Effect of front and side confinement on a vertical heated plate with two phase cooling

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Summary

Introduction & context

Why immersion cooling in the automotive field?

Heat to be dissipated from EV components is increasing:

- Battery
- E-Powertrain
- Processors

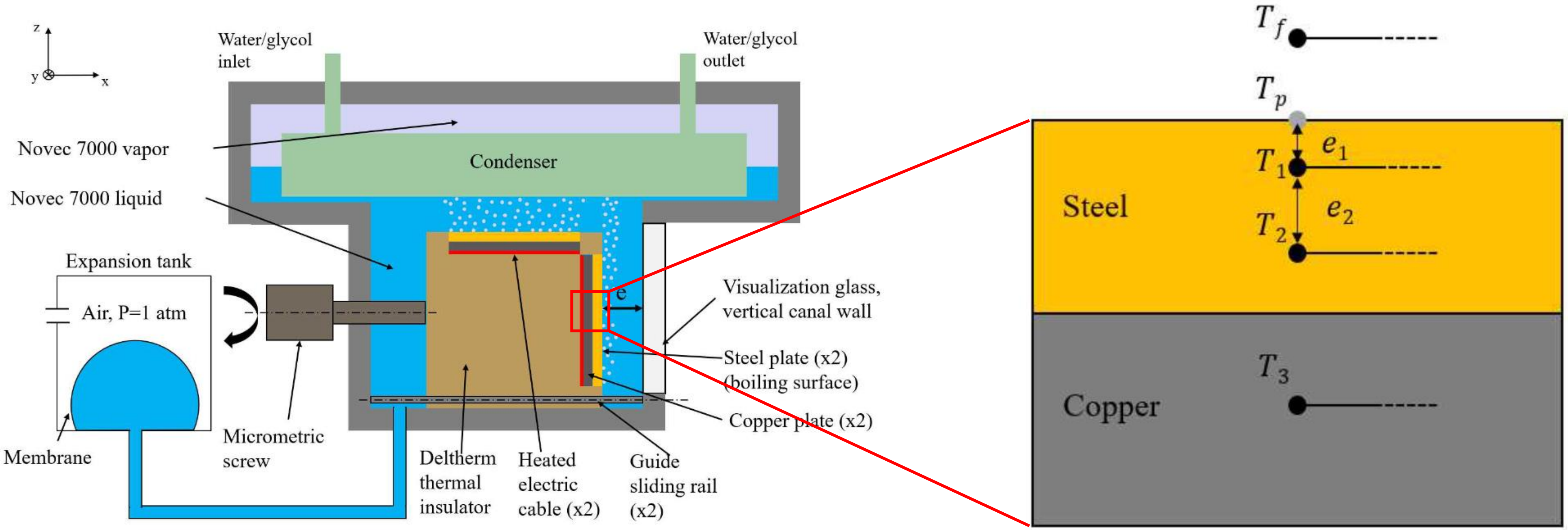
Two-phase pool boiling: simple system, passive (no pump required), high heat transfer coefficient can be reached

In order to enhance efficiency and compactness -> **confined boiling**

A. della Volpe Thesis (2021-2024): Boiling of dielectric fluid on a horizontal and vertical plate: confinement study

Introduction & context

Experimental setup



$HFE\ 7000$

$Tsat = 34°\mathrm{C}\ |\ P_{atm}$

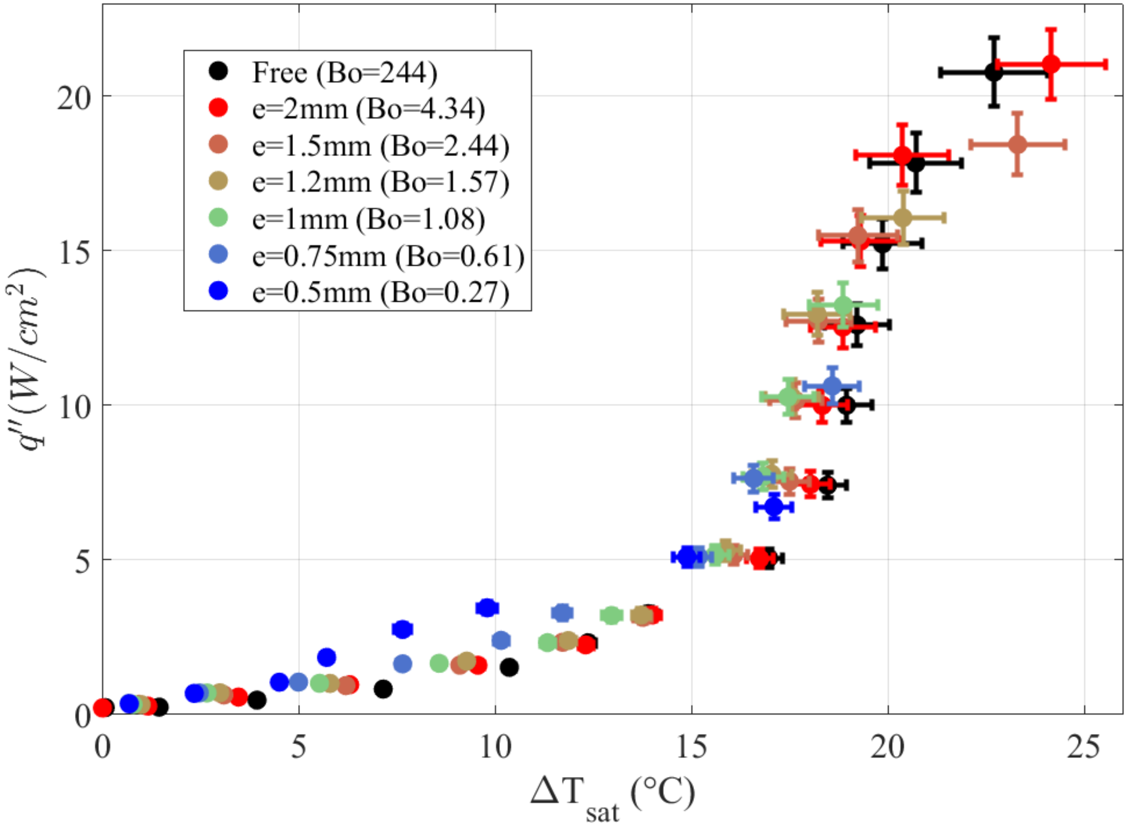
$\phi = \{\,0 - 20\,\}\mathrm{W/cm^2}$

$e = \{\,0.5 - 15\,\}\mathrm{mm} \pm 0.003$

A. della Volpe et al.
Appl. Therm. Eng. 2024

Introduction & context

Key results from A. della Volpe



→ Increased fluid velocity along the plate which leads to less bubble wait time and more bubbles rising to the top

→ Enhanced cooling rate due to the bigger number of bubbles rising up and cold fluid settling down instead

At low heat flux q'' :

- ΔT_{sat} decreases with increasing confinement

At high heat flux q'' :

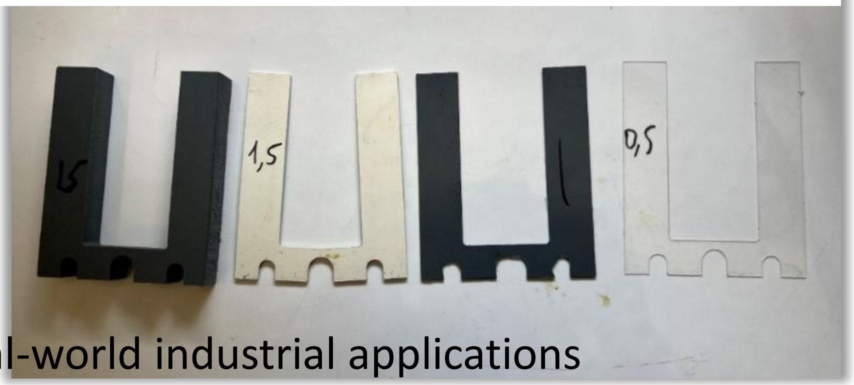
- Confinement decreases ΔT_{sat} as long as the critical heat flux is not reached

