

# Preliminary study of the impact of the filling level on the vaporization of water inside the channel of a smooth plate-type heat exchanger in the context of sorption chillers

Florine GIRAUD, Brice TREMEAC

CMGPCE - EA7341, CNAM, case 2D3P20, 292 rue Saint-Martin,  
75141 Paris Cedex 03, France



# Content

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- Context and background of the study
- Results obtained from previous studies
- Objective of this study
- Experimental results
- Conclusions and Perspectives

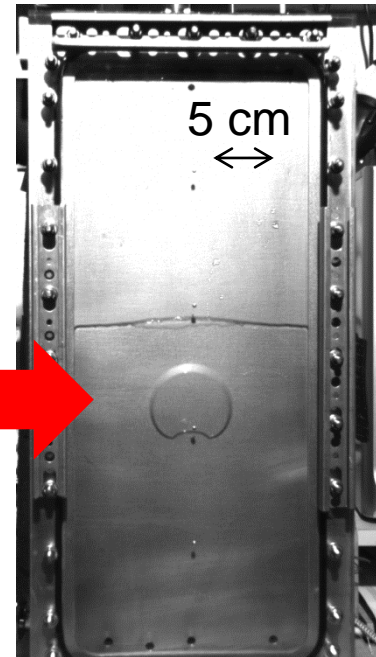
# Context and background of the study

## Motivations:

- Few compact evaporators used in sorption systems
- Lack of fundamental knowledge about boiling and vaporization phenomena at such low pressure
- Unusual behavior of these evaporators due:
  - to the low vapor density
  - to the hydrostatic pressure

Bubble of  
centimeter size

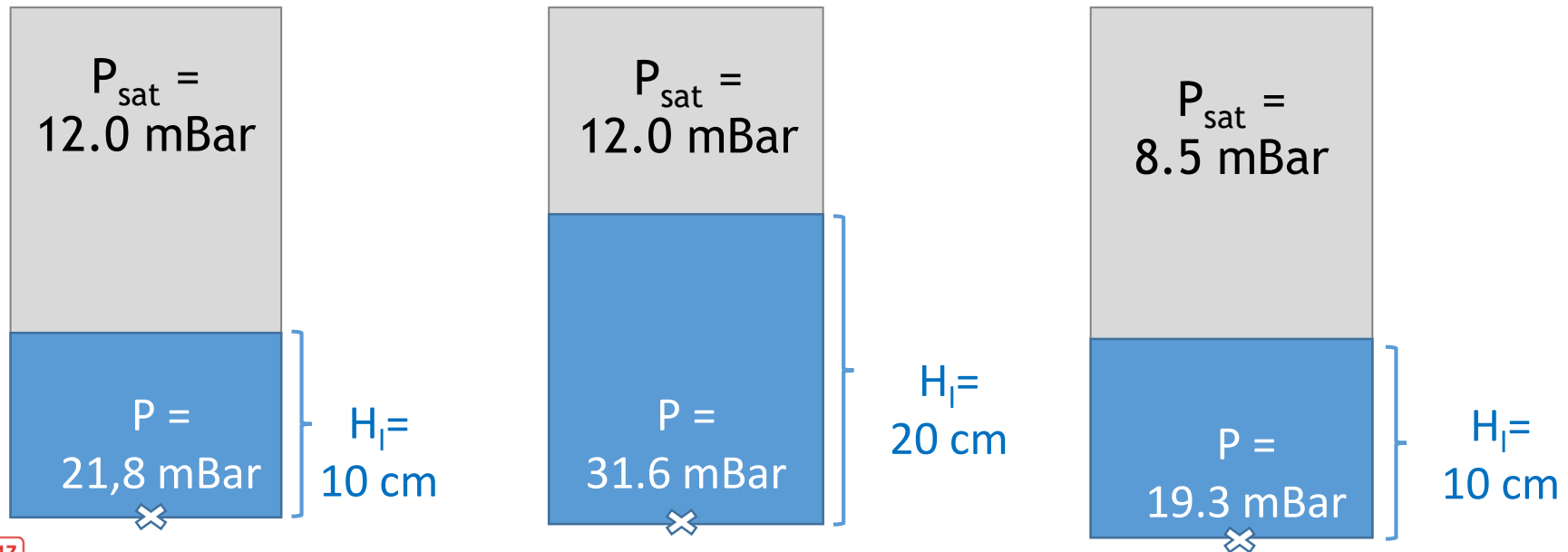
*Bubble observed inside the channel of the smooth plate-type evaporator at a working pressure of 1.3 kPa (working fluid: water)*



# Context and background of the study

## Influence of the hydrostatic pressure:

- Local pressure could be imposed by varying:
  - ✓ The height of the liquid level
  - ✓ The saturation pressure

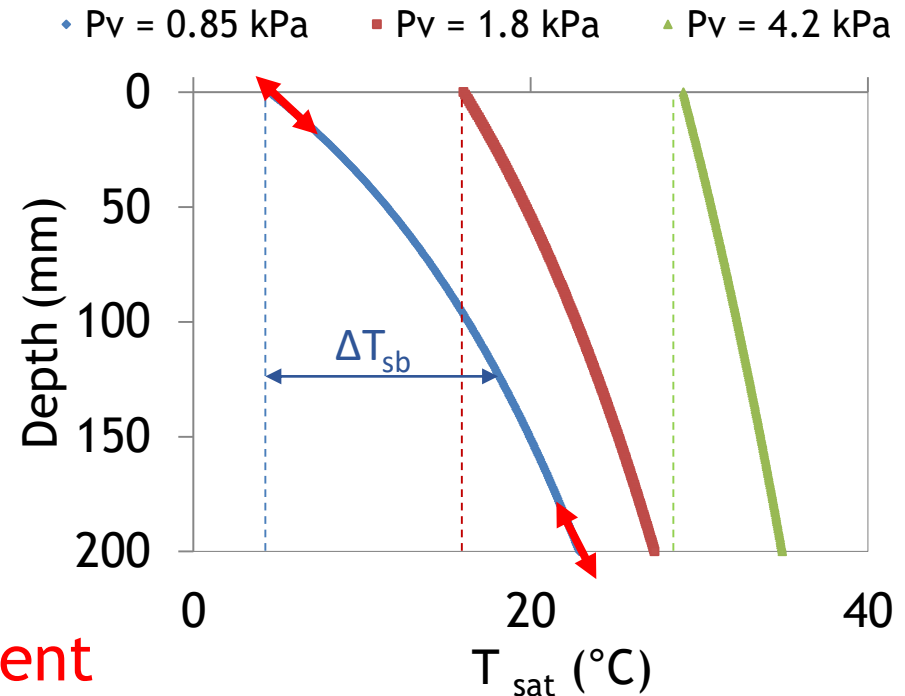


# Context and background of the study

## Influence of the hydrostatic pressure:

- Both result in a non-homogeneity of the boiling environment in:

- ✓ pressure,
- ✓ saturation temperature,
- ✓ subcooling degree,
- ✓ subcooling gradient.



