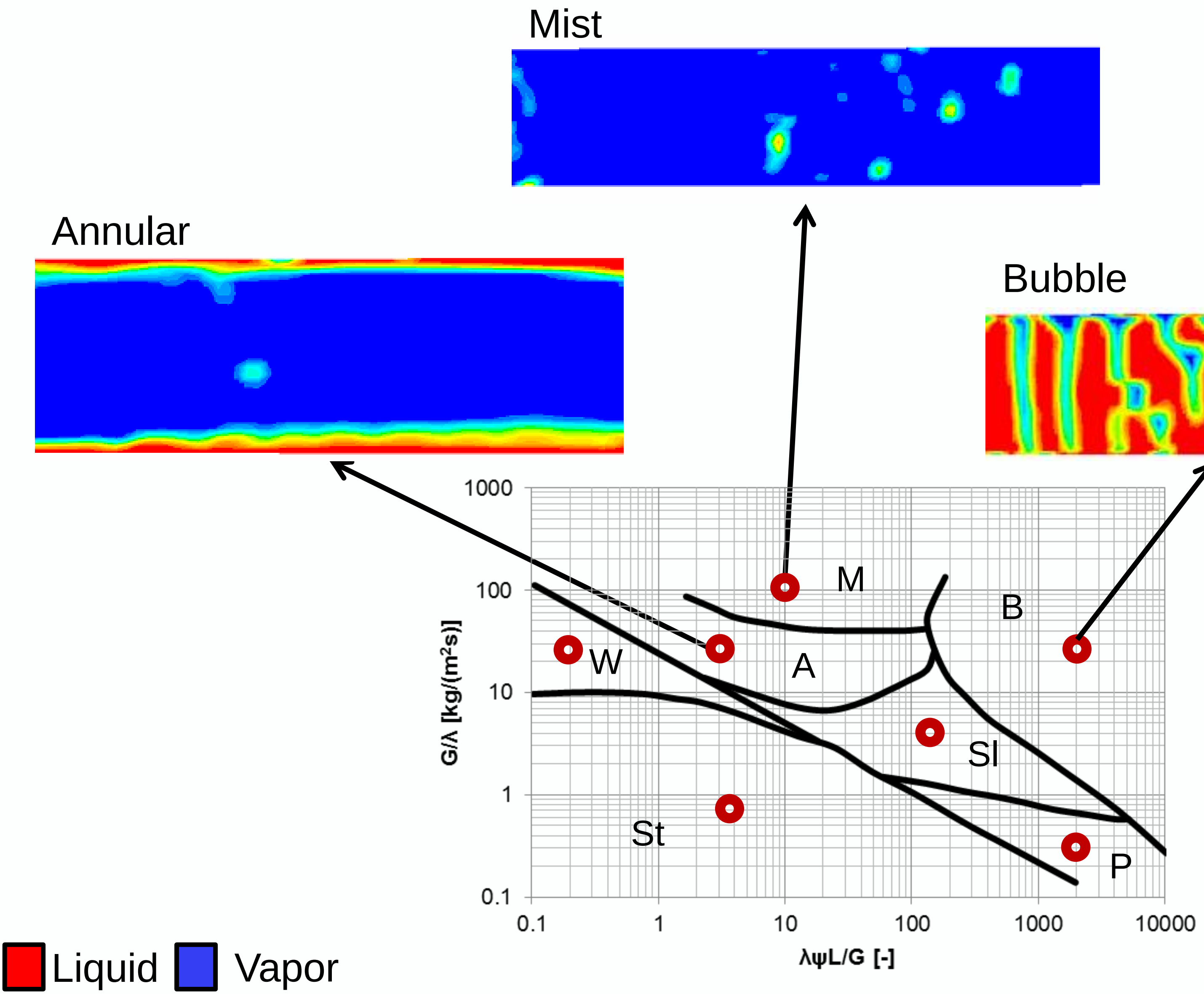


CFD results



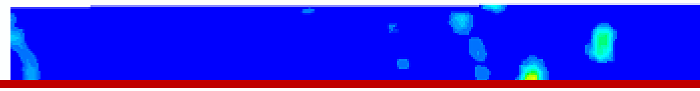
◊De Schepper, S. C. K.; Heynderickx, G. J.; Marin, G. B., CFD modeling of all gas-liquid and vapor-liquid flow regimes predicted by the Baker chart. *Chemical Engineering Journal* **2008,** 138, (1-3), 349-357

