Influence du confinement sur différents régimes d'ébullitions

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Summary

Introduction & context

Interest of immersion cooling for automotive field

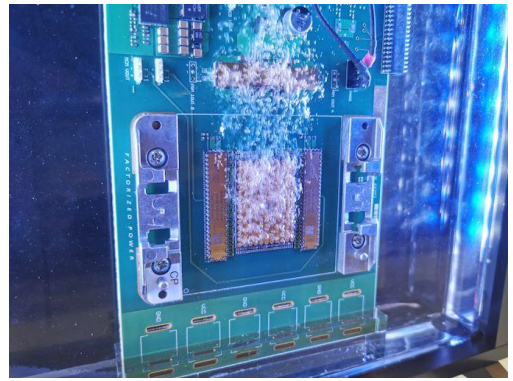
EVs components thermal outputs steadily increasing:
- Controllers/processors
- Battery thermal management & A/C
- Powertrain

Pool boiling: simple system, passive (no pump required)

Need to enhance efficiency and compactness ->
confined boiling

Confinement -> **risk of critical heat flux**

Today: 130kW DC charge
Target: 350kW DC charge

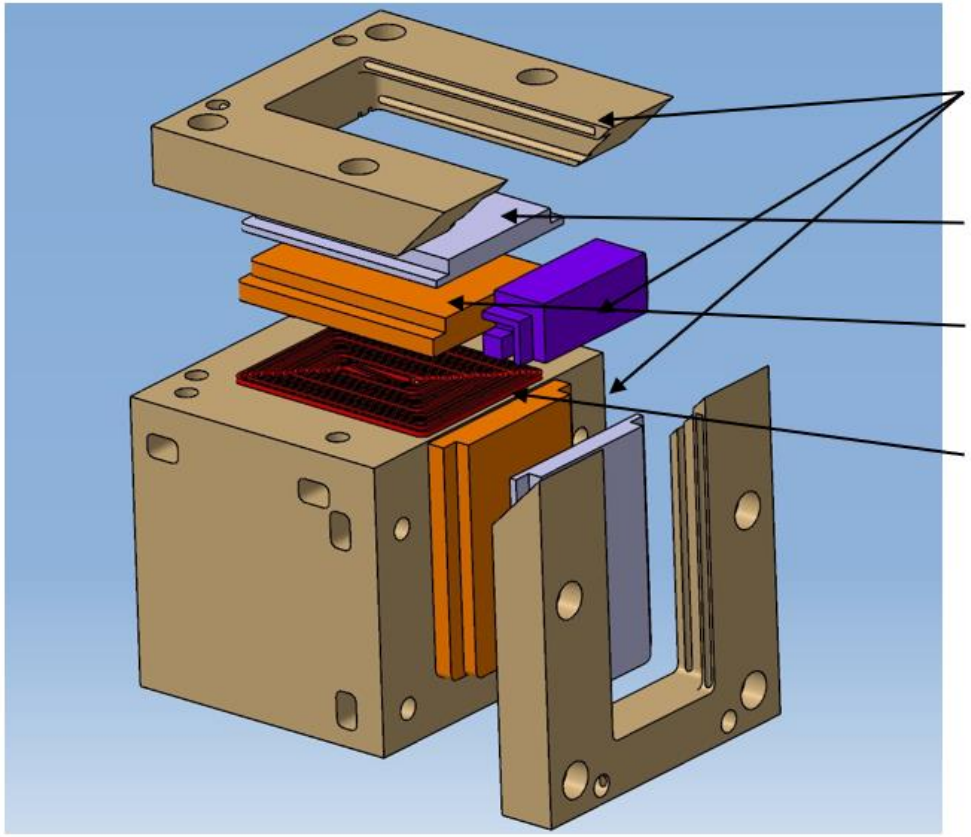


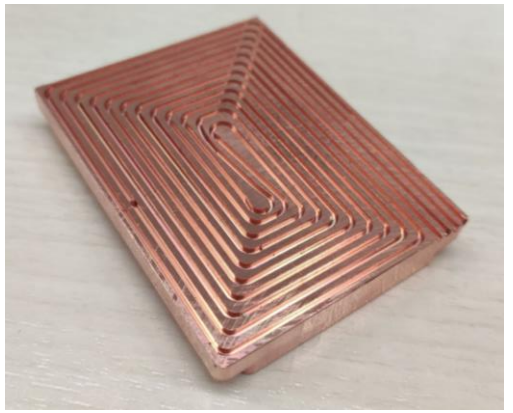
Need for specific study with a dielectric fluid
Construction of new test bench