A. della Volpe et al. Appl. Therm. Eng. 2024

Summary

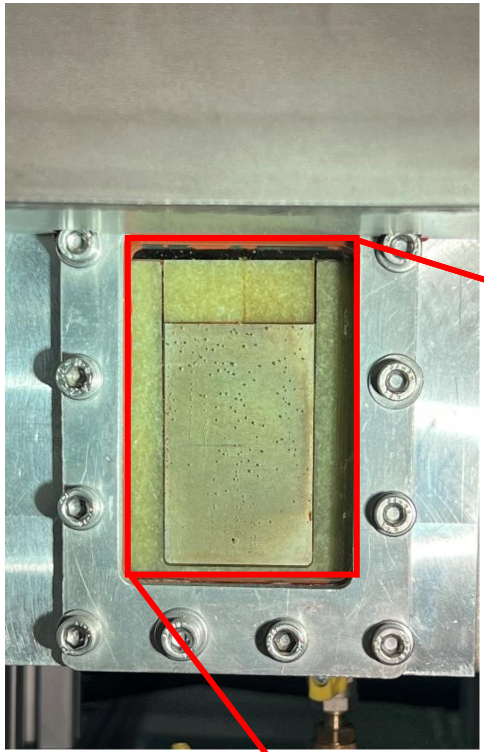
New experiments using a U-shaped plate

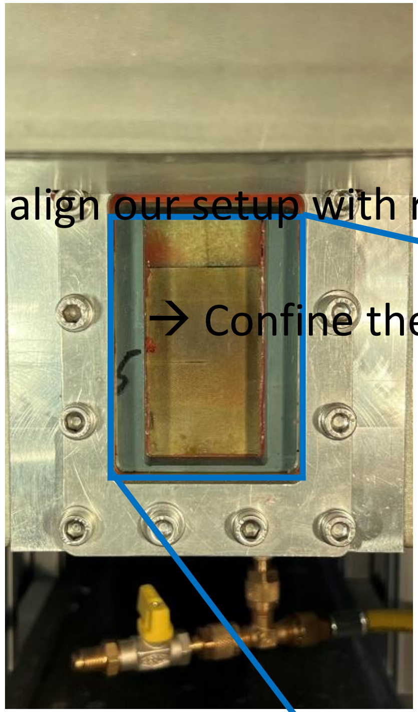
PVC U-plates – different thickness



To align our setup with real-world industrial applications

→ Confine the area around the hot plate more effectively



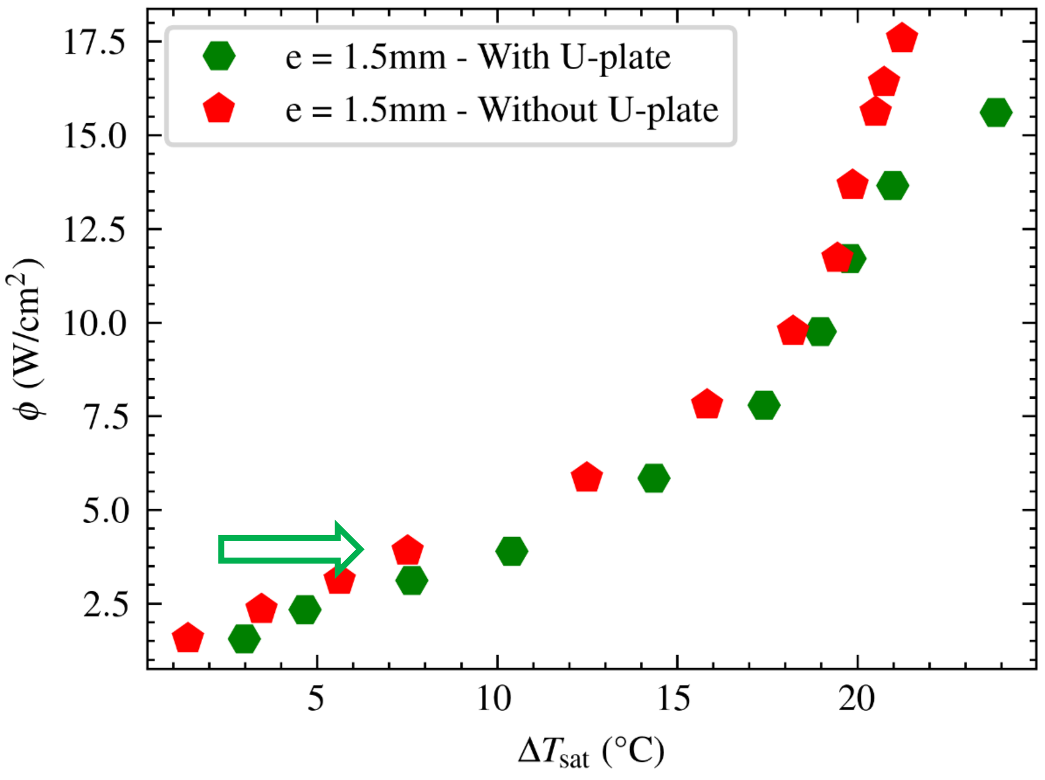


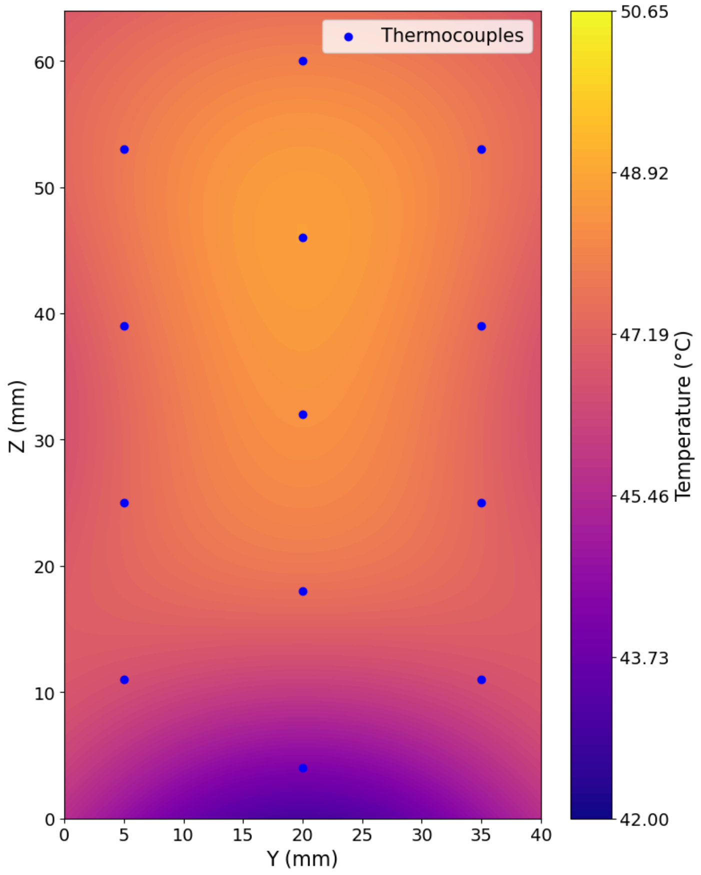