Parameters interdependent

*Evolution of the saturation temperature in the vessel for a given liquid column height*

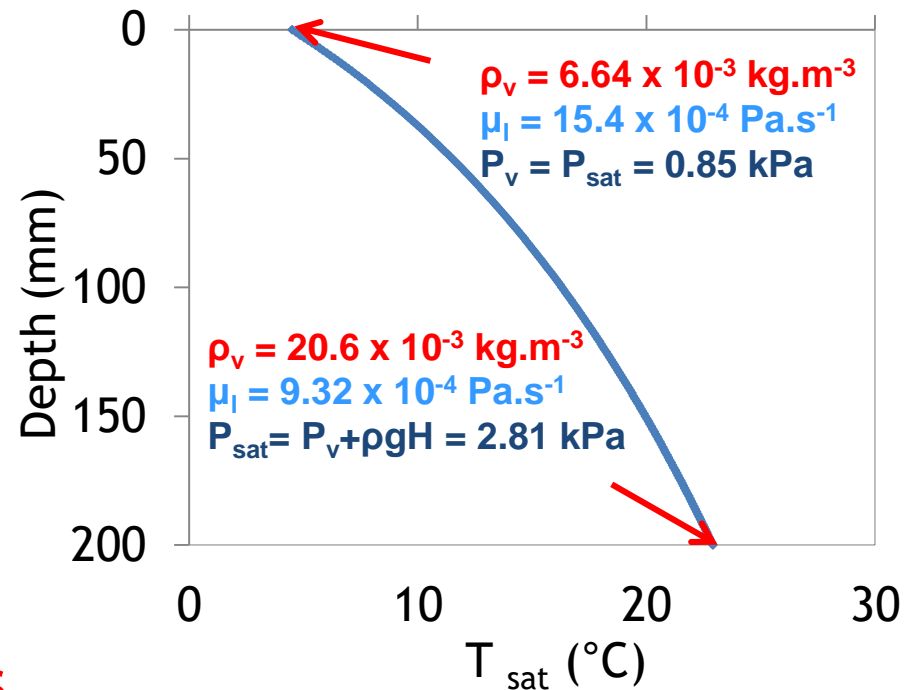
# Context and background of the study

## Influence of the hydrostatic pressure:

→ Impact on thermophysical properties, especially on:

- ✓ the vapor density  
( x 3 from the top to the bottom)
- ✓ the liquid viscosity  
( x 1.6 from the bottom to the top)

➡ Difficulties to obtain comparables running conditions



*Evolution of the saturation temperature in the vessel for a given liquid column height*

# Context and background of the study

## Motivations:

- ✓ understand the behavior of compact plate-type heat exchanger
- ✓ design correctly such evaporators



### Vaporization inside the channel of a smooth plate-type evaporator:

- ✓ Thermosyphon configuration
- ✓ Adsorption configuration



Local heat transfer coefficient  
Visualization

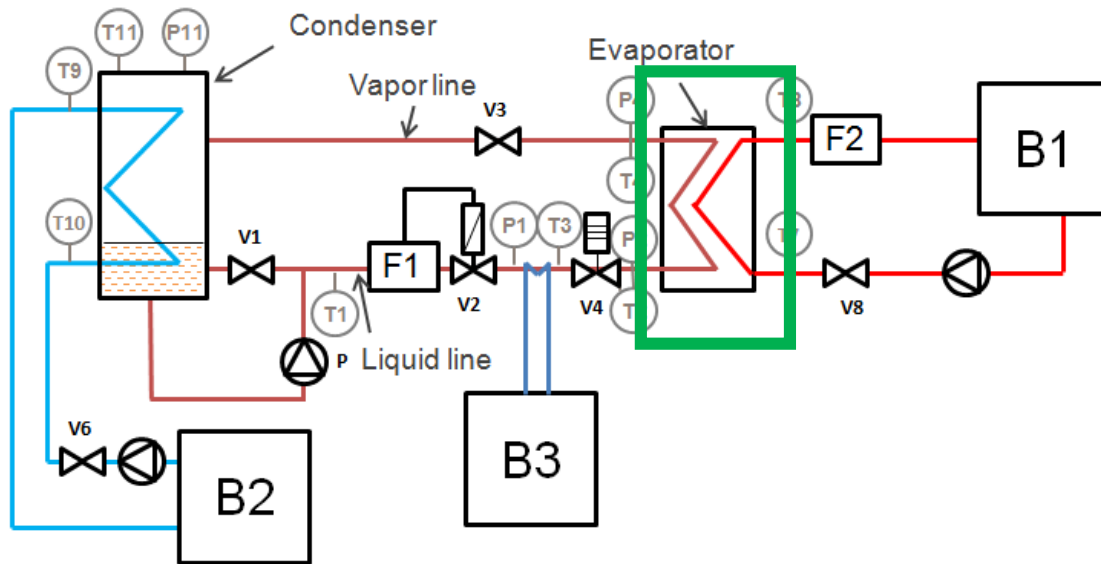


### Plate-type evaporator behavior at the system scale

Adsorption system of 5 kW  
(Zeolite 13X)

# Results obtained from previous studies

## Experimental test set-up:



*Drawing of the experimental setup*

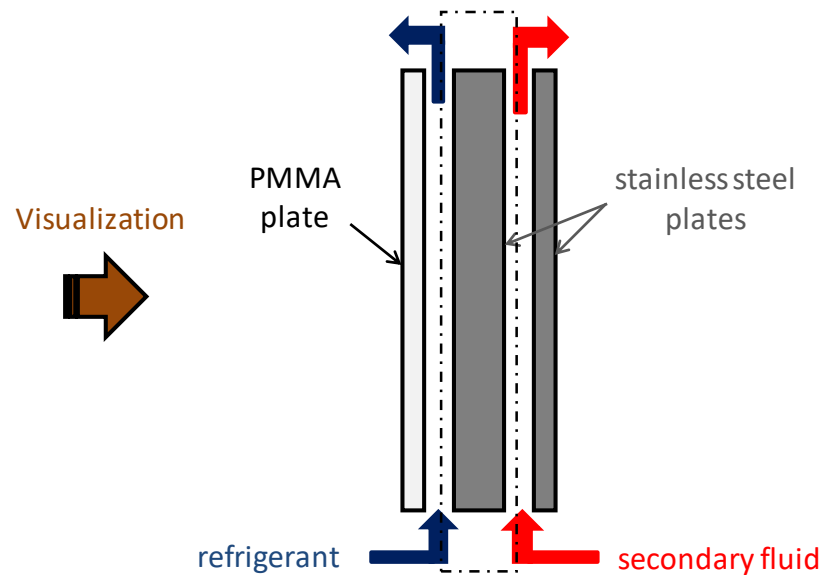
- Pump-assisted closed-loop thermosyphon → simulate an absorption chiller with different driving pressures  $\Delta P$
- Mass flow controller F1 (control the liquid level in the evaporator)
- Given vapor quality at the evaporator inlet