Summary

Heating elements

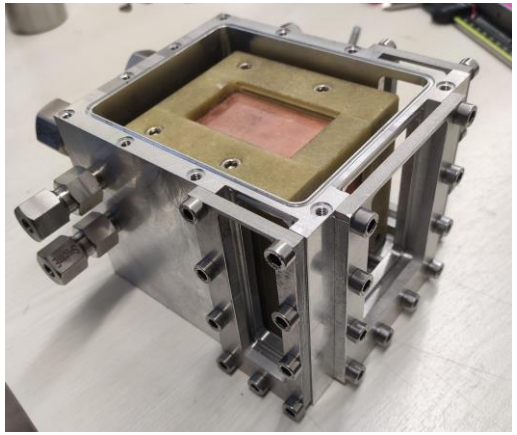
Two heated plates at a 90° angle





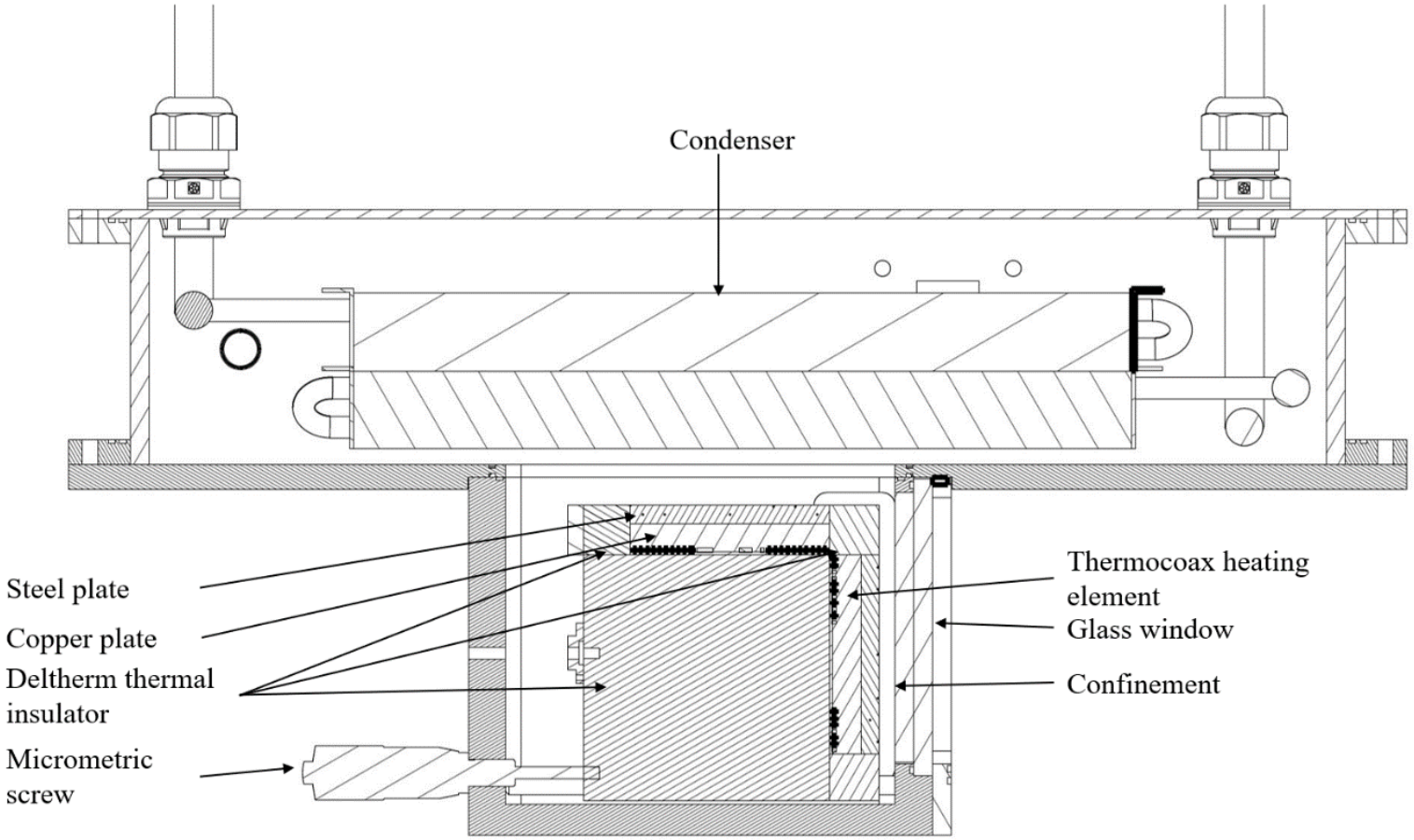
Back of copper plate, with groove for heating element cable