CFD results

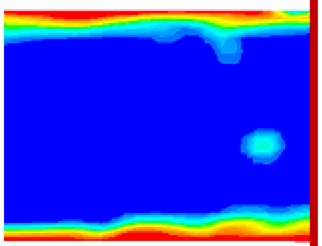

Mist
Annular
Bubble
1000
100
10
1
0.1
G/λ [kg/(m²s)]
0.1
1
10
100
1000
10000
λψL/G [-]
M
B
W
A
Sl
St
P
Liquid
Vapor

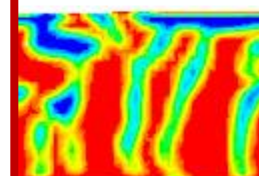
CFD results

Mist



Annular

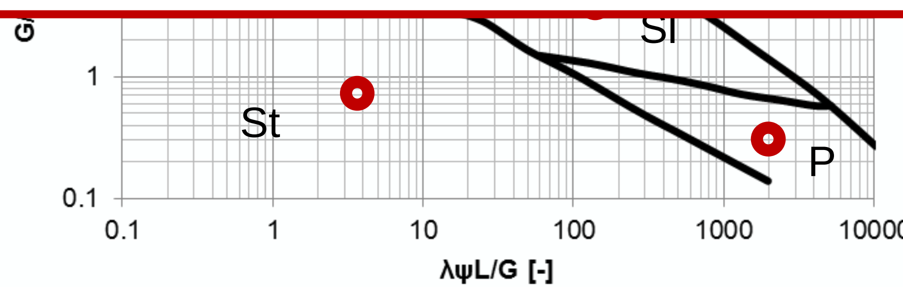




Evaporation has an effect on flow regimes

⬇

Diabatic flow regime map



Liquid Vapor

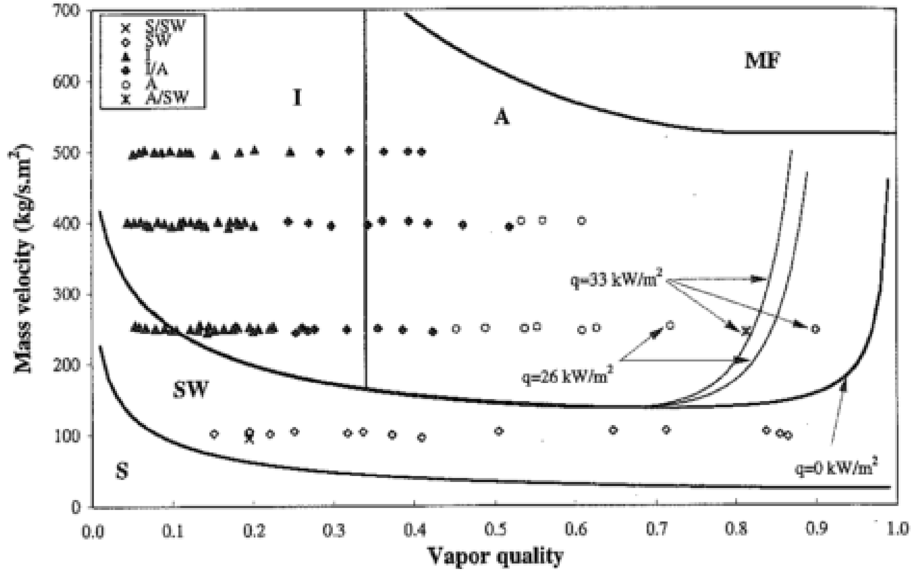
Diabatic flow regime map

Kattan, Thome and Favrat (1998) ◊

Based on experimental databases
cooling fluid R134a

Correlations are developed to construct the boundaries

Boundaries dependent on
Geometry
Fluid property
Wall heat flux



Correlations valid for heavy hydrocarbons?