New experiments using a U-shaped plate

Boiling curve

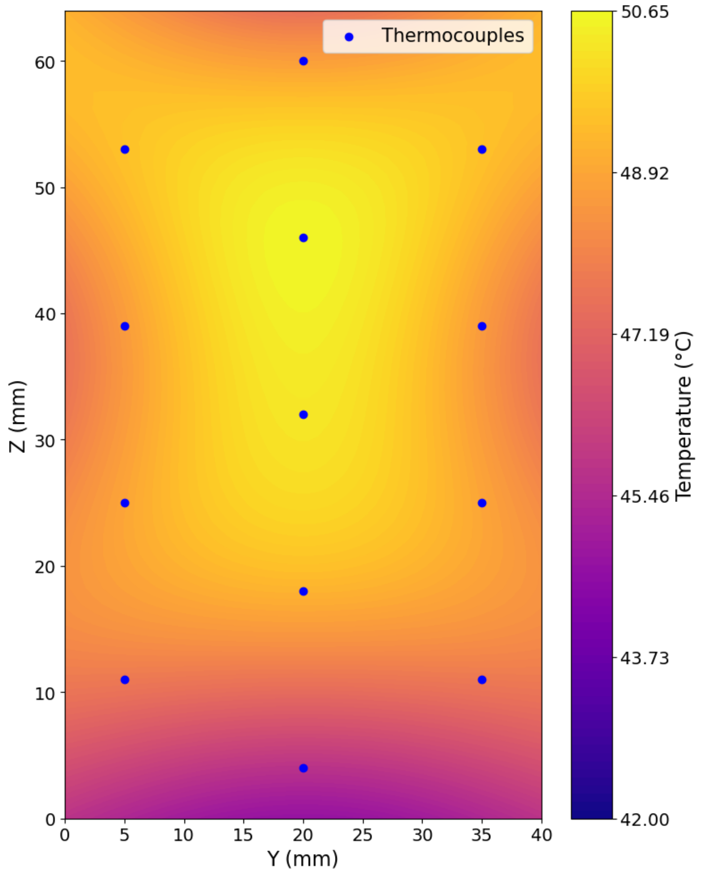
$e = 1.5$ mm $\quad \phi = 4$ W/cm^2

At the middle of the heated plate



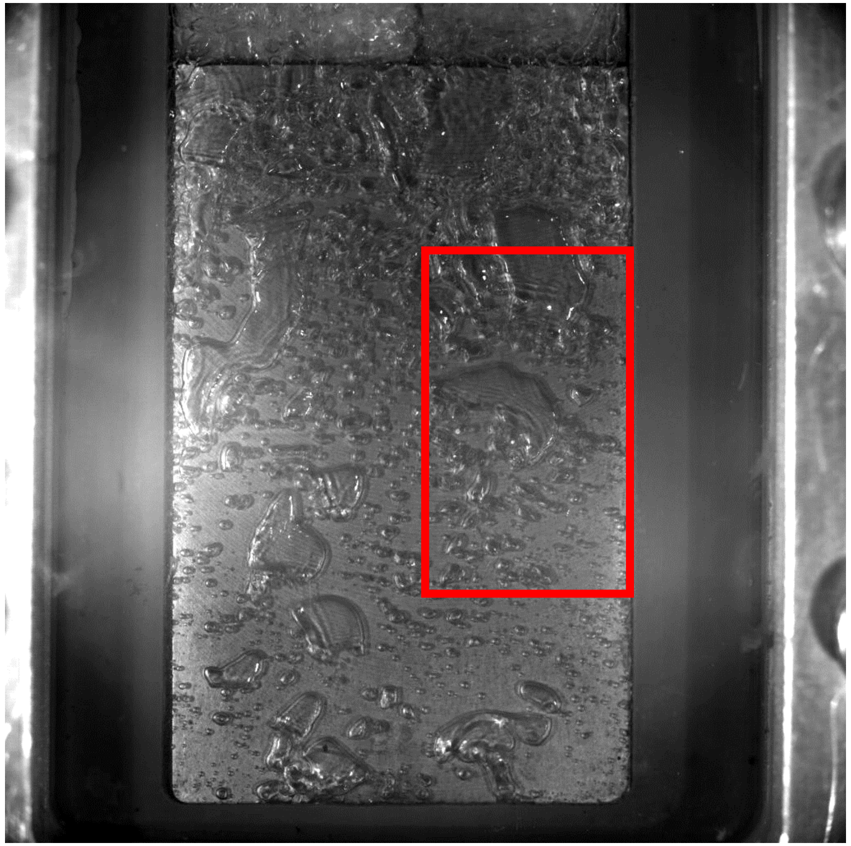


Without U - plate



With U - plate

New experiments using a U-shaped plate



- Unusual bubble movement observed during heating
- Descending swirling motion spotted at the right side of the heated plate