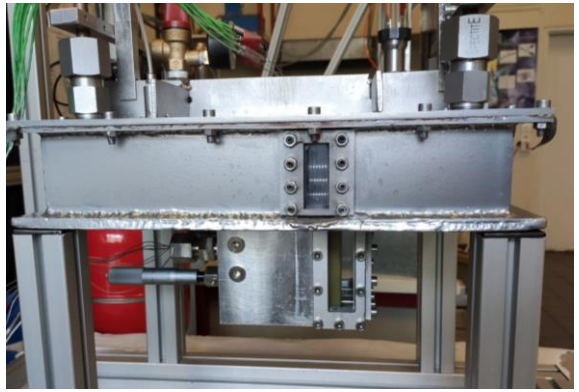
Assembled in lower part of testbench



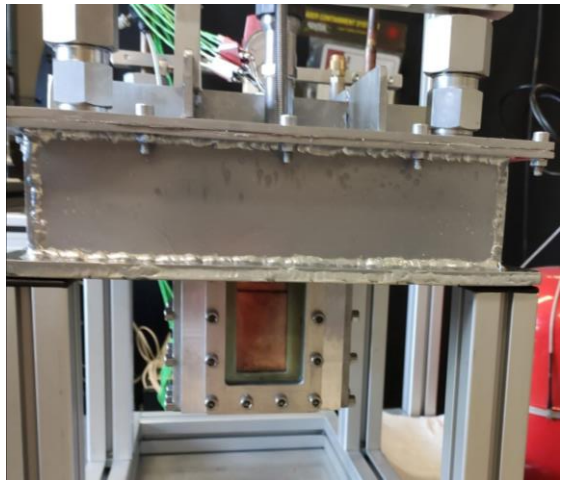
Experimental apparatus

General assembly





Side view



Front view

Experimental apparatus

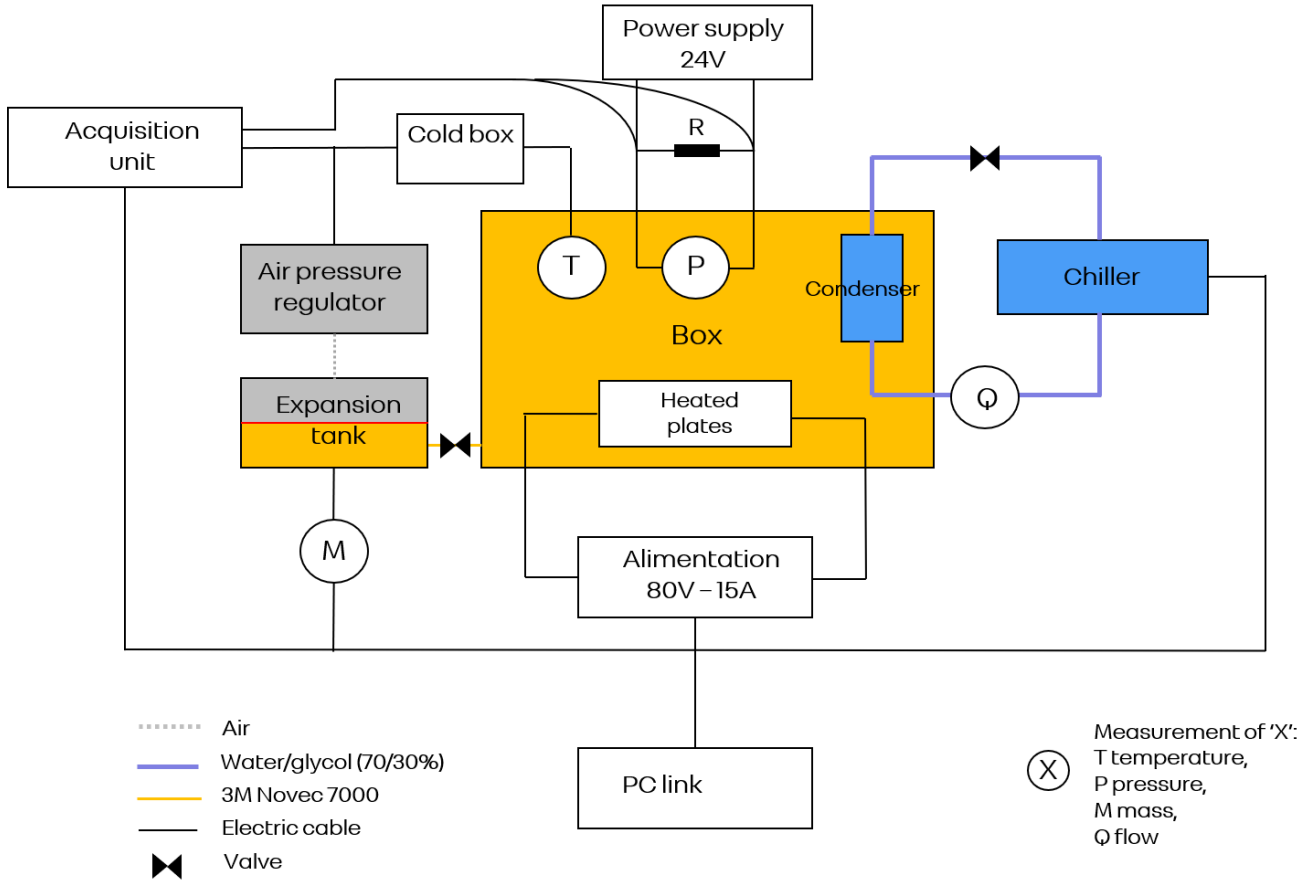
Measurements

45 K-type thermocouples in total:
-> in fluid and in heated plates

Absolute pressure sensor

Chiller to set condenser coolant mass flow and temperature

Expansion tank to regulate pressure



Summary

Data reduction

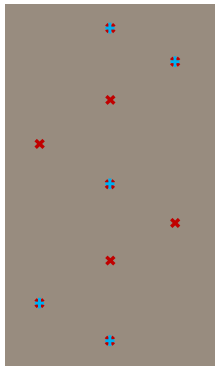
Thermocouples at two depths to measure heat flux

$$T_S = T_1 - R_{th,1} q'' S \quad (1) \qquad q'' S = \frac{T_2 - T_1}{R_{th,2}} \quad (2)$$

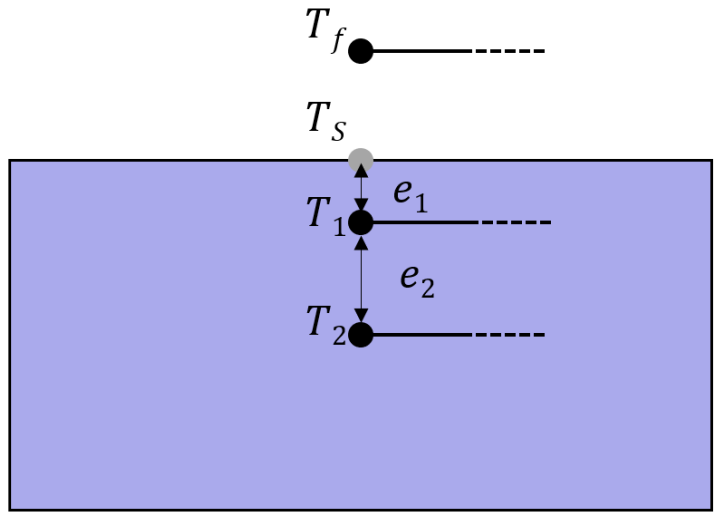
T_x: fluid temperature at x $(°C)$
R_{th}: thermal conductive resistance (K/W)
q'': heat flux density (W/m^2)
S: surface area perpendicular to heat flux (m^2)

ΔT: wall superheat $(°C)$

h: heat exchange coefficient $(W/m^2.K)$



$e1 = 0.7\ mm, e2 = 2.3mm$



$$T_S = T_1 - \frac{e_1}{e_2}(T_2 - T_1) \quad (3)$$

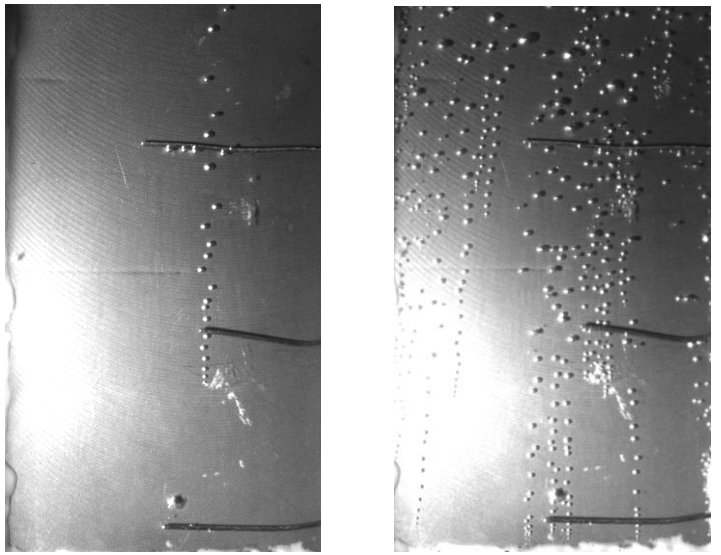
$$\Delta T = T_s - T_{sat}(P) \quad (4)$$

$$h = \frac{q''}{T_s - T_f} \quad (5)$$

Results and data analysis

Experimental procedure

- Filling/draining/filtration of refrigerant
- Boiling hysteresis
- Testing procedure
- Repeatability test



Increasing heat flux | Decreasing heat flux

Boiling hysteresis
visualization at 0,3 W/cm²

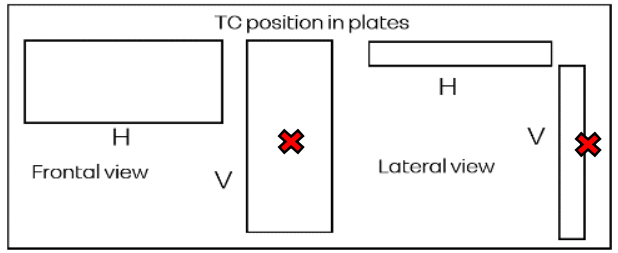
All boiling curves at decreasing heat flux

All points at atmospheric pressure (Novec 7000, $T_{sat} = 34°C$)