◊Kattan, N.; Thome, J. R.; Favrat, D., Flow boiling in horizontal tubes: Part 1 - Development of a diabatic two-phase flow pattern map. *Journal of Heat Transfer-Transactions of the Asme* **1998,** 120, (1), 140-147

CFD simulations

CFD model adaptation

Phase change model

$coeff = 0.1\ s^{-1}$

Evaporation ($T > T_{sat}$)

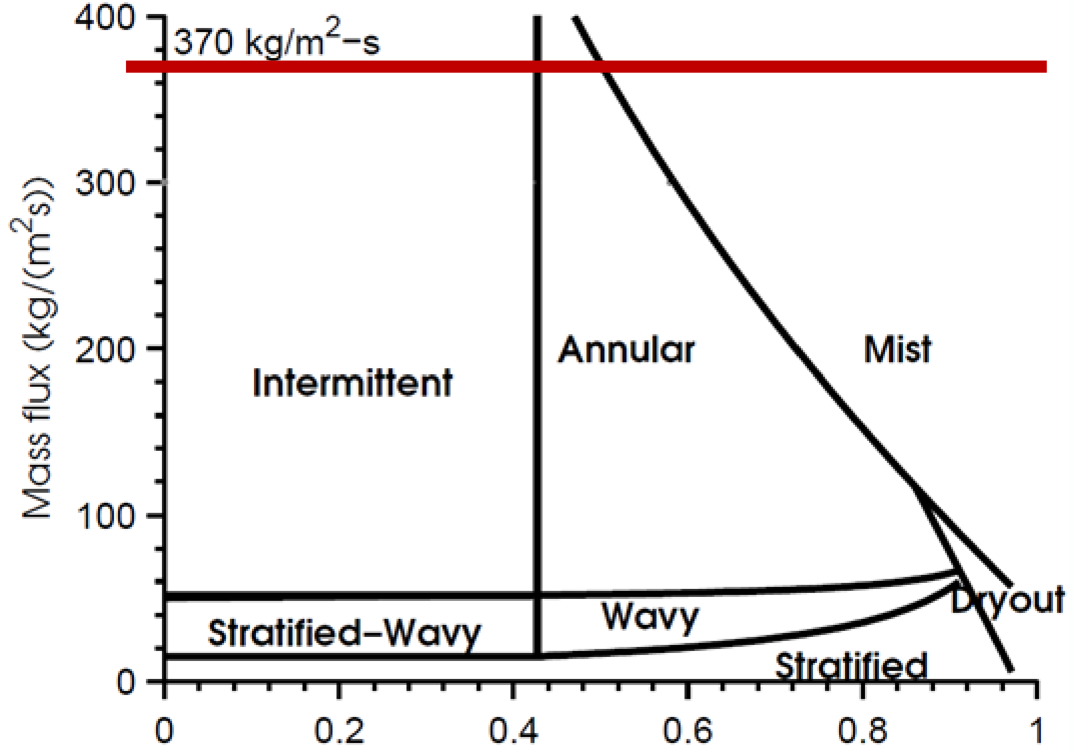
$$m_{lv} = coeff.\alpha_l.\rho_l.\frac{T - T_{sat}}{T_{sat}}$$

Condensation ($T < T_{sat}$)