# Results obtained from previous studies

## Experimental test set-up:

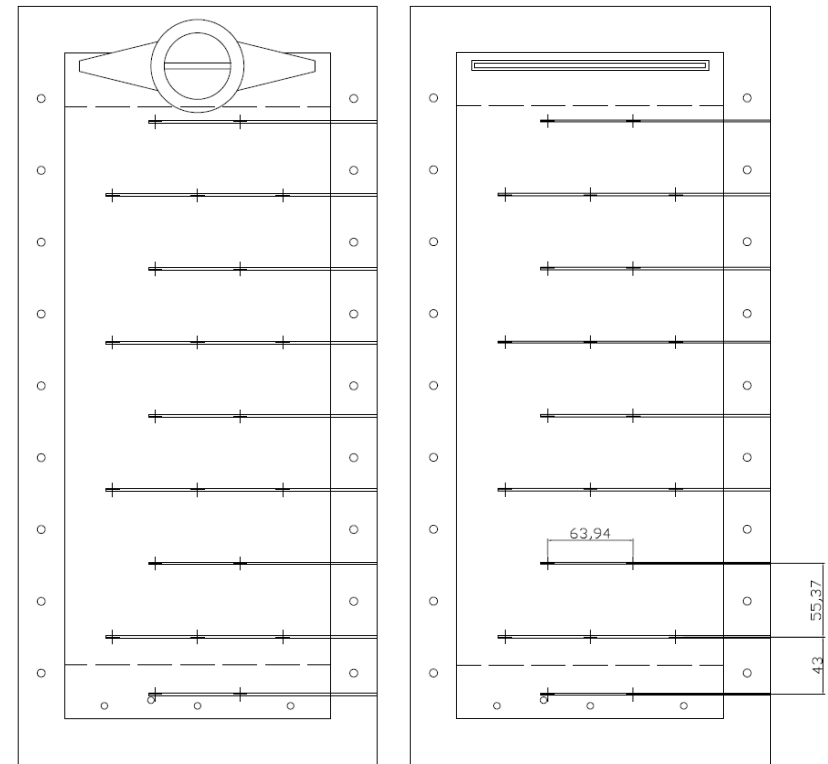
44 thermocouples inserted inside the central plate



Width : 20 cm

Height : 50 cm

Thickness of the channel: 4 mm



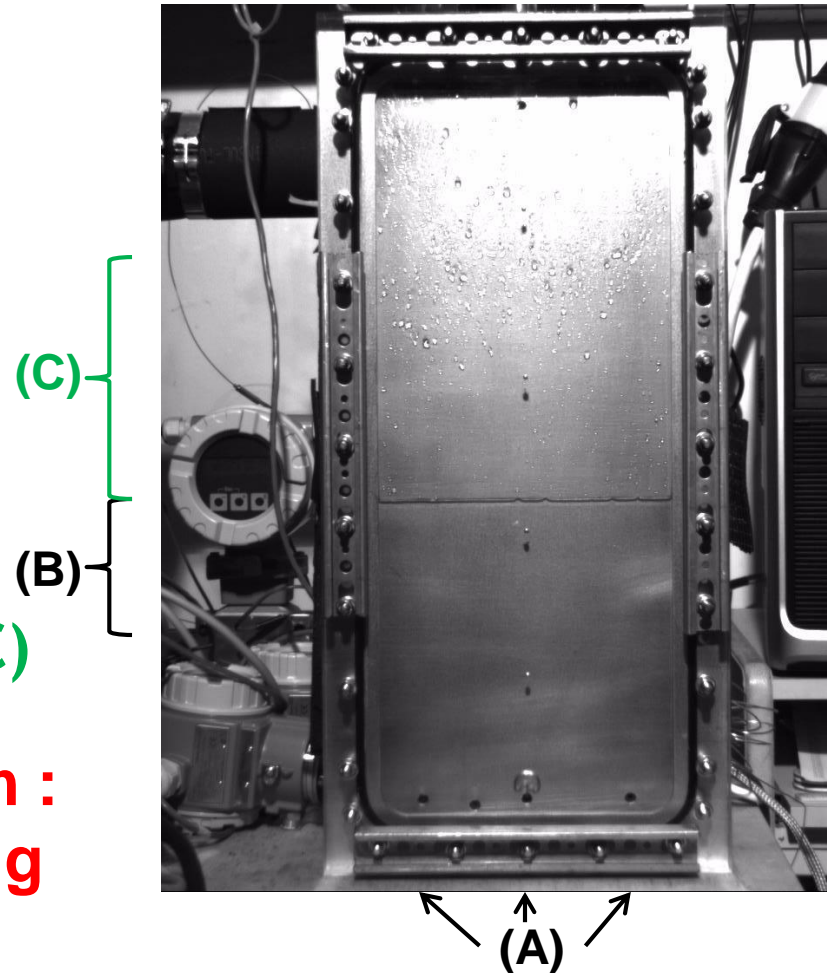
*Location of thermocouples inside the central plate*

# Results obtained from previous studies

## Visualization:

- Bubbles collapse at the inlet of the plate (A)
- Bubbles appear about 5 cm below the free surface (B)
- **Evaporation of the liquid film previously created by the breaking of the large bubble (C)**

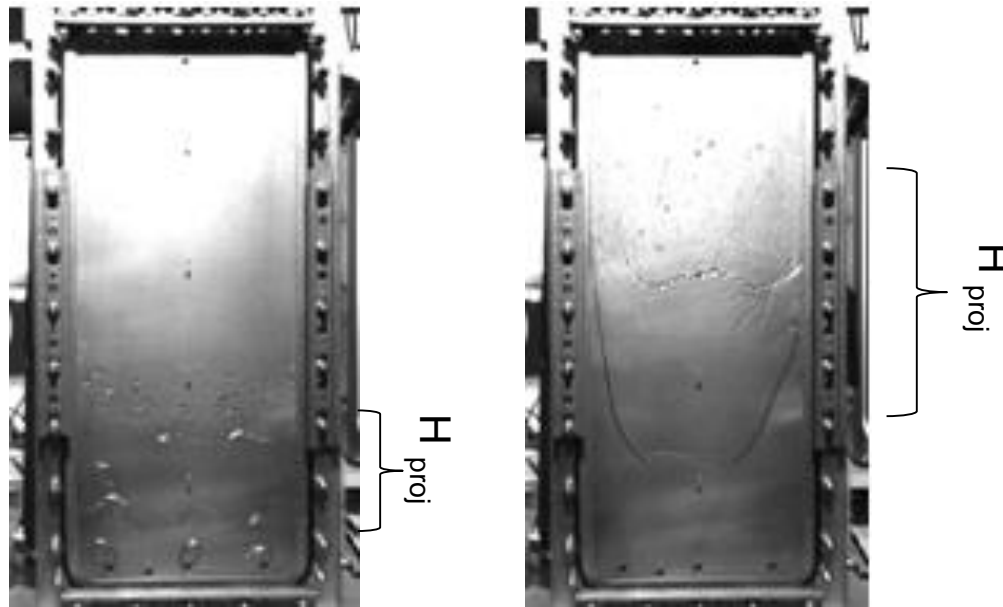
**➡ Evaporation of the liquid film :  
More than 70% of the cooling  
capacity obtained**



# Results obtained from previous studies

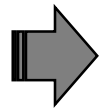
## Phenomenology:

- ✓ High  $H_l$  means **unfavorable condition to set the boiling on** but a **certain volume of water** is **needed** to induce splashing of liquid up to a significant height