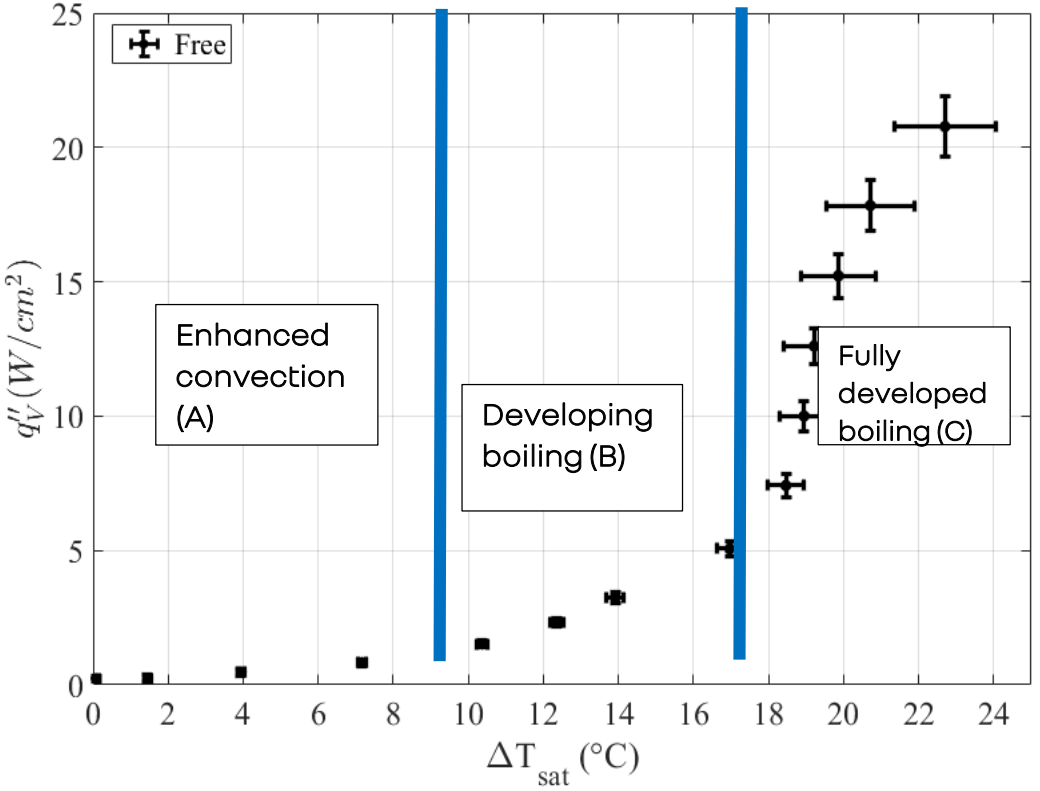
e=[0.5;15] mm ⇔ Bo=[0.2;245]

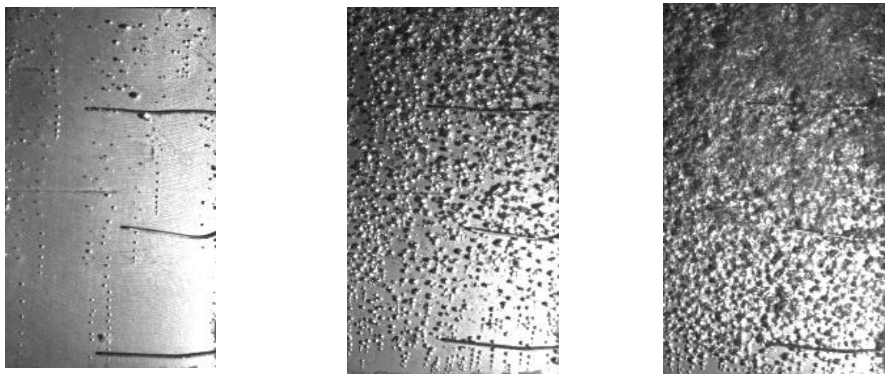
Results & Data Analysis

Free boiling curve



$T_{condenser}$=32 °C
Free configuration

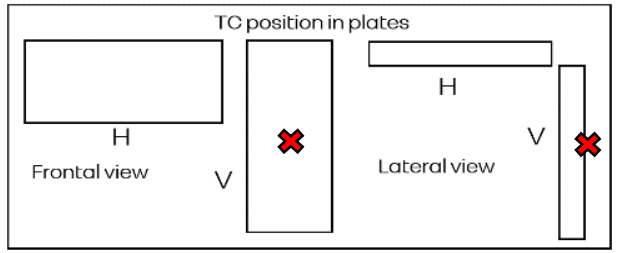




(A) (B) (C)

Résultats et analyse

Free boiling curve



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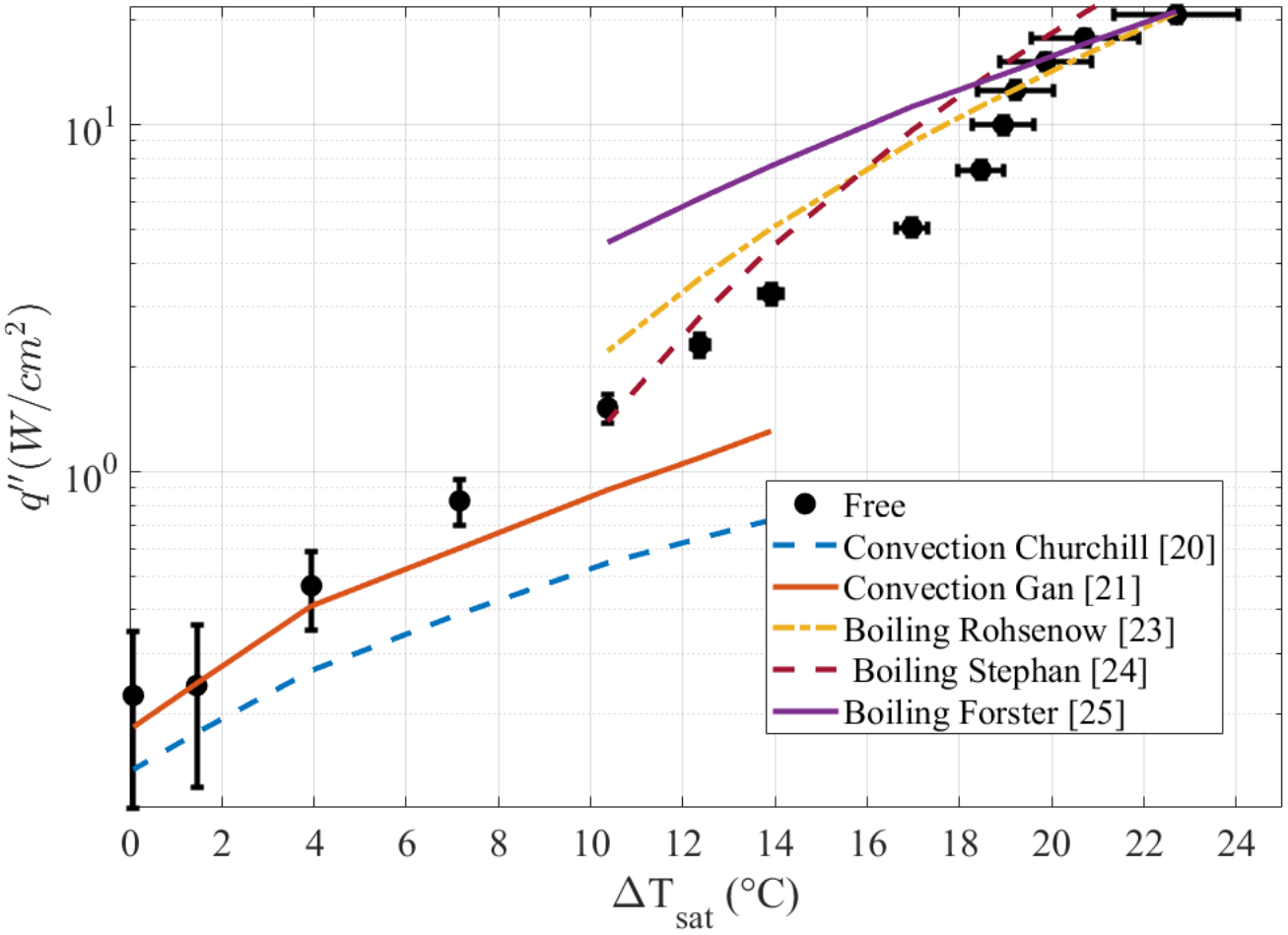
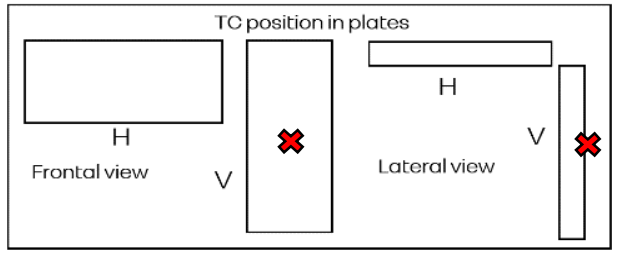