→ Need to analyse the videos using different techniques

→ Try to quantify those videos and correlate them with the experimental results

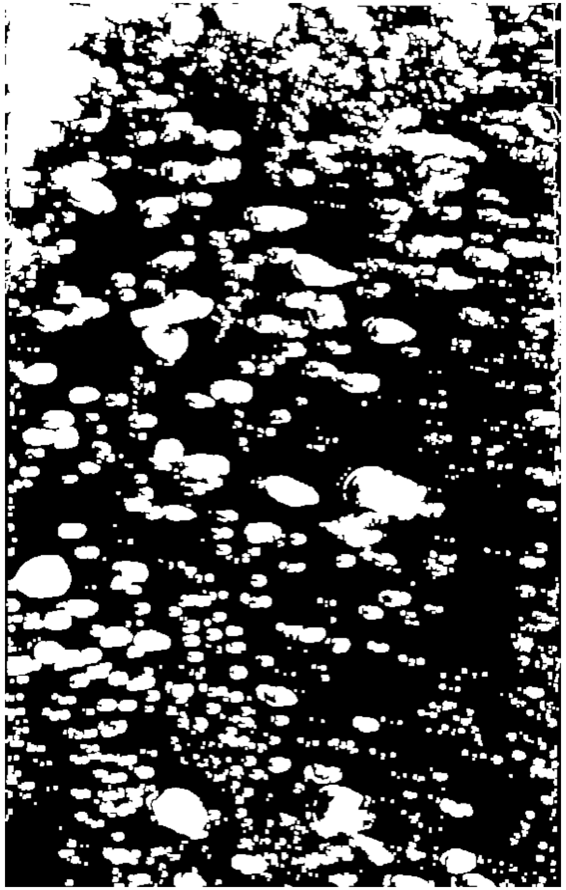
Summary

LTEN

Image analysis

Binarization

$e = 1.5\ \mathrm{mm} \quad \phi = 4\ \mathrm{W/cm^2}$

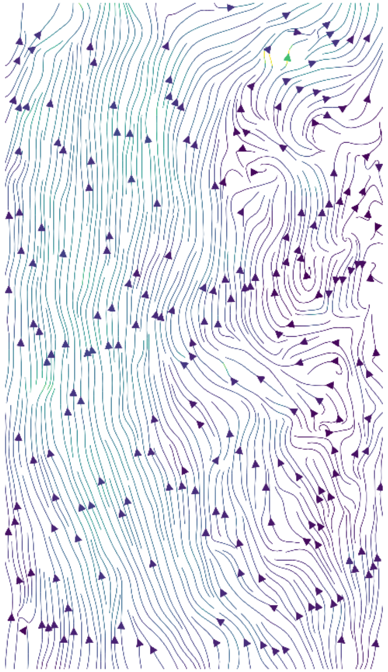


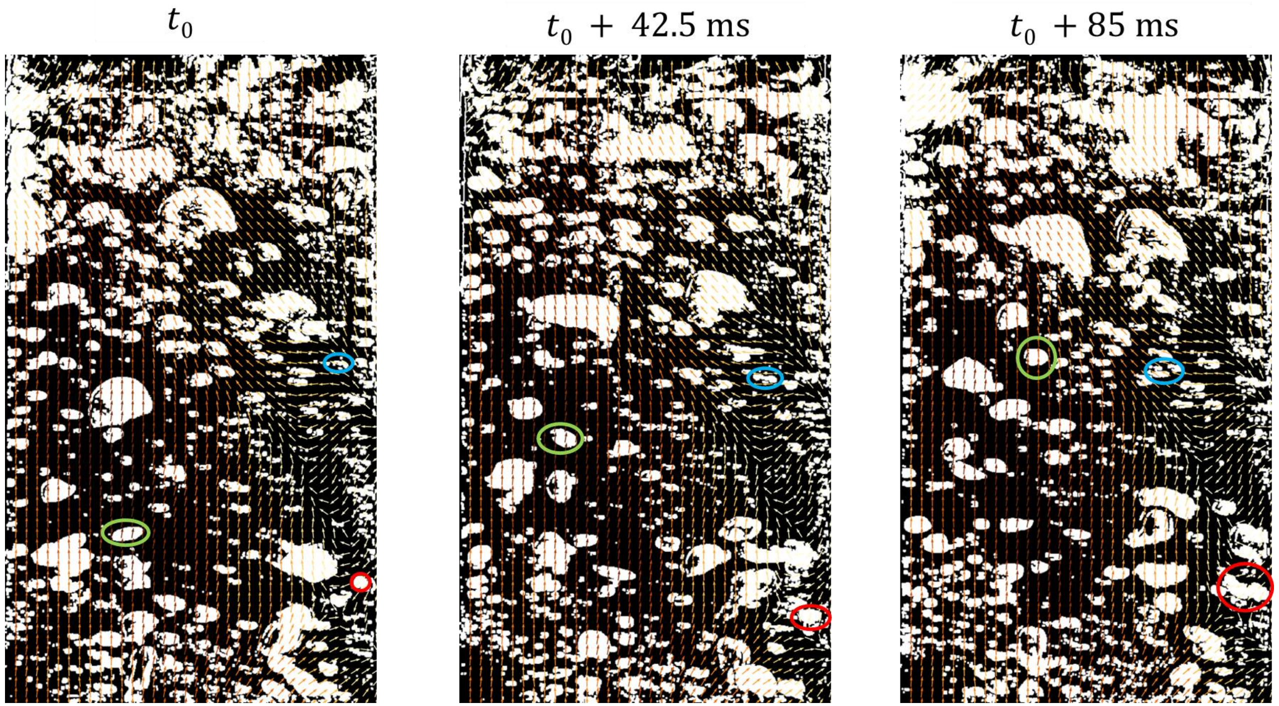
→ Otsu binarization method

→ Mathematical filters have been applied

Image analysis

PIV-like analysis





Red bubble: downward spiral movement preceeding the upward motion

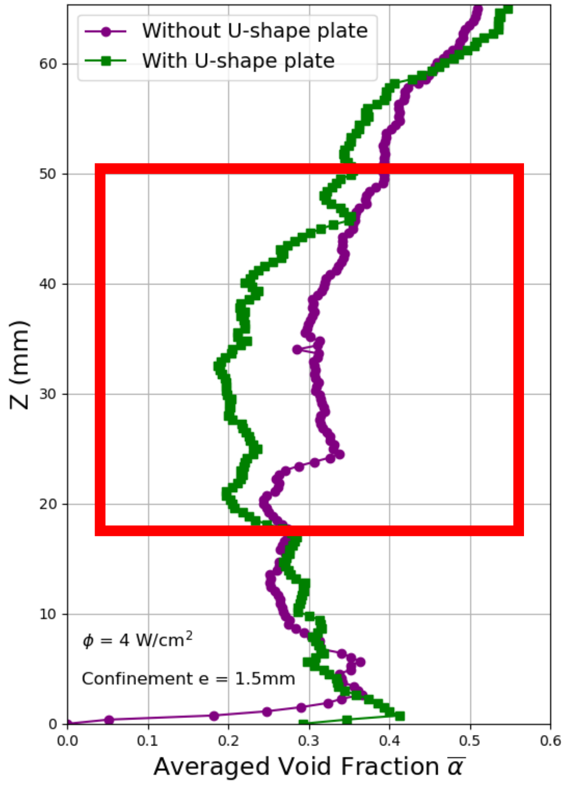
Green bubble: normal upward motion

Blue bubble: Horizontal motion preceeding the upward motion

Image analysis

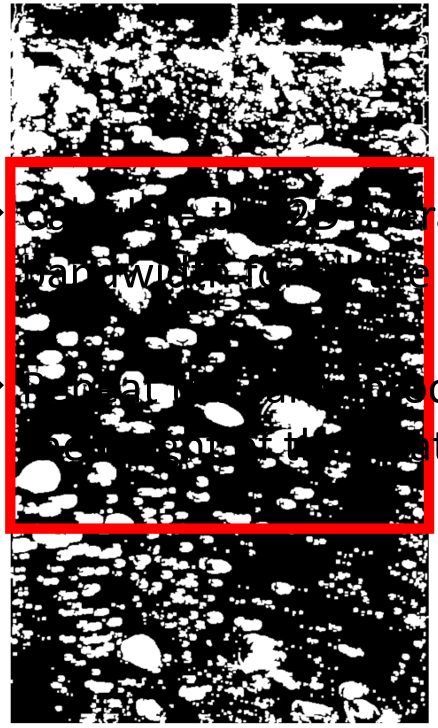
Void fraction comparison

$e = 1.5\ \mathrm{mm} \qquad \phi = 4\ \mathrm{W/cm^2}$

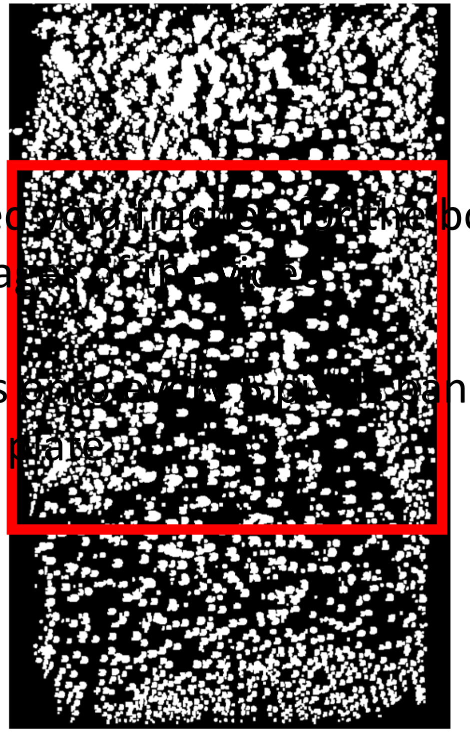


→ ... averaged void fraction ... bottom 5 pixels bandwidth ... images ...

→ ... process ... bandwidth sliding up ... heated plate.