$$m_{vl} = coeff.\alpha_v.\rho_v.\frac{T_{sat} - T}{T_{sat}}$$

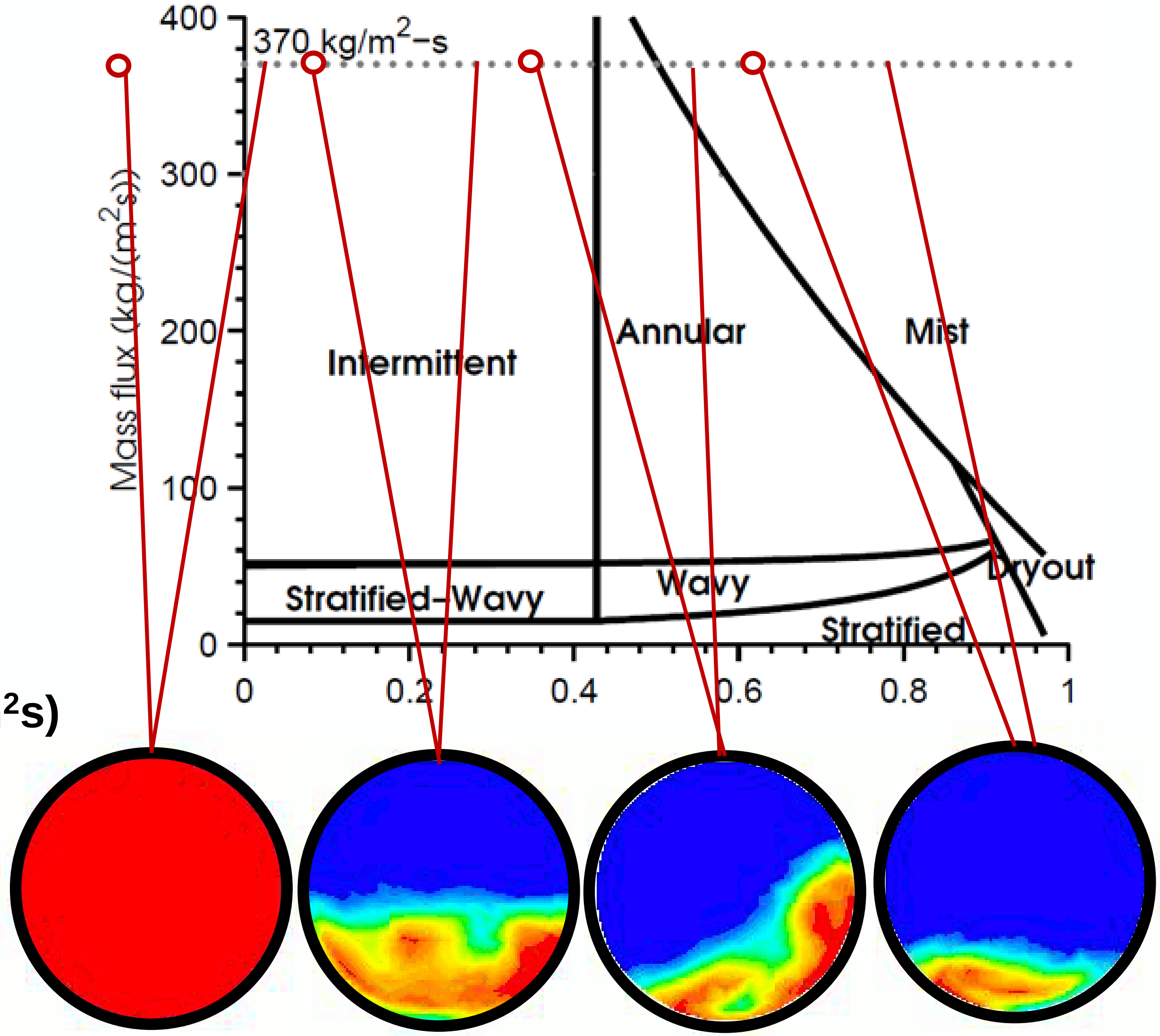
Simulation conditions

370 kg/(m^{2}s)