Experimental boiling curve against litterature correlations

Résultats et analyse

Free boiling curve



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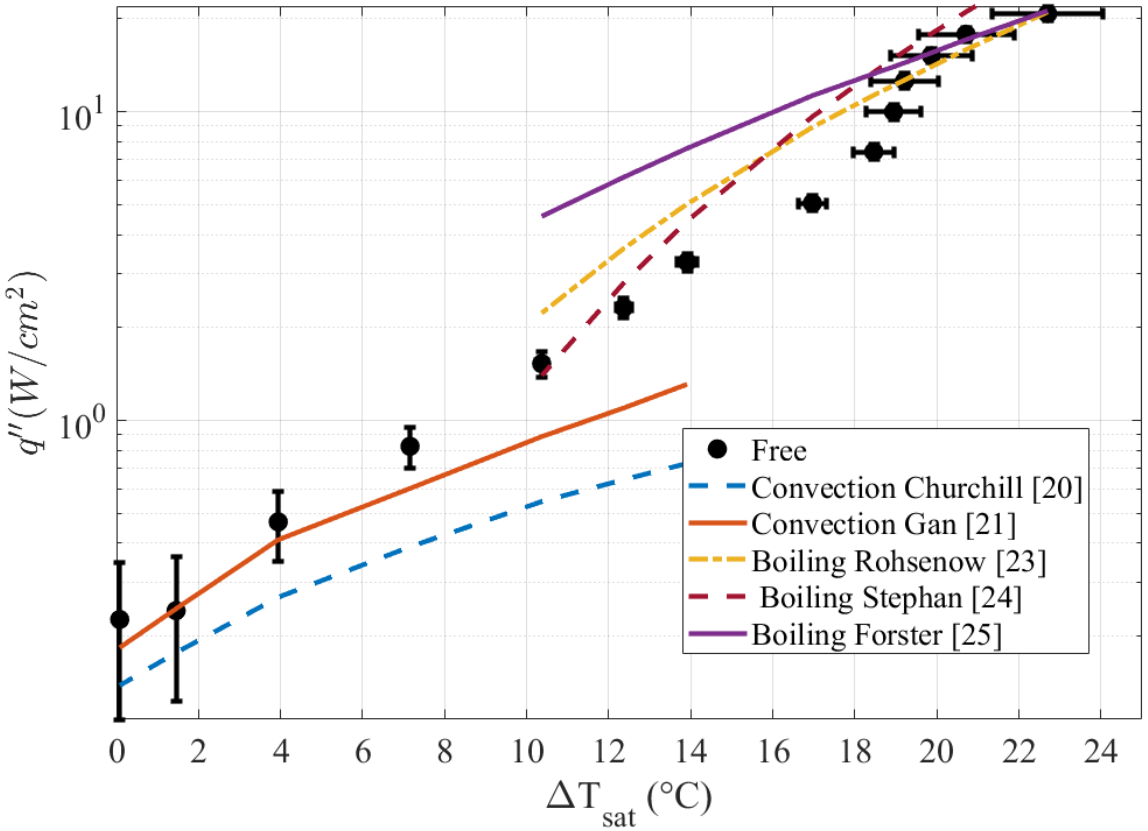
Free configuration



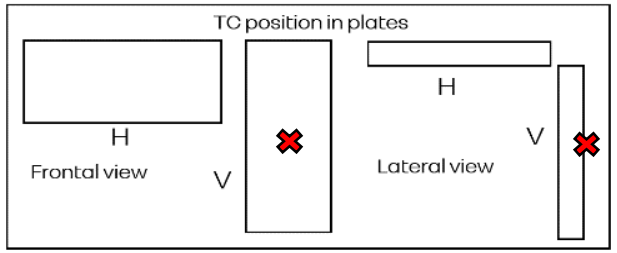
Experimental boiling curve against litterature correlations

Perspectives :

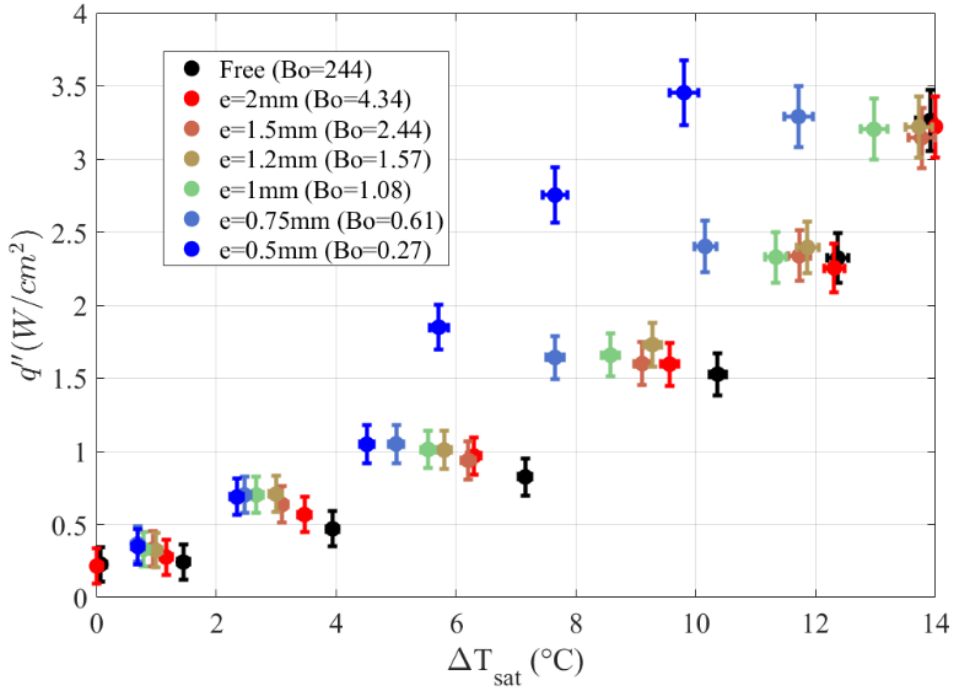
- Etude en convection naturelle
- Comparaison à ébullition en canal, prise en compte de *x*
- Etude sur toute la surface + paroi horizontale