With U-plate



Without U-plate

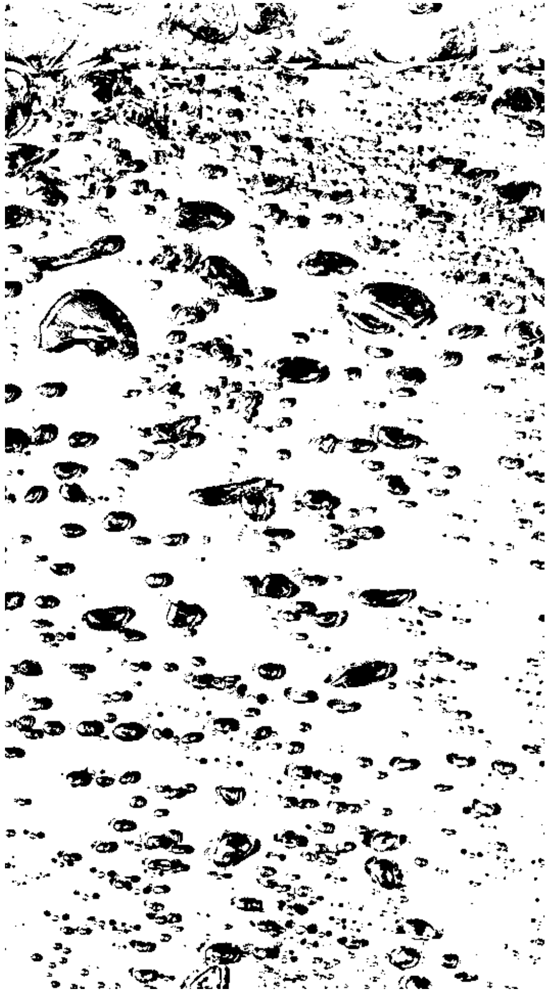
The usage of the U-plate reduced the void fraction at the center of the heated plate.

Likely reasons:

- Increased bubble coalescence.
- Many small, isolated bubbles merged into fewer, larger bubbles.

Image analysis

Bubble detection using machine learning



BubMask

Kim & Park
Scientifc Reports, 2021

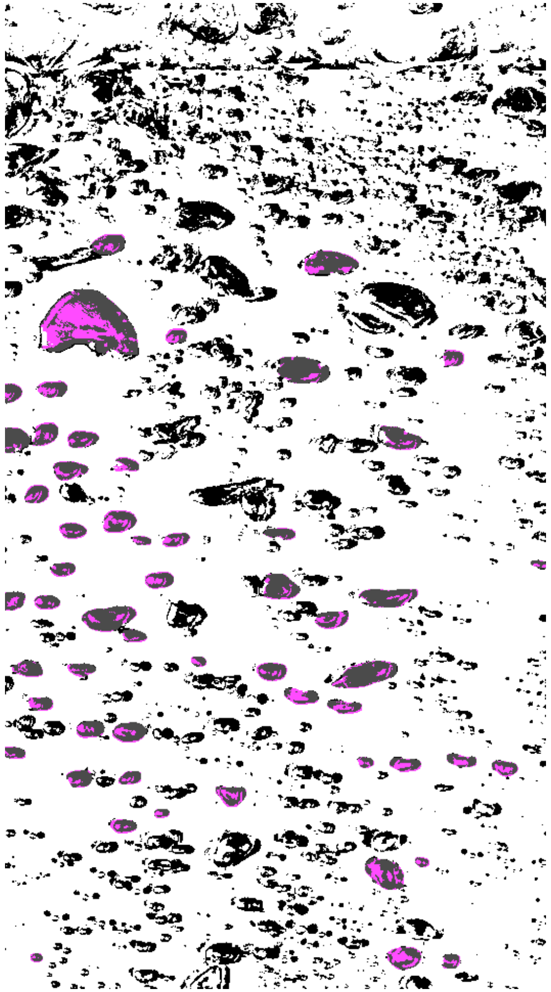
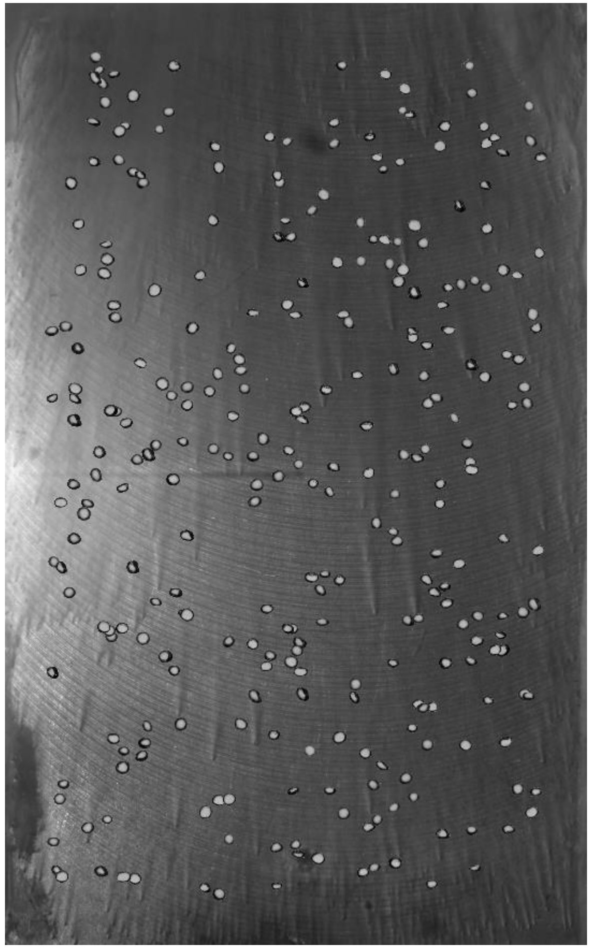
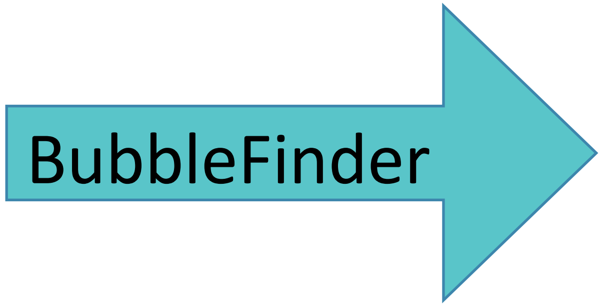
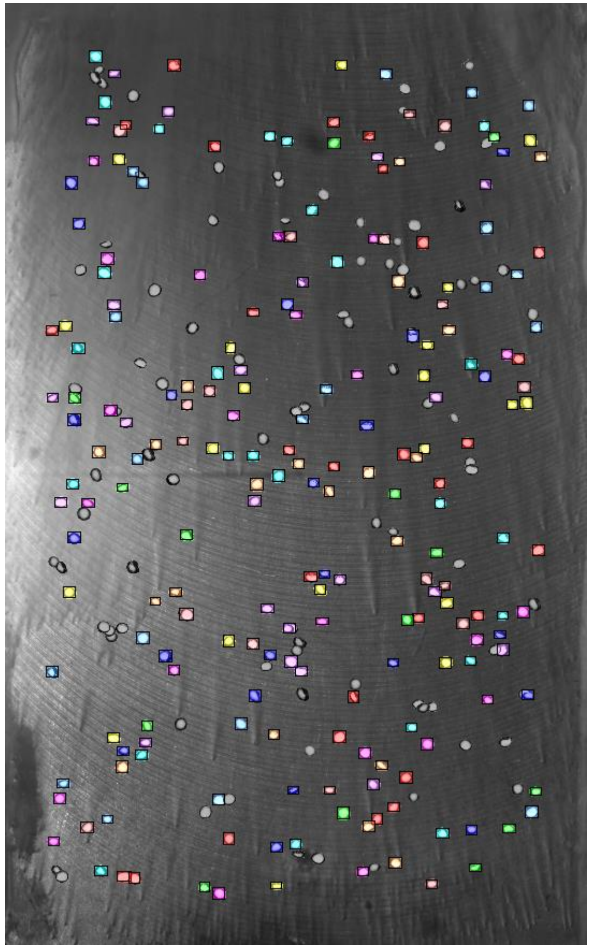