- There is an **optimal filling ratio** for given operating conditions

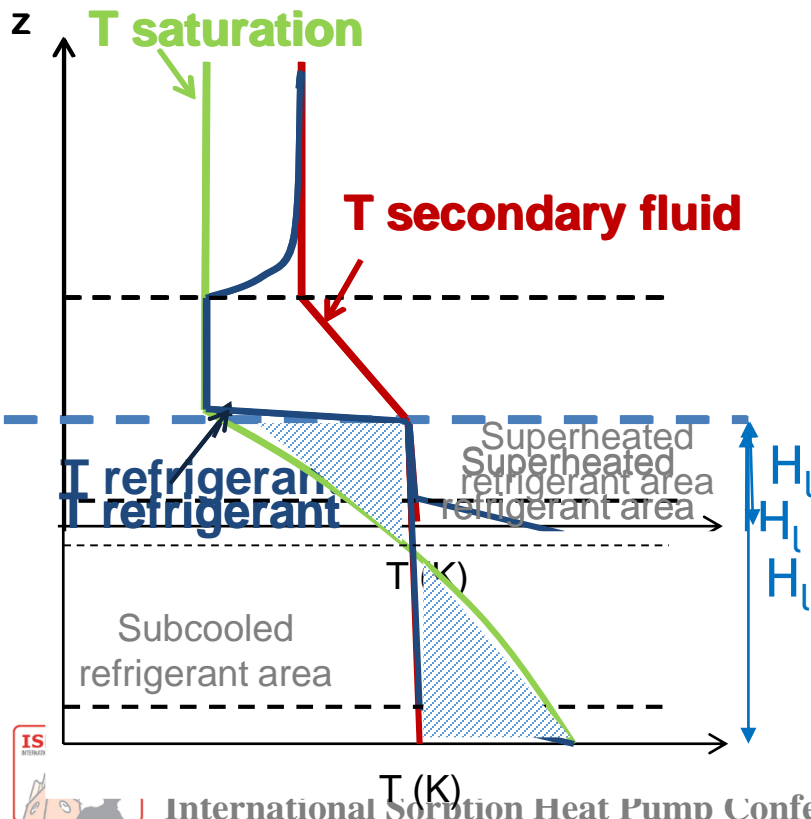
# Objective of this study



Impact of the filling ratio on:

- ✓ The evaporator performance
- ✓ Phenomena observed

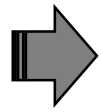
## Experimental procedure:



- ✓  $P_{\text{sat}}$  constant (= 7 mBar)
- ✓  $H_l = 5:2.5:25$  cm

→ **change the superheated refrigerant area and the subcooled refrigerant area**

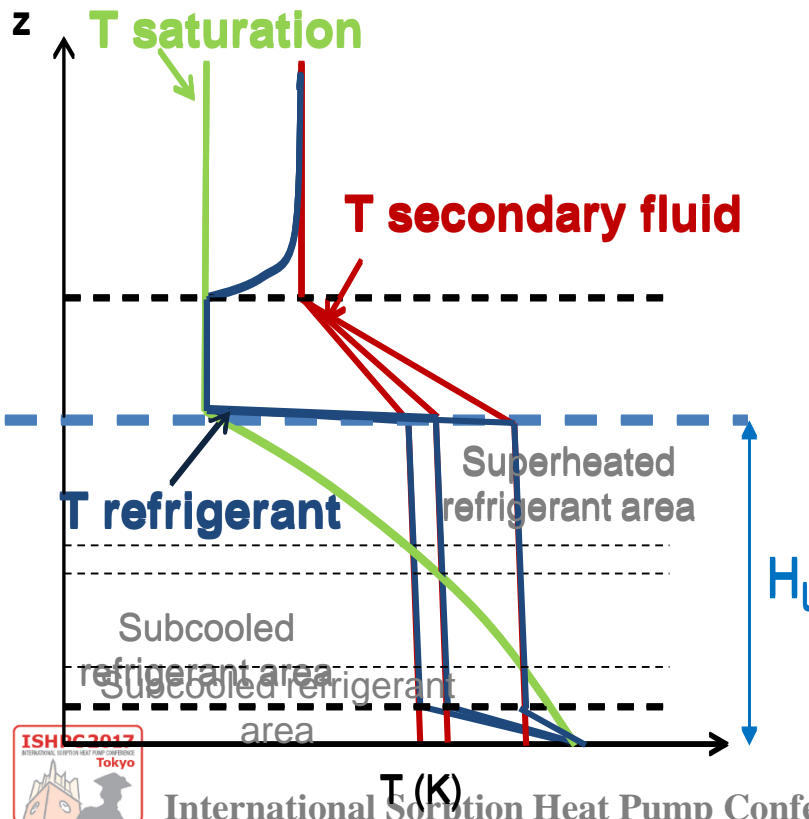
# Objective of this study



Impact of the filling ratio on:

- ✓ The evaporator performance
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## Experimental procedure:



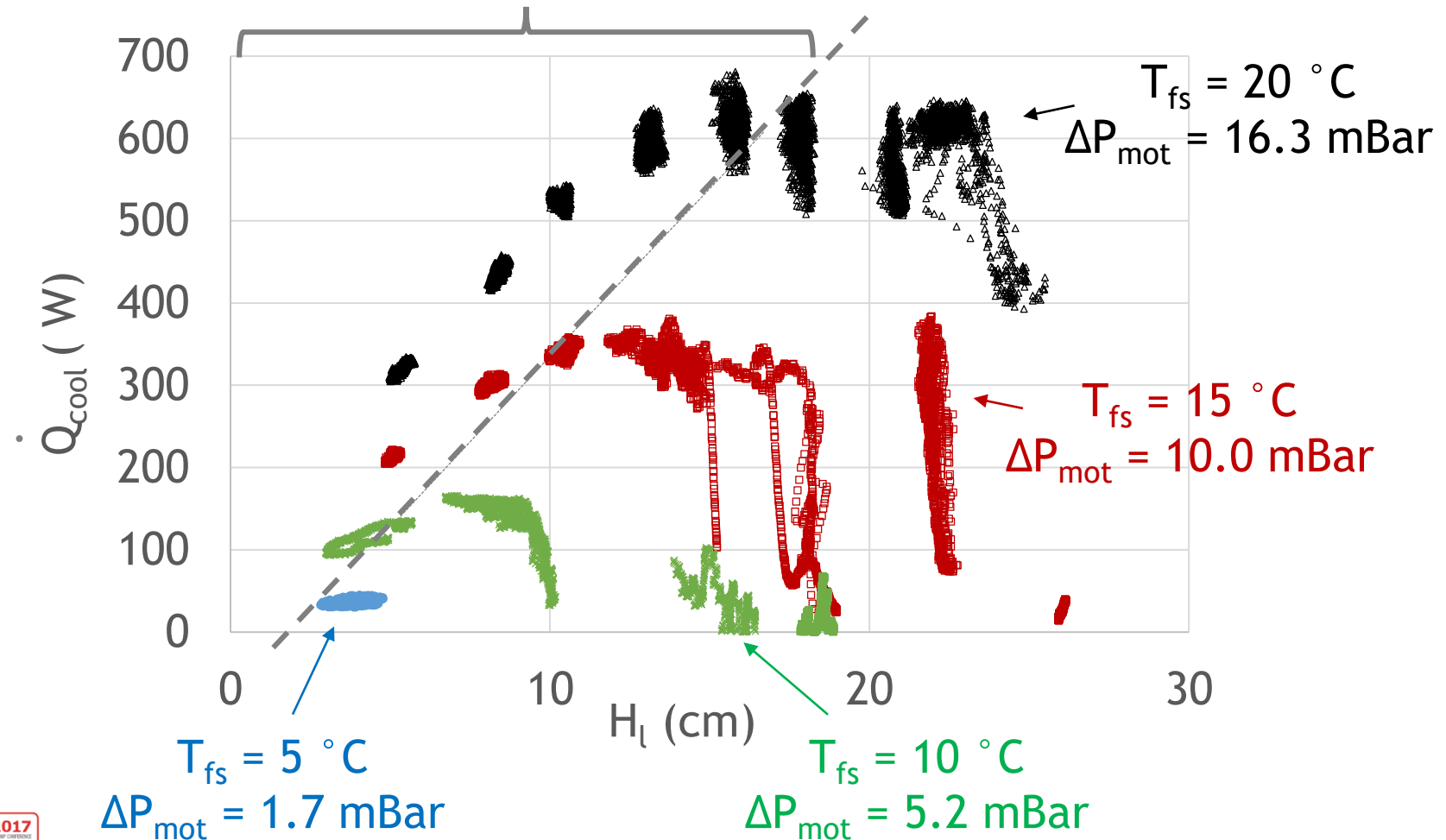
- ✓  $P_{\text{sat}}$  constant (= 7 mBar)
- ✓  $H_l = 5:2.5:25$  cm
- ✓  $T_{\text{fs}} = 5:5:20$  °C