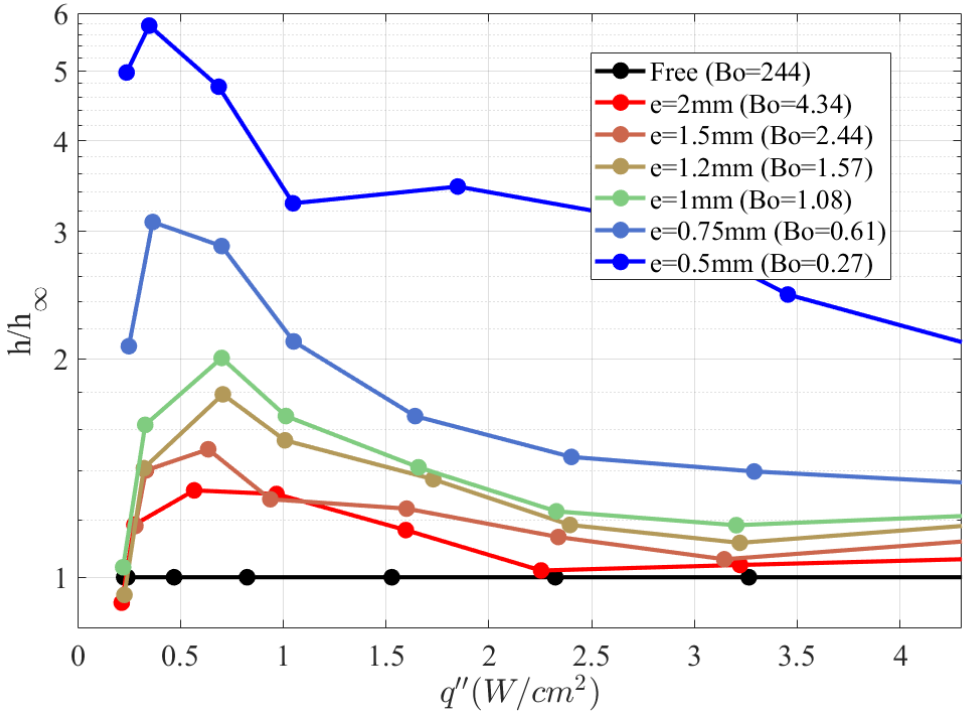
Résultats et analyse

Influence du confinement



$T_{condenser}$=32 °C



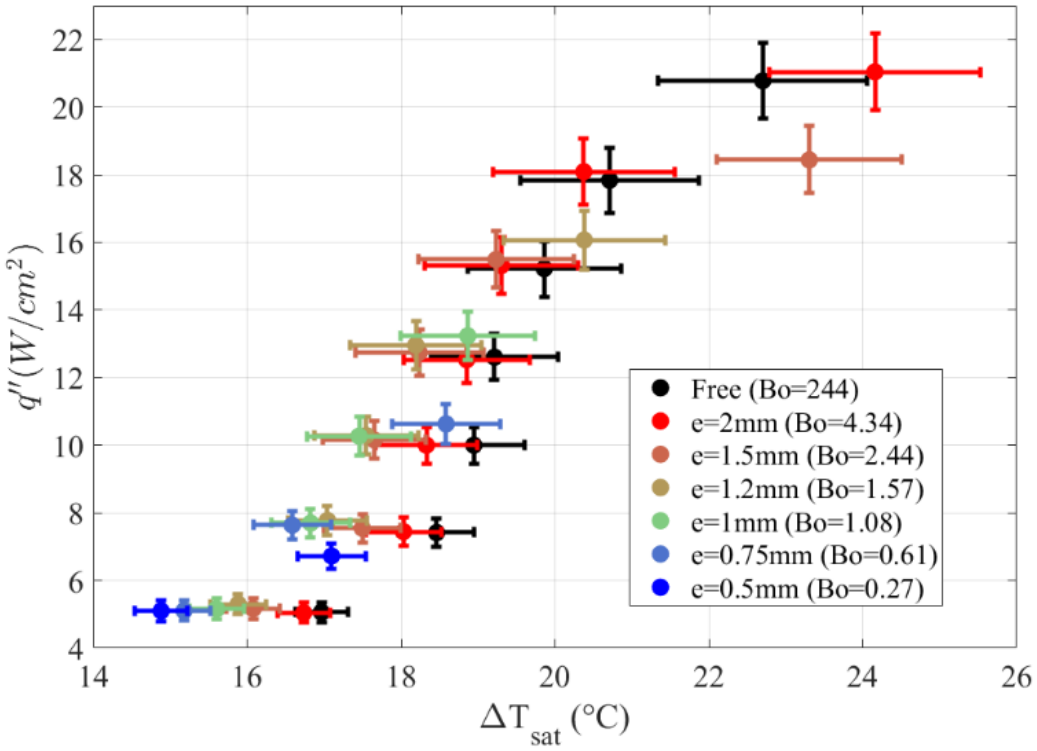


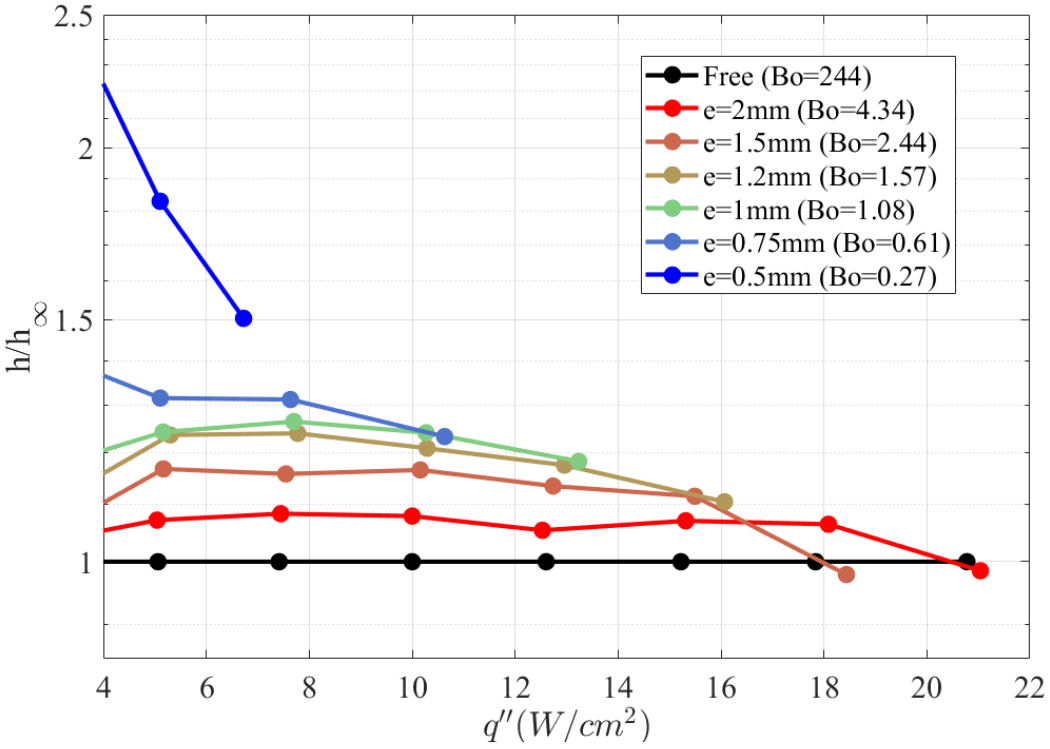
A bas flux:

- e ↗ ΔT_{sat}
- Influce de e sur ΔT_{sat} n'est pas linéaire
- *HTC* améliorés jusqu'à 600% à petit flux

Influence du confinement

$T_{condenser}$=32 °C



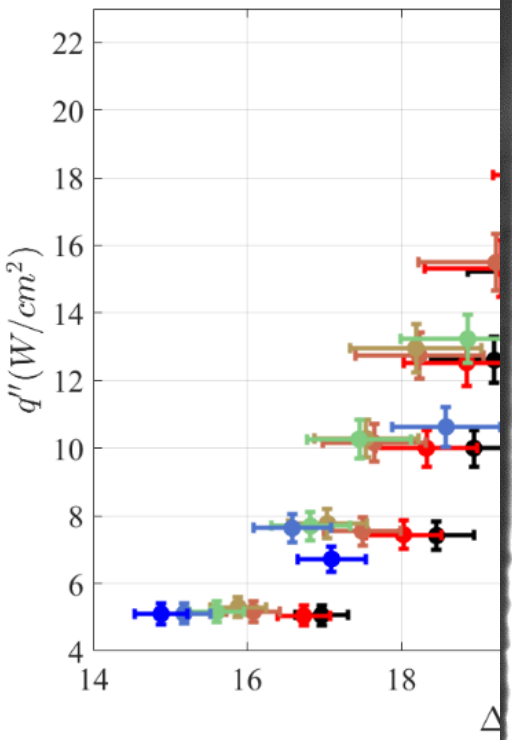


A haut flux:

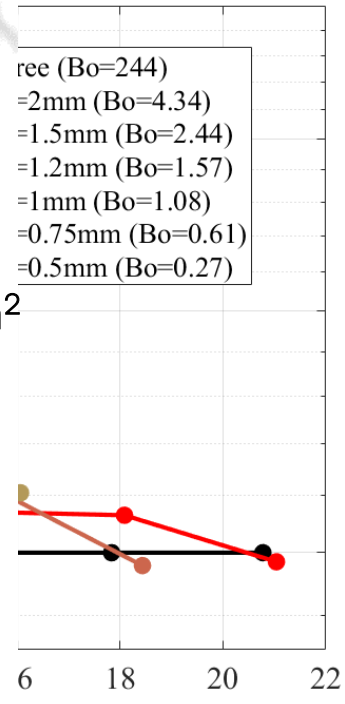
- *e* a une influence négligéable (avant d'atteindre le flux critique)
- Configuration libre ≈ épaisseurs de canal