Image analysis

Bubble detection using machine learning



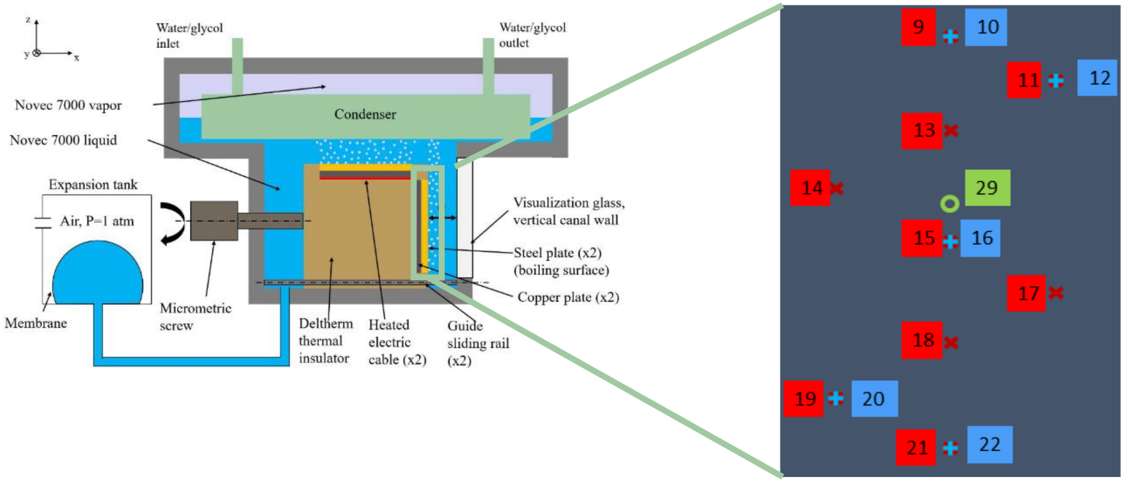




Current limitations/issues

- Only local measurement of temperature is possible

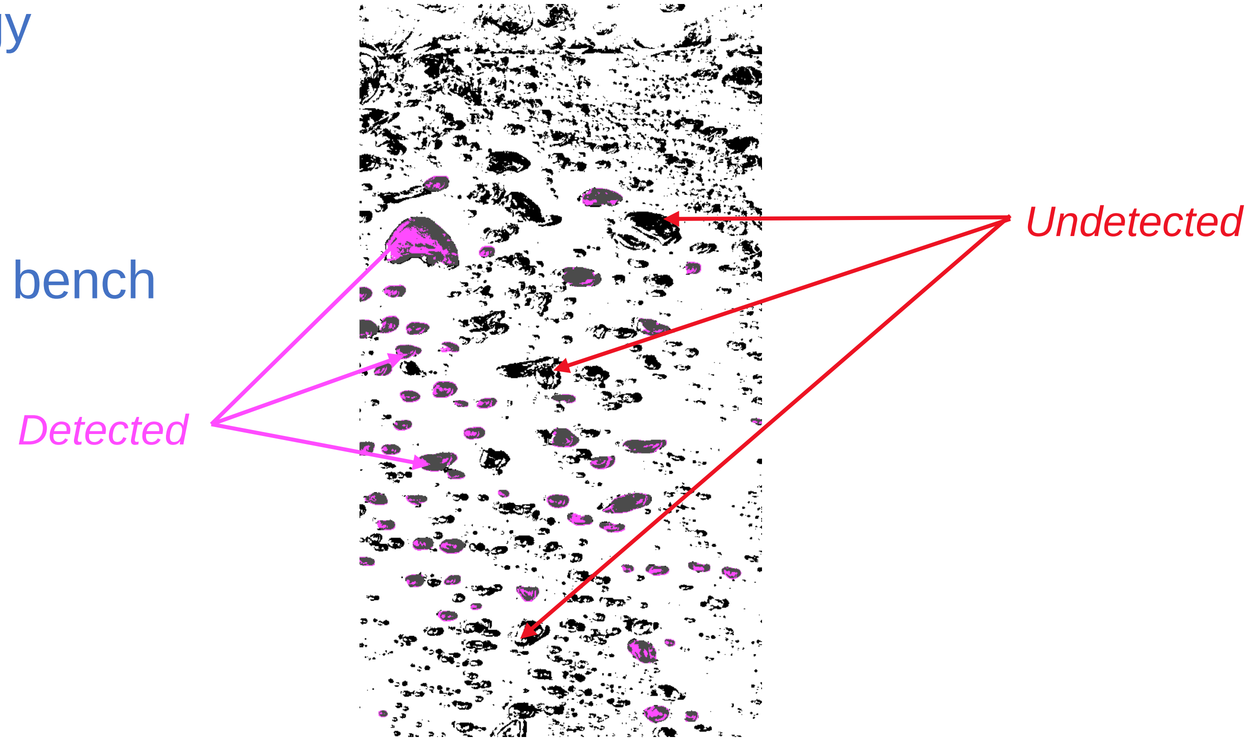
→ Need to acquire a field measurement



- Under detection of bubbles

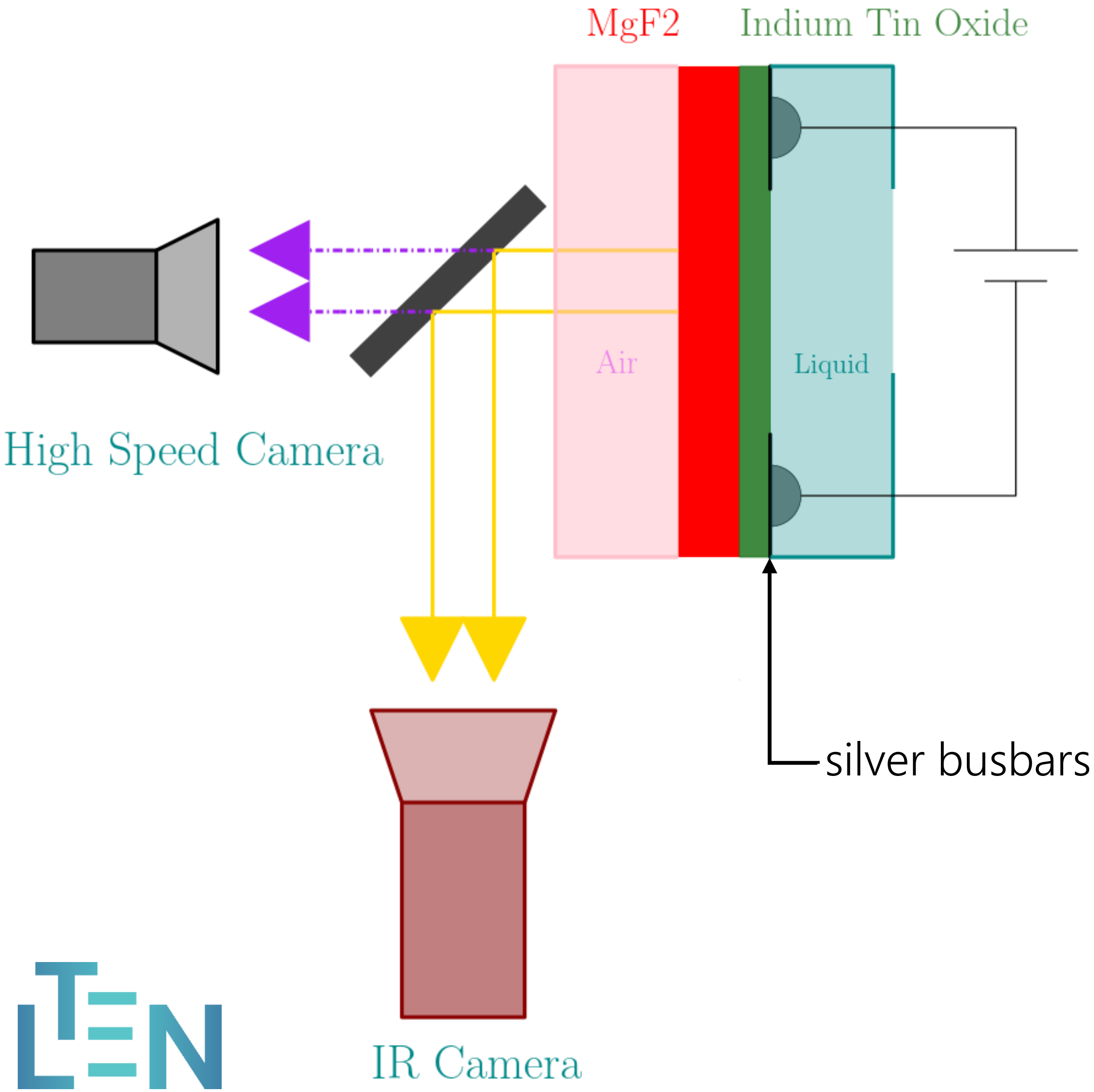
→ Employment of a more adapted detection strategy