→ change the superheated refrigerant area and the subcooled refrigerant area

# Results obtained

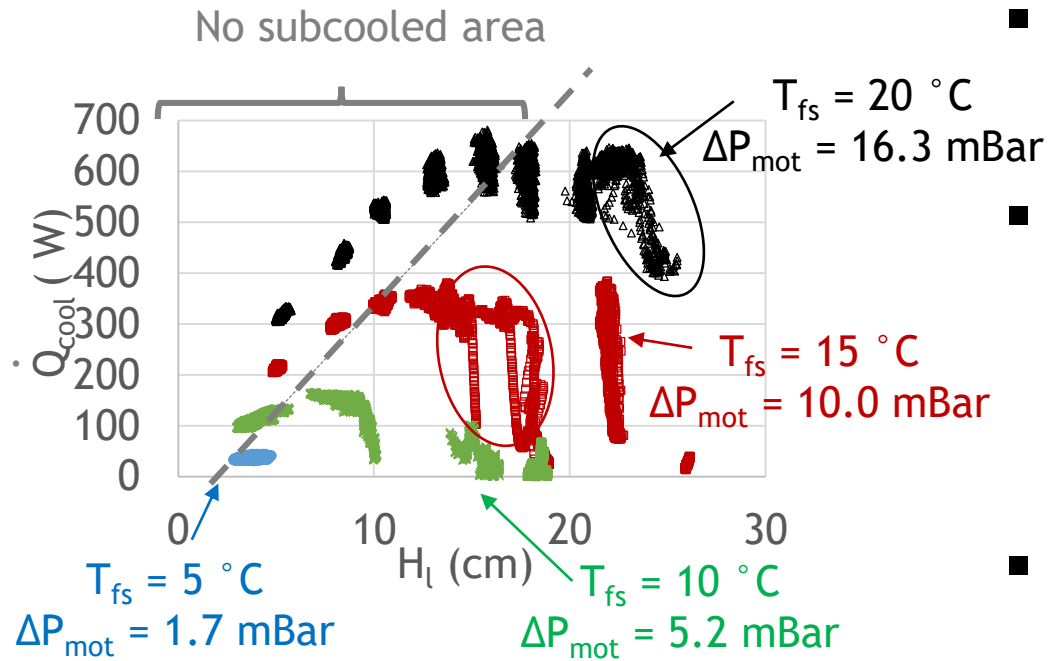
## Cooling capacity:

No subcooled area



# Results obtained

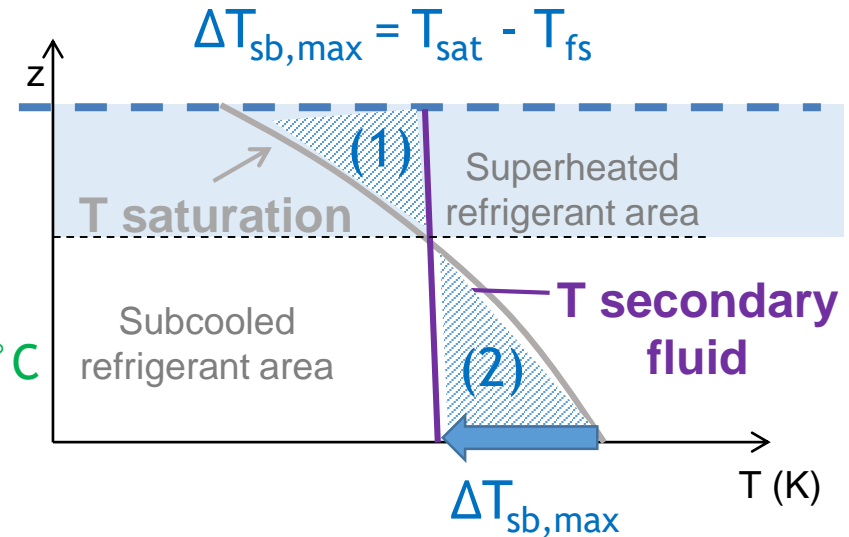
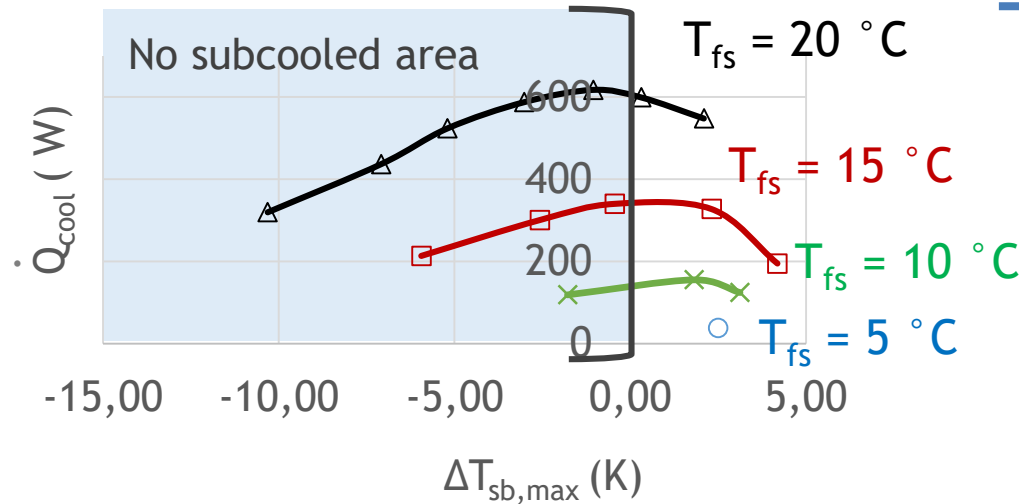
## Cooling capacity:



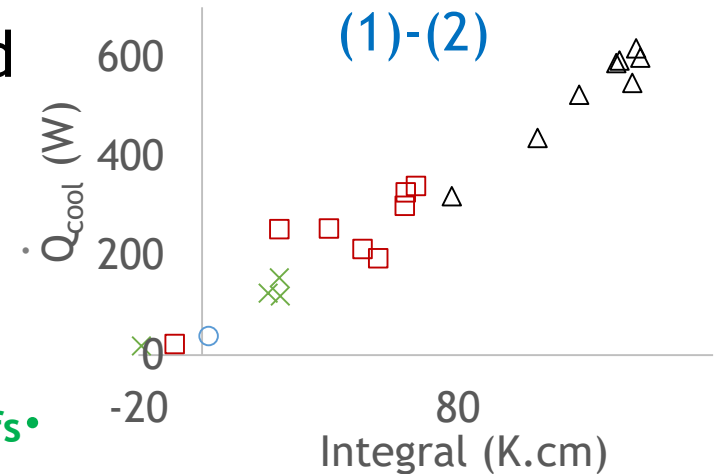
- Increase of  $Q_{cool}$  with the increase of  $T_{fs}$ .
- For  $T_{fs} = 15\text{ }^{\circ}\text{C}$  and  $T_{fs} = 20\text{ }^{\circ}\text{C}$ , high influence of the filling ratio where the subcooling area is null.
- Appearance of highly unsteable phenomena when the subcooled refrigerant area is no null.