Résultats et anal

Influence du co =32 °C



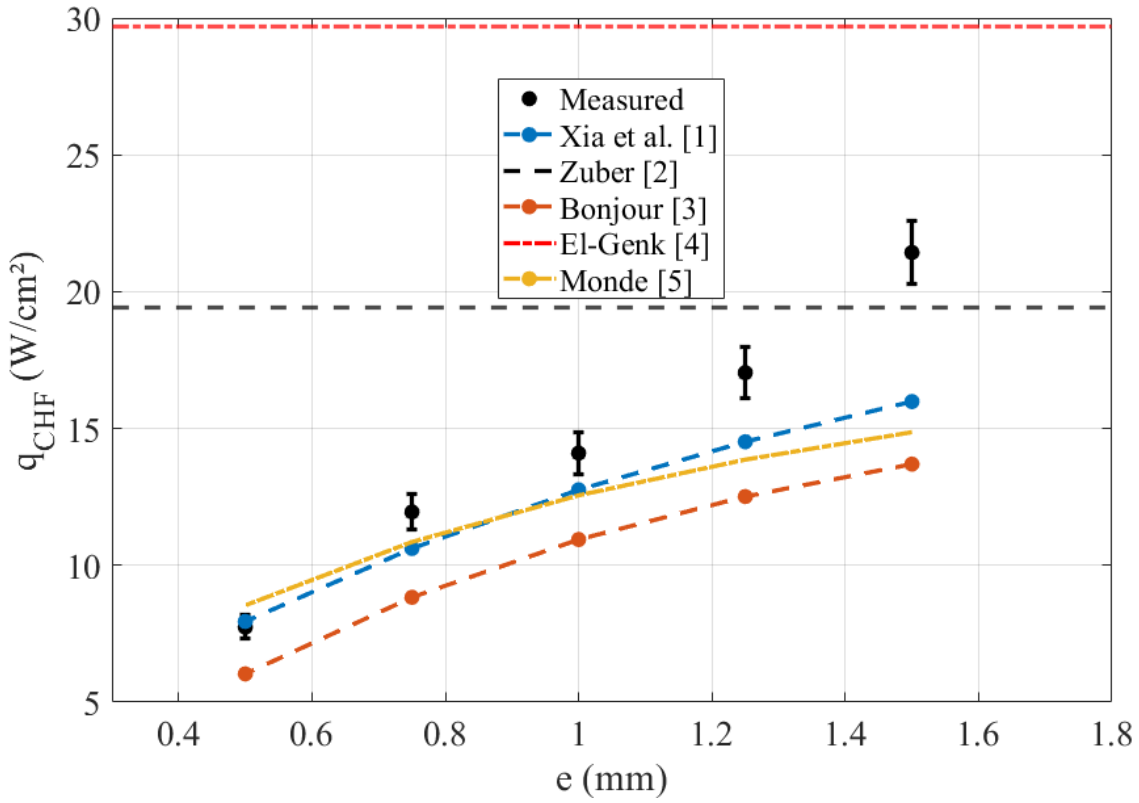
Φ~4 W/cm²



A

-
-

Critical heat flux



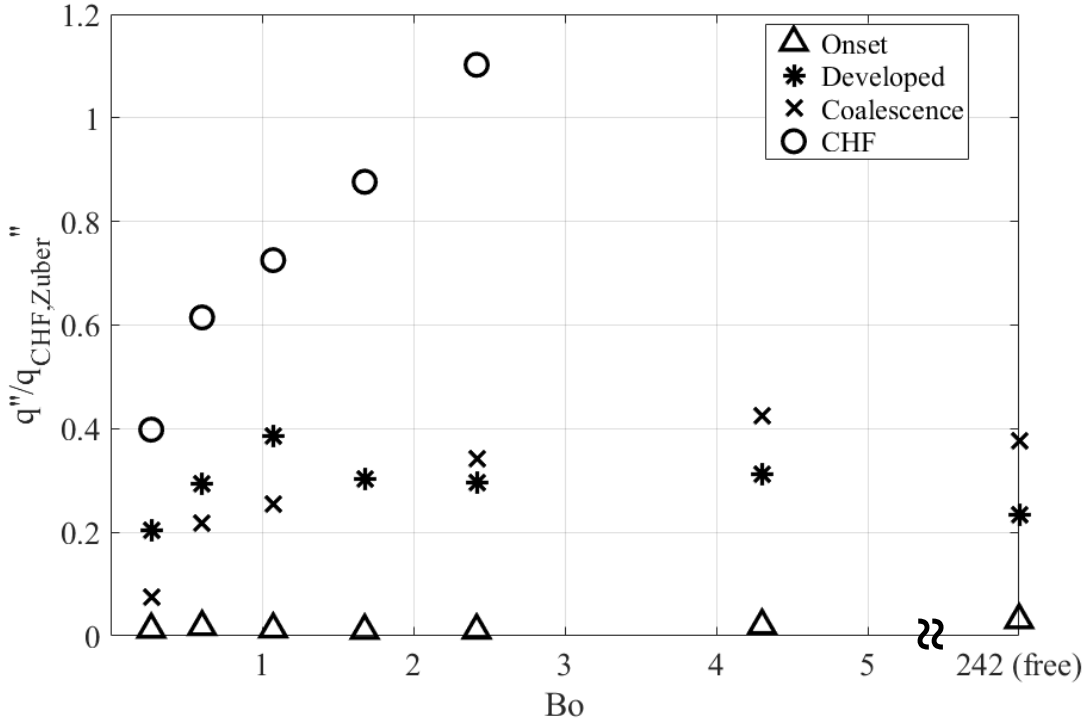
$T_{condenser}$=32 °C

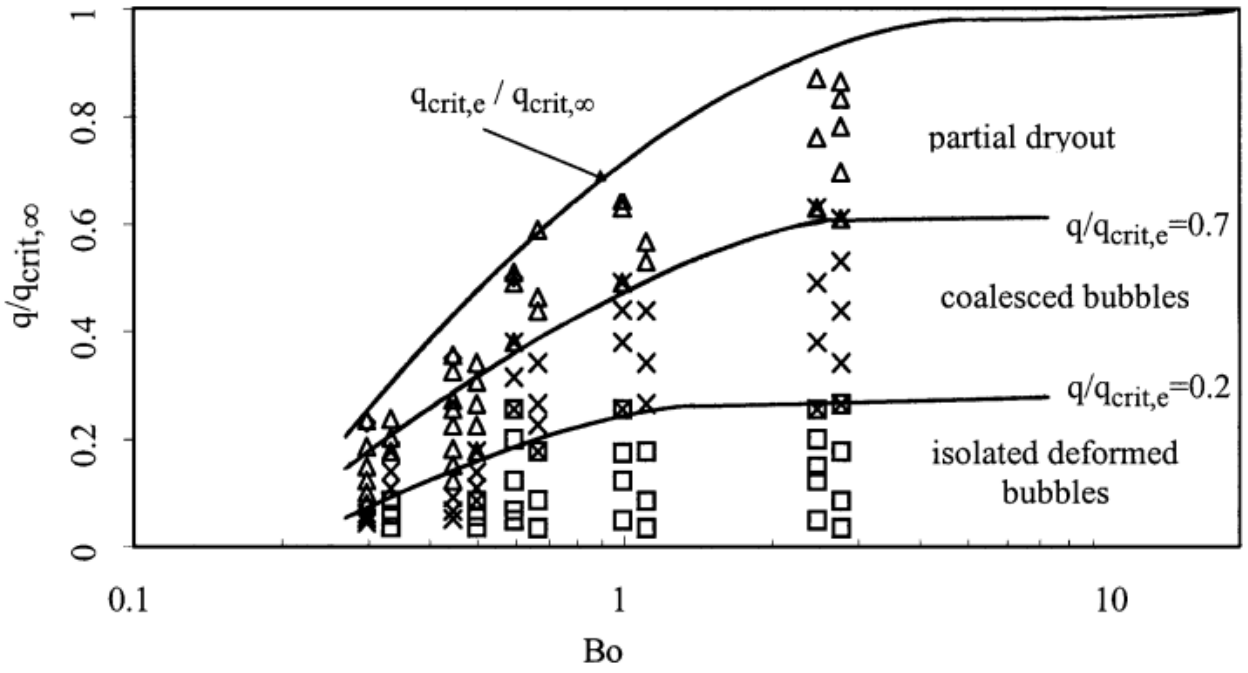
- CHF ↘ with e
- Zuber and El-Genk : not a function of e

- Xia et al: R-113 on vertical copper plate
- El-Genk : Novec 7000, P=0,85 bar and on copper vertical surface
- Bonjour: R-113 fluid on copper vertical surface
- Monde: R-113, benzene, water, ethanol with copper vertical heater

Difficulté à mesurer visuellement le début de l'assèchement partiel
→Méthode retenue: changement pente des HTC

Patterns map





Bonjour et Lallemand, R-113 fluid, Int. J. Multiphase Flow 24 (1998)

- Same regime behaviour is confirmed
- Difficulty measuring start of partial dryout regime

Summary

Conclusion & perspectives

Present study conclusions

- Dedicated testbench for study Novec 7000 confined boiling
- Confinement ↗ heat exchange at low-medium heat flux (<10 W/cm²)
- Confinement ↗ heat exchange at high heat flux (>10 W/cm²)
- Confinement ↘ CHF
- 3 main boiling regimes observed

Perspectives for the future

Study of:

- subcooling
- onset of boiling
- surface rugosity
- pressure

Improve visual data treatment

Perspectives :

- Etude en convection naturelle
- Comparaison à ébullition en canal, prise en compte de *x*
- Etude sur toute la surface + paroi horizontale => manip plus fine
- Comparaison avec écoulement type Hel et Shaw
- Fluide non PFAS
- Transitoire

Remarques/Questions :

- Discussion autour des fluides de travail et de leur potentielle interdiction. Certains ont de l'espoir dans des HFOs
- Quid de l'effet de la géométrie/effets de bord : Bonjour et al. => «cheminée», Lips et al. => caloduc plat mais pas forcément rempli entièrement, current study => caloduc plat rempli mais espace sur les côtés

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Thank you!