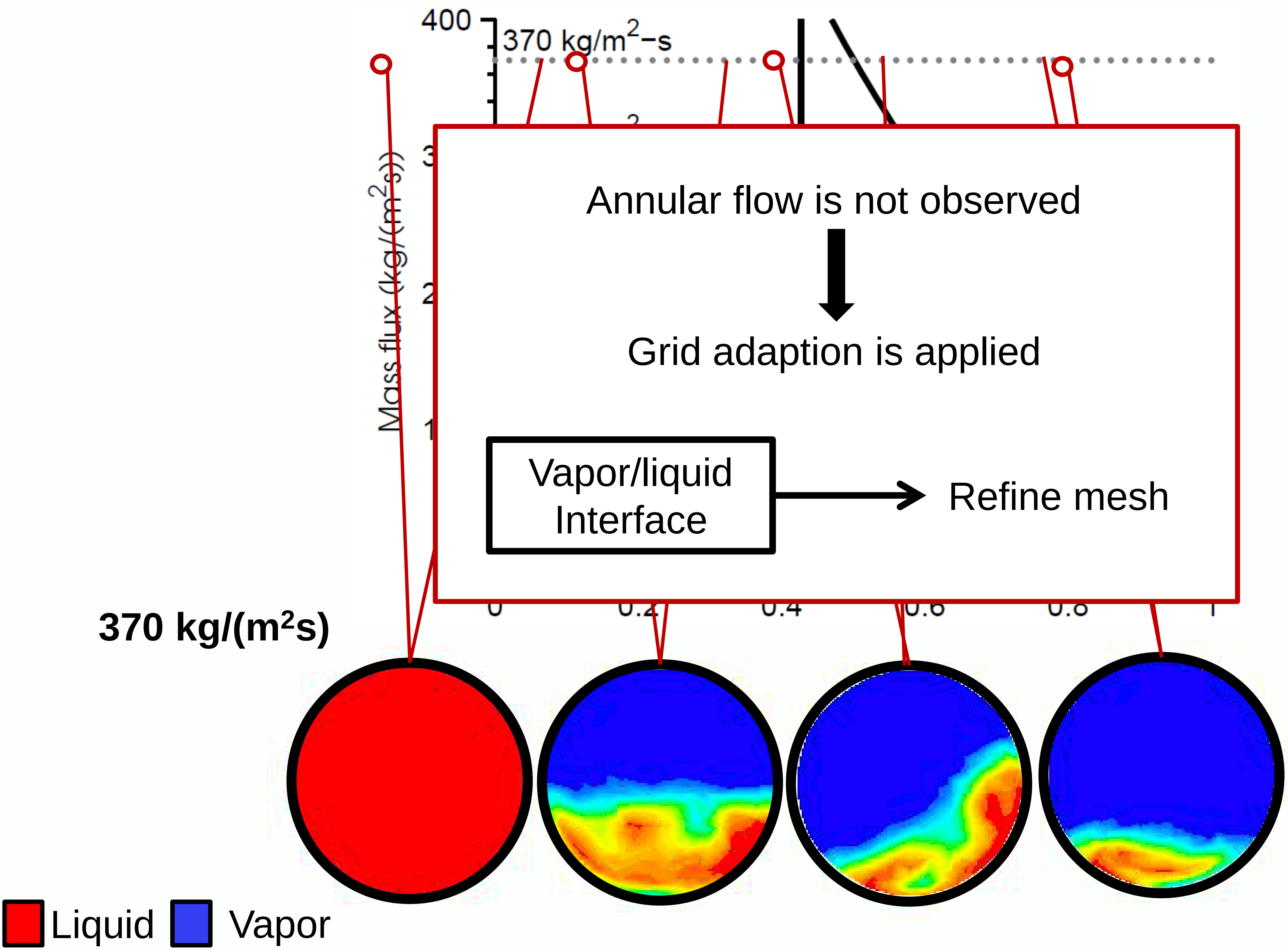


CFD results

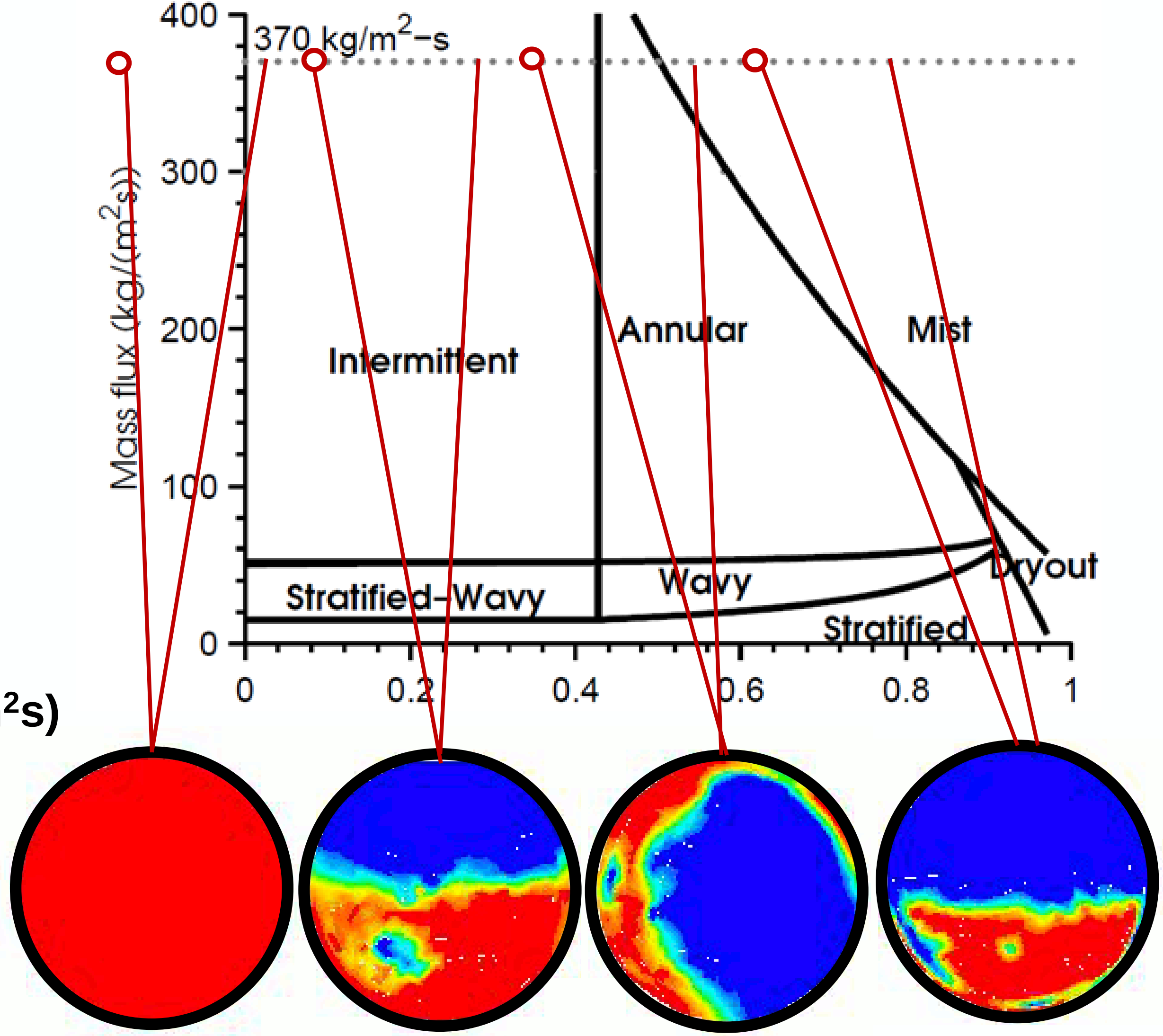
370 kg/(m²s)



CFD results


400
370 kg/m^2–s
Mass flux (kg/(m^{2}s))
Annular flow is not observed
Grid adaption is applied
Vapor/liquid Interface
Refine mesh
0
0.2
0.4
0.6
0.8
1
370 kg/(m^{2}s)
Liquid
Vapor