→ Imperative need to develop/design a new lab test bench

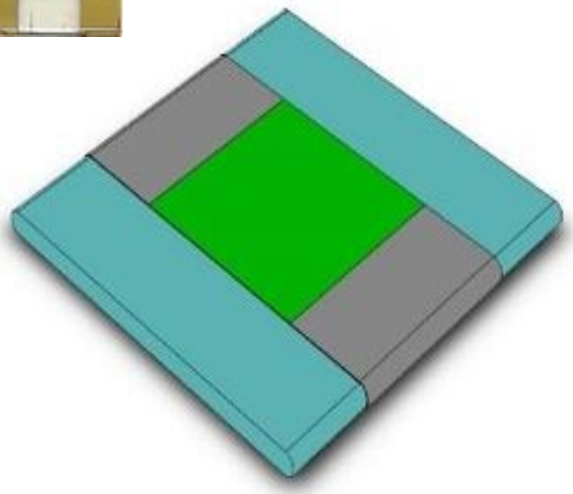


Summary

New experimental setup



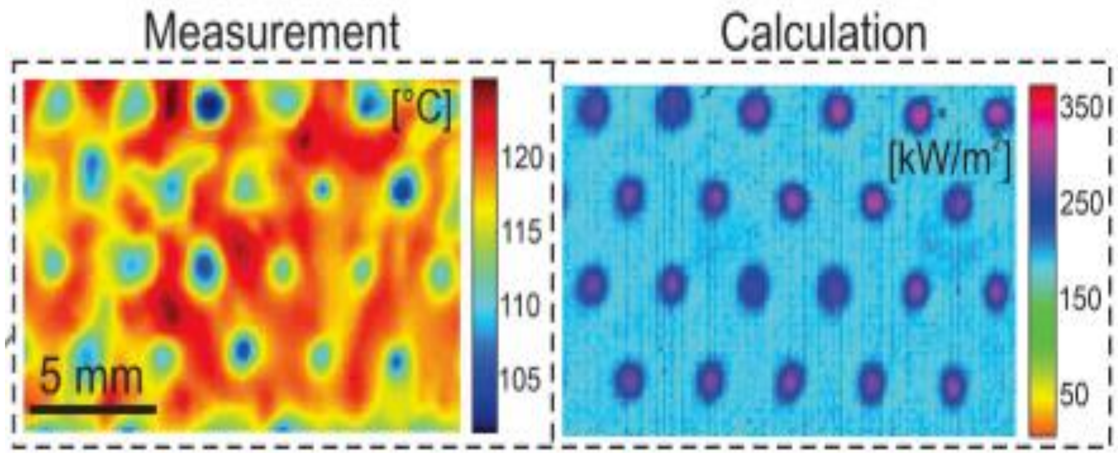
- ✓ Transparent material to IR light and to visual light: **MgF2**
- ✓ An IR-opaque, transparent to light, electrically semi-conductive coating serving as a boiling surface: **ITO**
- ✓ Conductive pads to connect electrical wires: **Silver busbars**



Bucci et al.
Exp. Therm. Fluid Sci. 2018

New experimental setup

Perspectives

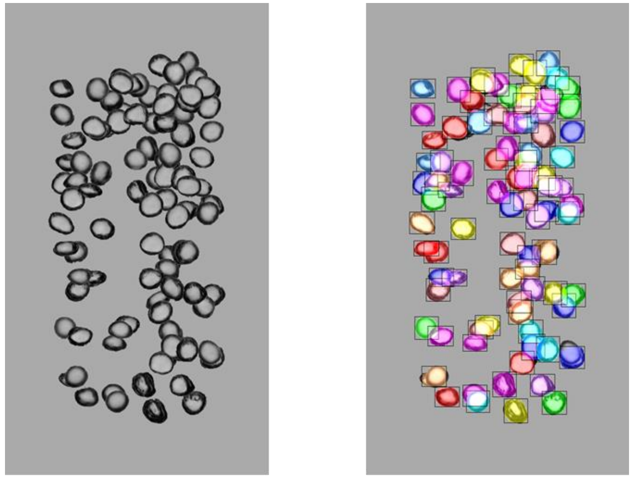


M. Bucci et al.
Appl. Therm. Eng. 2021

- Vertical heated wall only
- IR thermography: $T(y, z)$ and $\phi(y, z)$
- LED phase detection + high speed imaging: flow description

Deep learning algorithms:

- ➢ Synthetic model → training → bubble velocity/diameter
- ➢ Flow classification



BubbleFinder

PFAS ban: test of mixtures

PFAS = Per- and Polyfluoroalkyl Substances ("forever chemicals")

- **Highly persistent** in the environment and human body
- **Linked** to health risks (e.g., cancer, immune issues)