# Results obtained

## Cooling capacity:



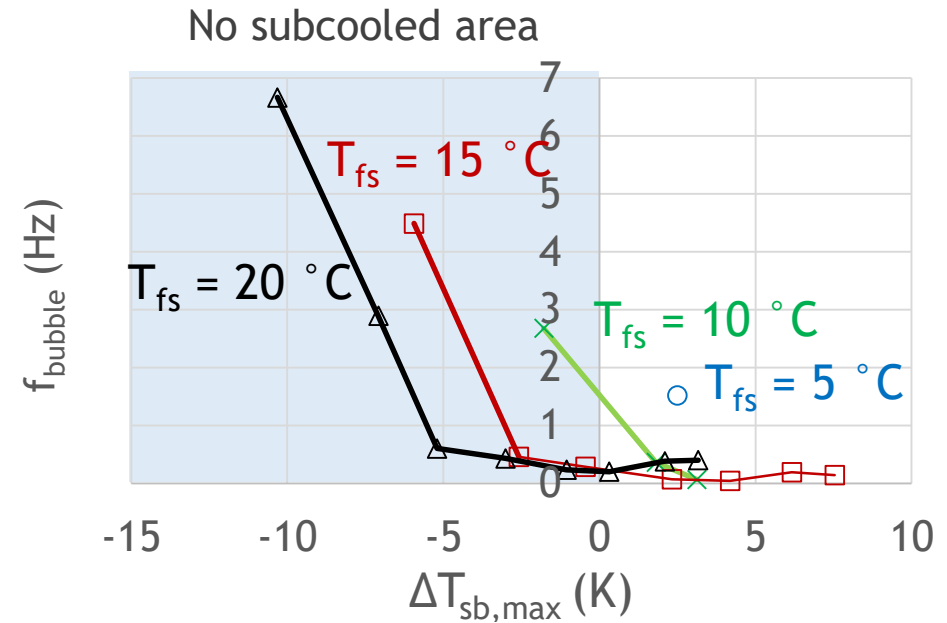
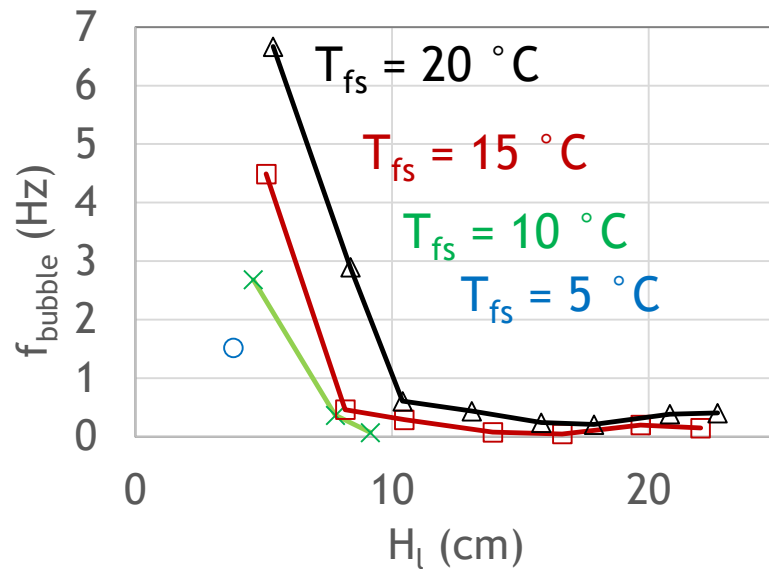
- Influence filling ratio less pronounced when translated in term of maximum subcooling degree.
- Cooling capacity increases with the increase of (1) - (2) whatever the  $T_{fs}$ .





# Results obtained

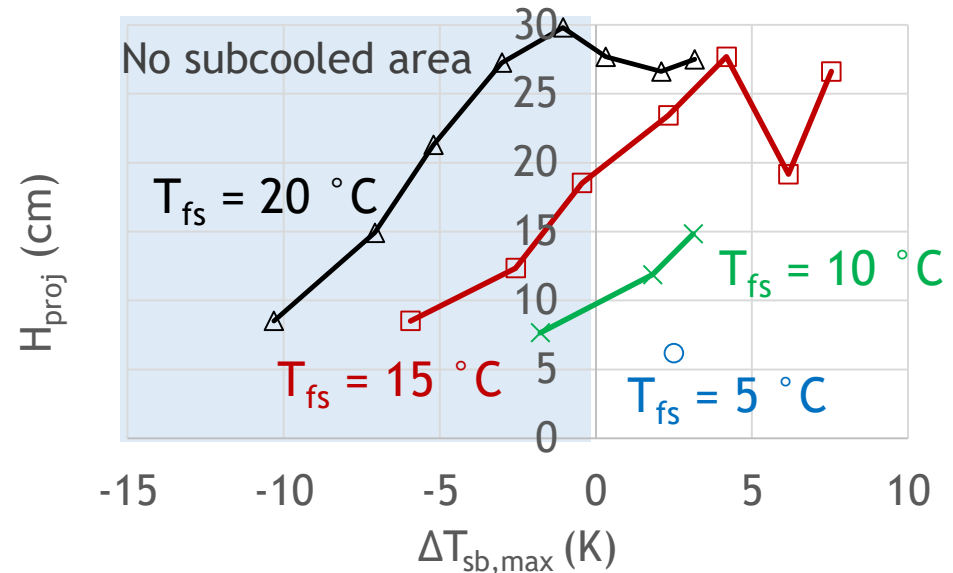
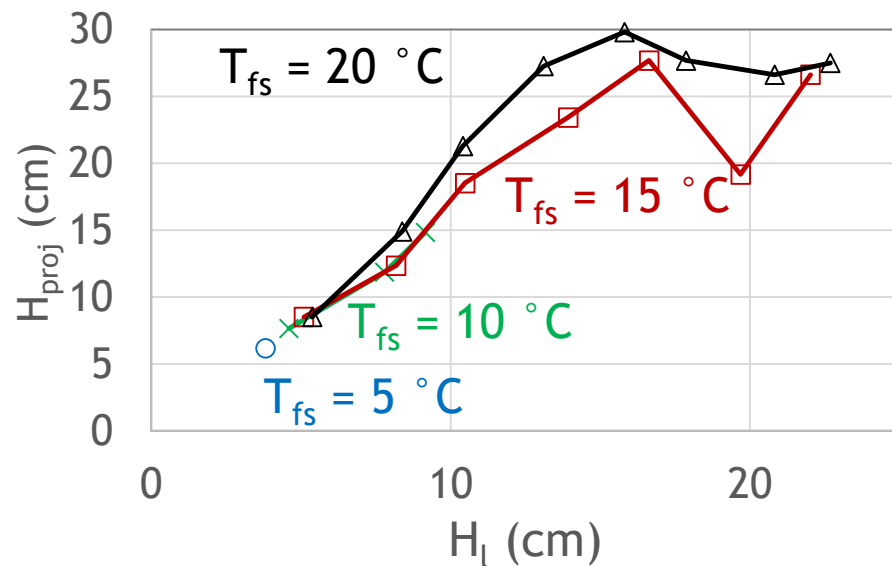
## Frequency:



- Decrease of bubble frequency with the increase of  $H_l$
- Increase of bubble frequency with the decrease of  $T_{fs}$
- No significant change of trends with the occurrence of a subcooled area

# Results obtained

## Height up to which the liquid is plashed:



- Increase of  $H_{proj}$  with the increase of  $H_l$  up to a maximum
- No significant change of trends with the occurrence of a subcooled area

# Results obtained

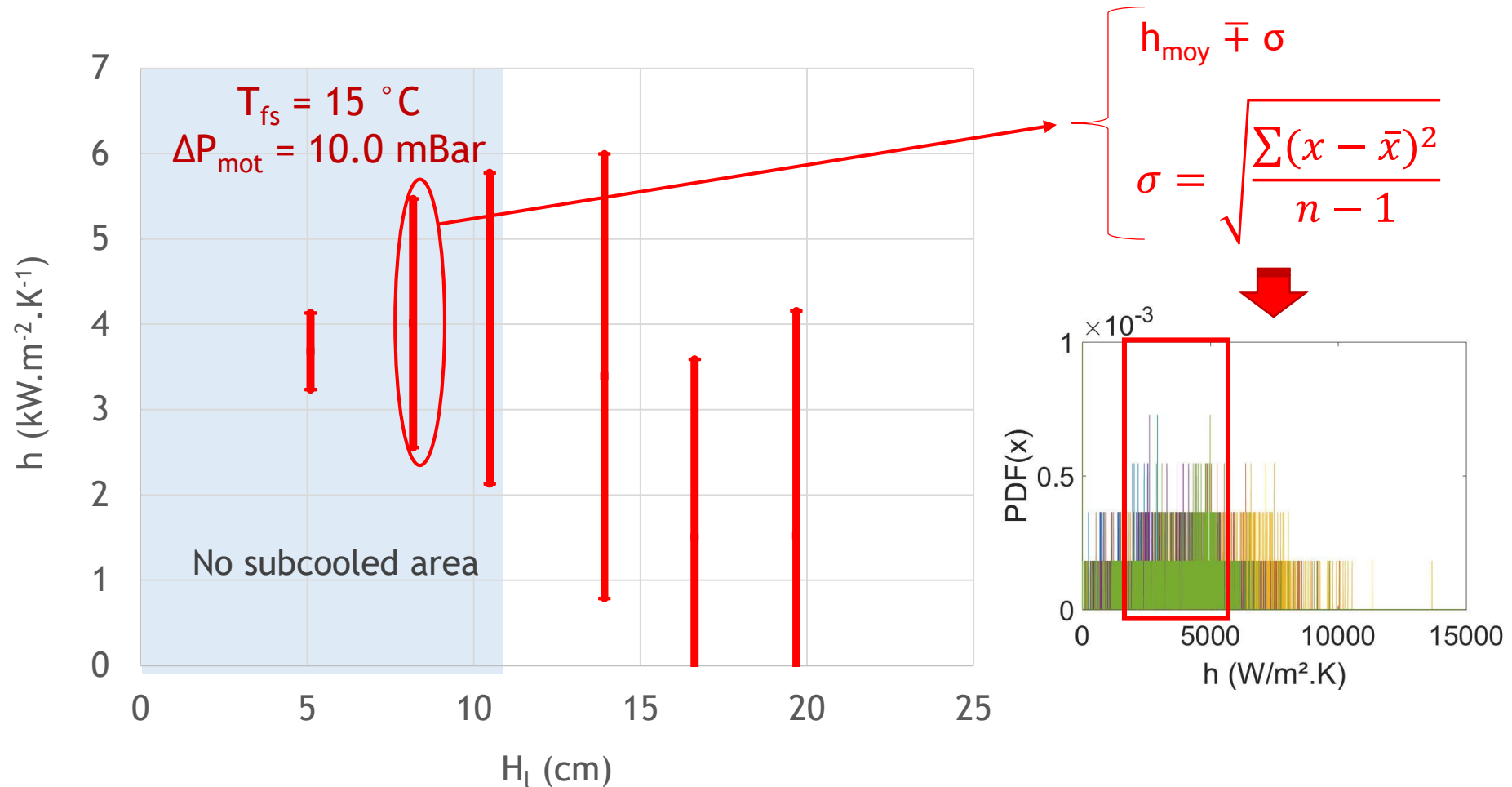
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Frequency + Height up to which the liquid is plashed

➡ Impact on the heat transfer coefficient

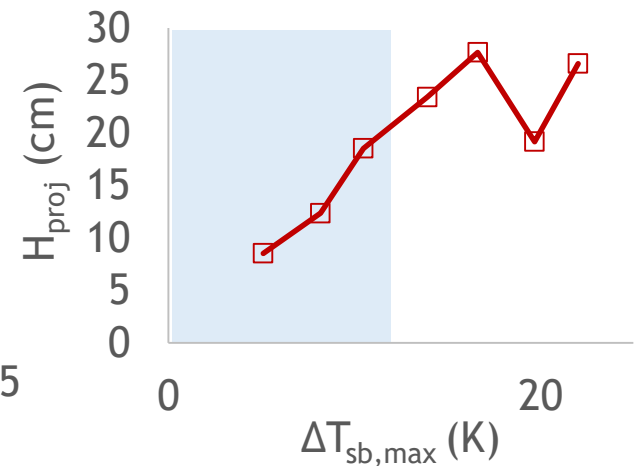
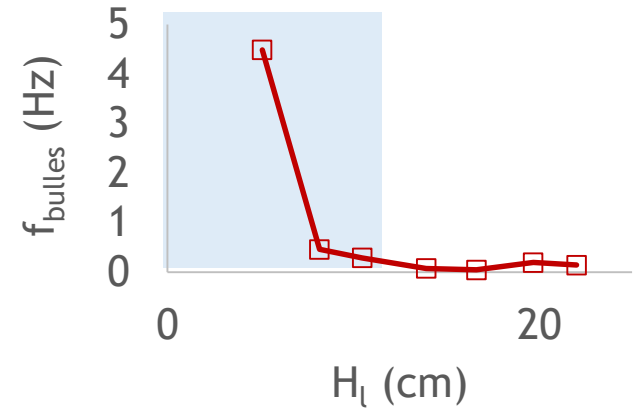
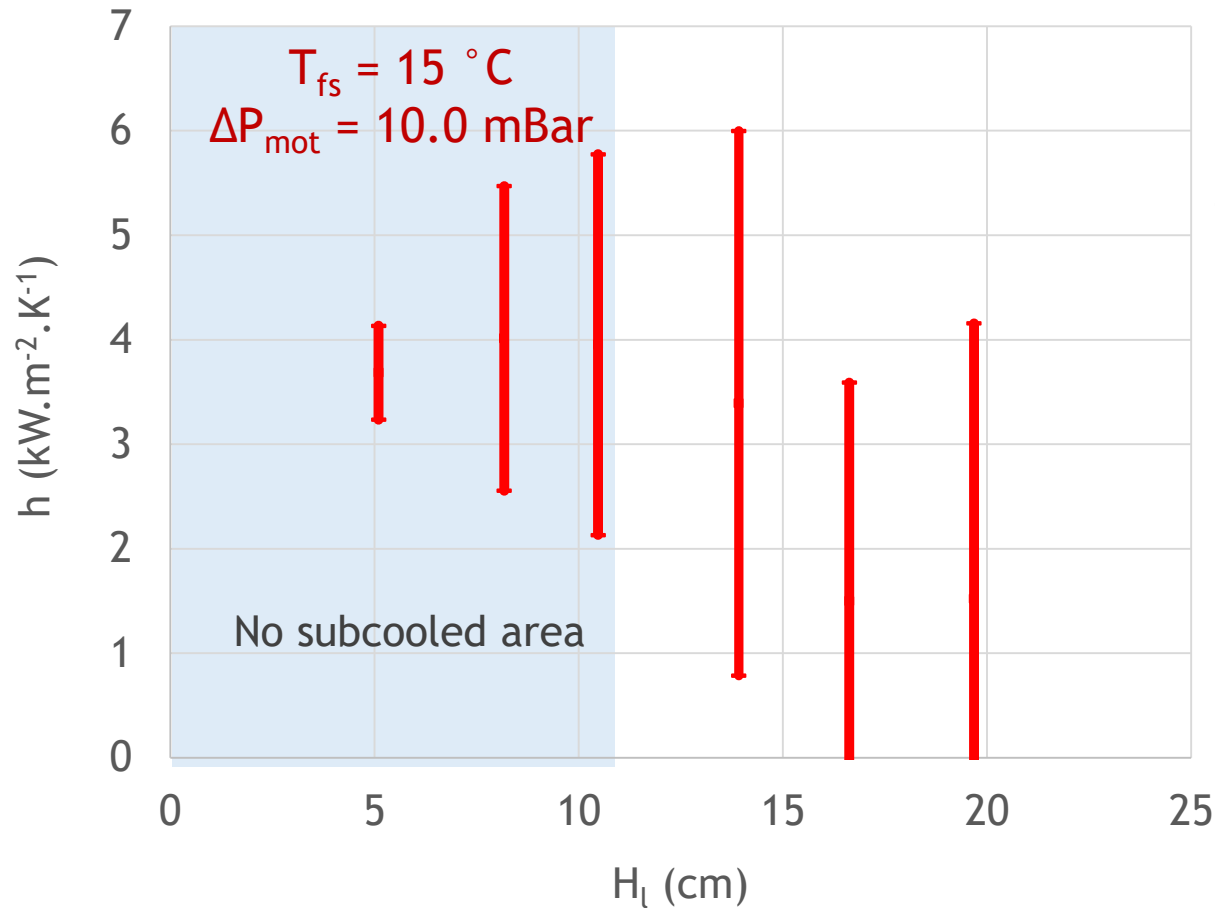
# Results obtained