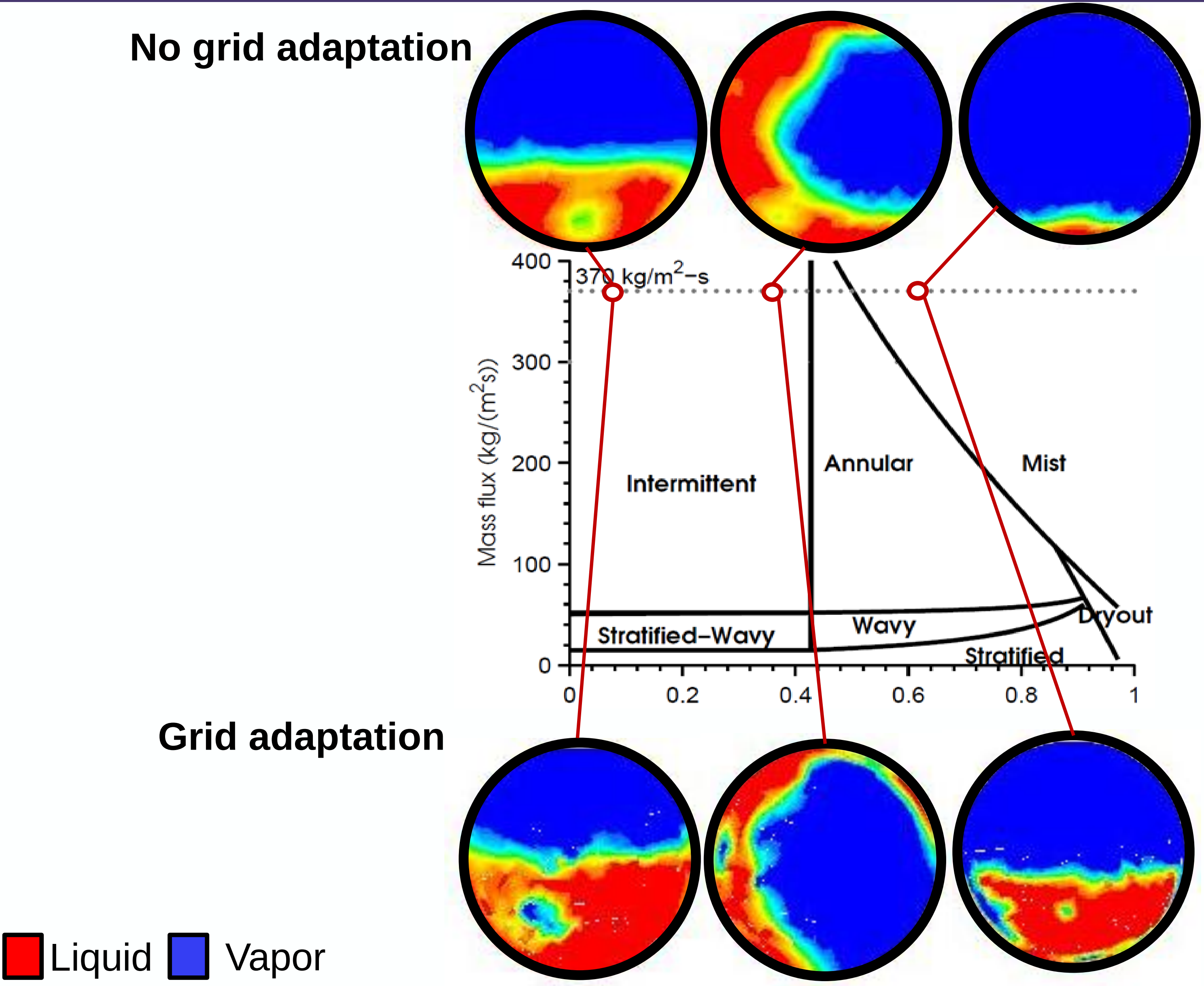
CFD results – Grid adaption



370 kg/(m^{2}s)