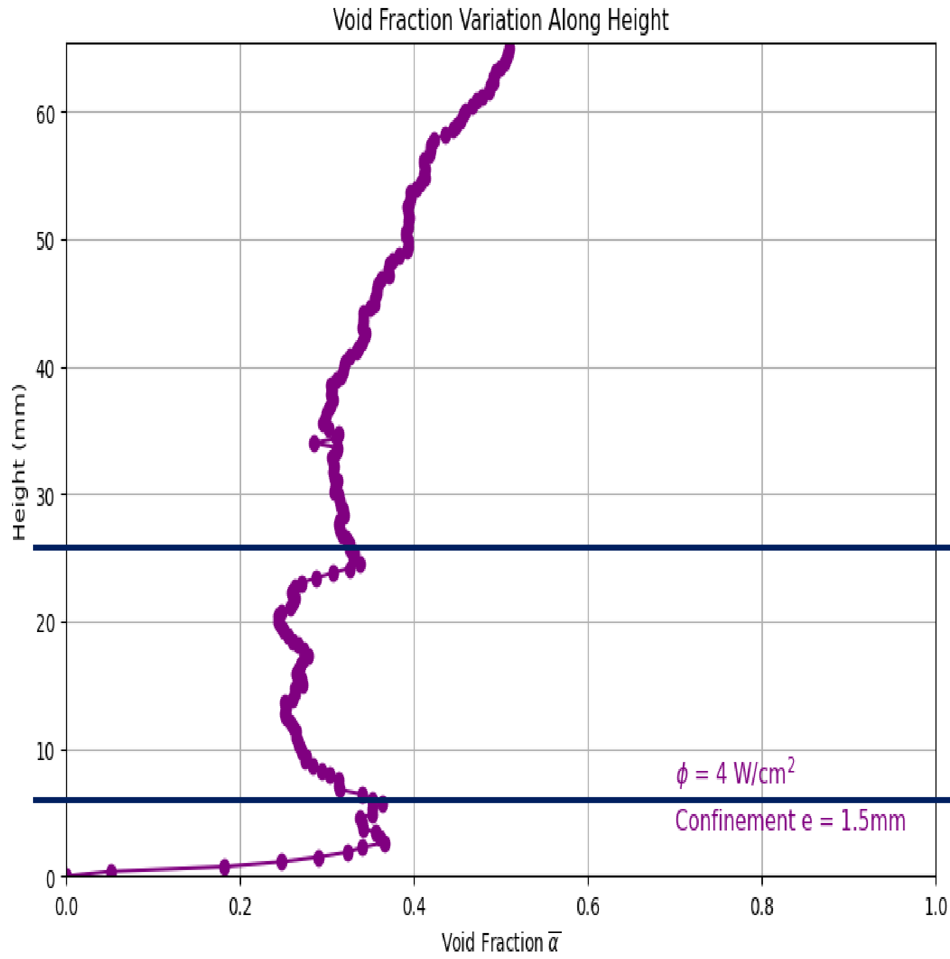
Bans & restrictions being introduced globally.
The EU aims to ban most PFAS by 2025.

A need to test several mixtures:

- Water + Ethanol
- Ammonia + Water

Thank you

Annexe



Loi de conservation de masse:

$$V = \frac{4}{3}\pi {R_2}^3 = 2 * \frac{4}{3}\pi {R_1}^3$$

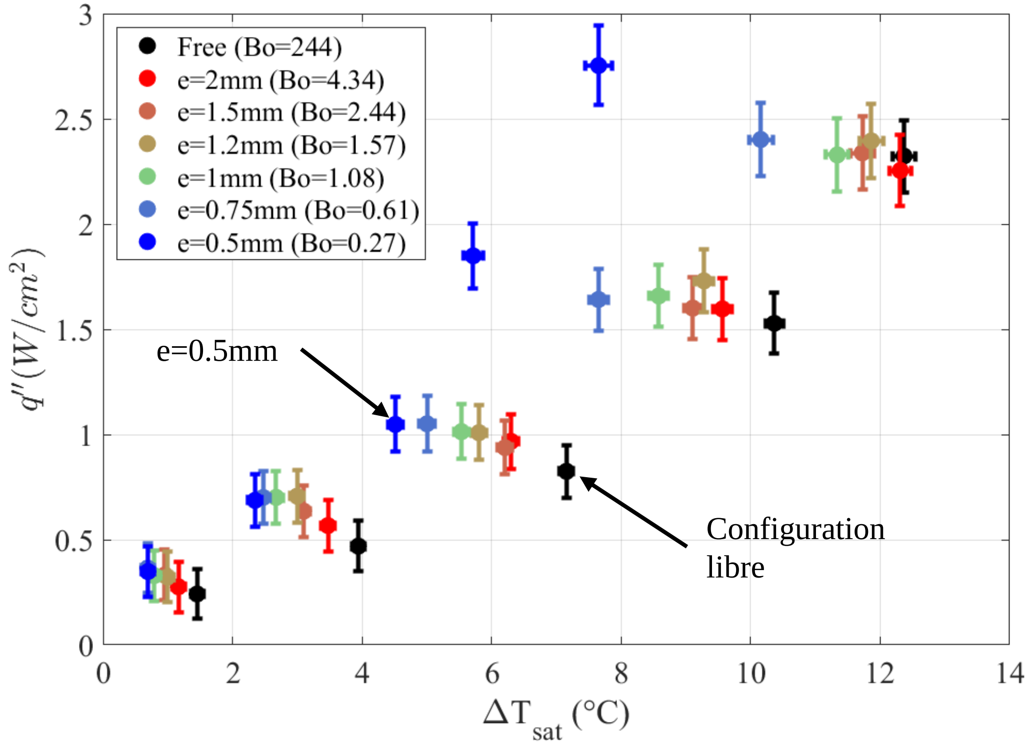
$$R_2 = 1.26 R_1$$

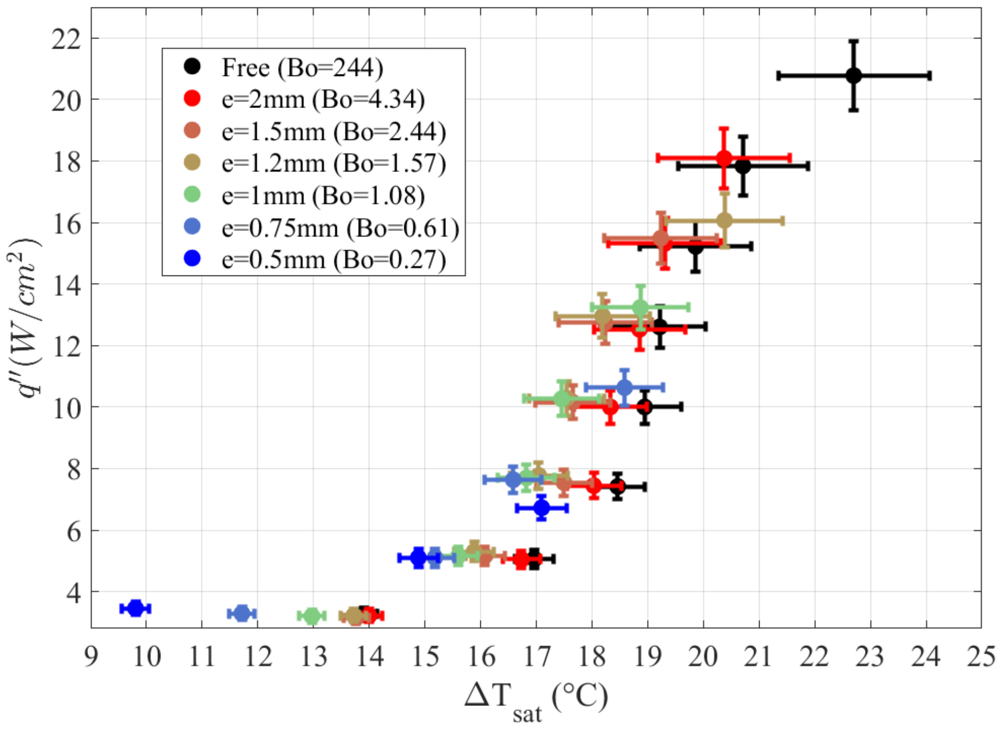
20 bulles de volume
V2 = 2V1 et rayon
R2 = 1,26 * R1

$$\alpha_2 = \frac{25*\pi*{R_2}^2}{R_2*e} = \frac{25*\pi*R_2}{e} = \frac{31{,}5*\pi*R_1}{e} < \alpha_1$$

40 bulles isolées de
volume V1 et rayon
R1 = 0,1 mm

$$\alpha_1 = \frac{40*\pi*{R_1}^2}{R_1*e} = \frac{40*\pi*R_1}{e}$$


Free (Bo=244)
e=2mm (Bo=4.34)
e=1.5mm (Bo=2.44)
e=1.2mm (Bo=1.57)
e=1mm (Bo=1.08)
e=0.75mm (Bo=0.61)
e=0.5mm (Bo=0.27)
e=0.5mm
Configuration libre
$q''(W/cm^2)$
ΔT_{sat} (°C)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