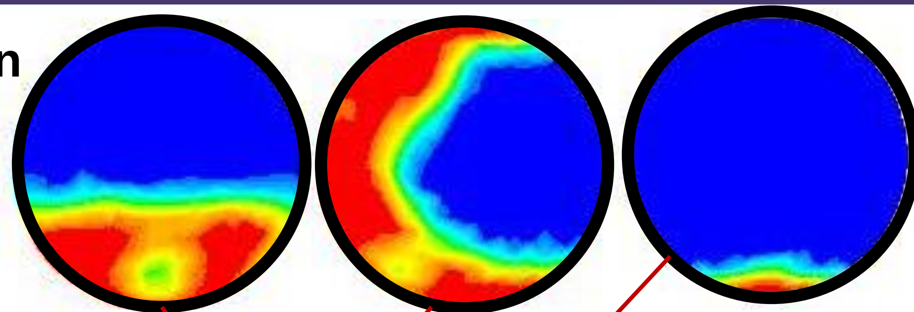
Liquid Vapor

CFD results – Grid adaption



CFD results – Grid adaption

No grid adaptation



Annular flow still not stable

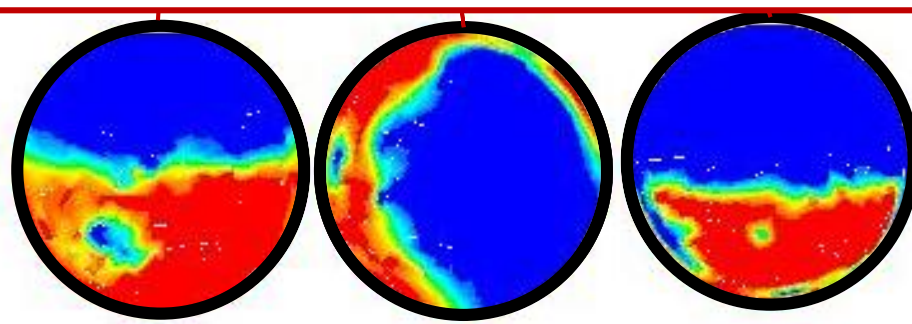
↓

Nucleation at the wall not modeled
Lack of nucleation models

↕

Accurate regime map?

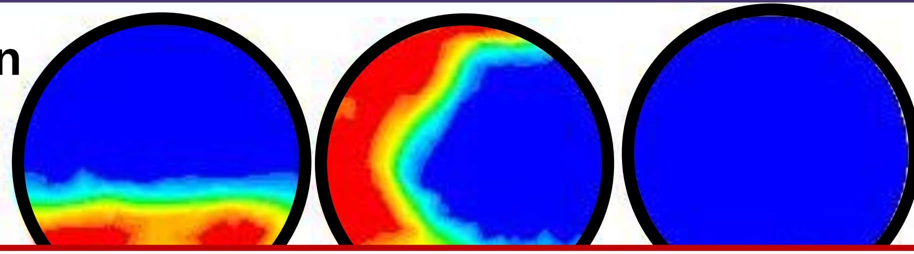
Grid adaptation



Liquid Vapor

CFD results – Grid adaption

No grid adaptation



Annular flow not stable

⬇

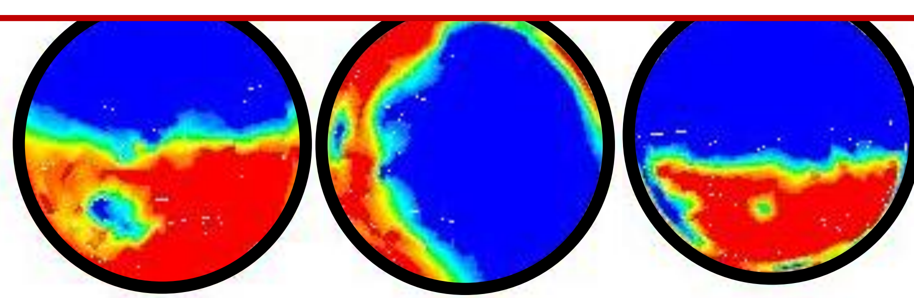
Wall is less wetted as expected

⬇

Heat transfer coefficient ↘

Wall temperature ↗

Grid adaptation



Liquid Vapor

Conclusions & future work

Adiabatic CFD model was validated by Baker chart

Diabatic CFD simulations did not completely agree with the constructed regime map

- Proper regime map?
- Nucleation at the wall

acknowledgement

Long Term Structural Methusalem Funding
by the Flemish Government

UGent High-Performance Computing
Stevin