## Heat transfer coefficient (falling film):



# Results obtained

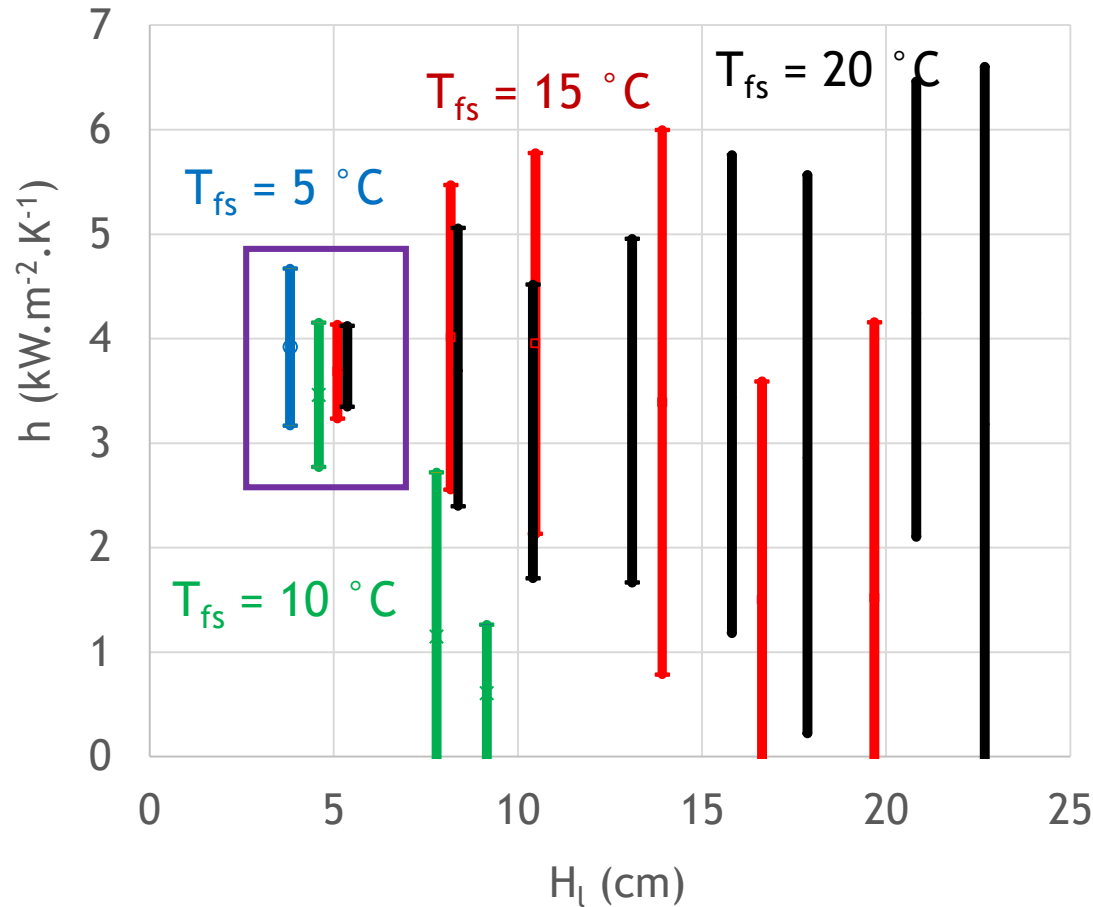
## Heat transfer coefficient (falling film):



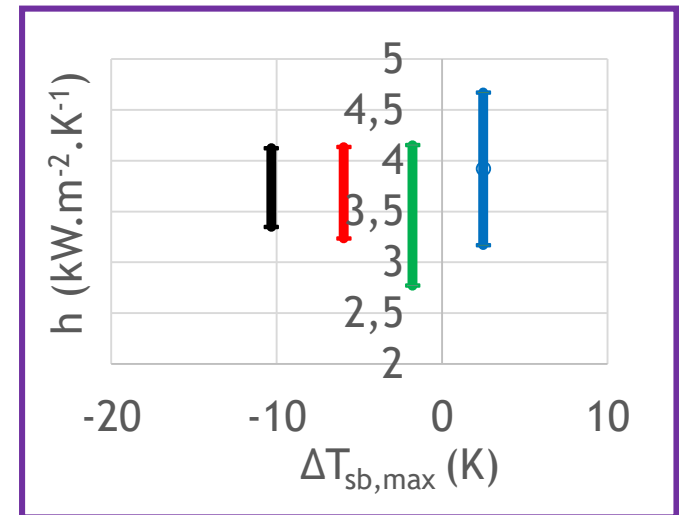
- Fluctuations of heat transfer coefficient increase with the increase of  $H_l$

# Results obtained

## Heat transfer coefficient:



- For a given  $H_l$ , increase of fluctuations with the increase of  $\Delta T_{sb,max}$



# Results obtained

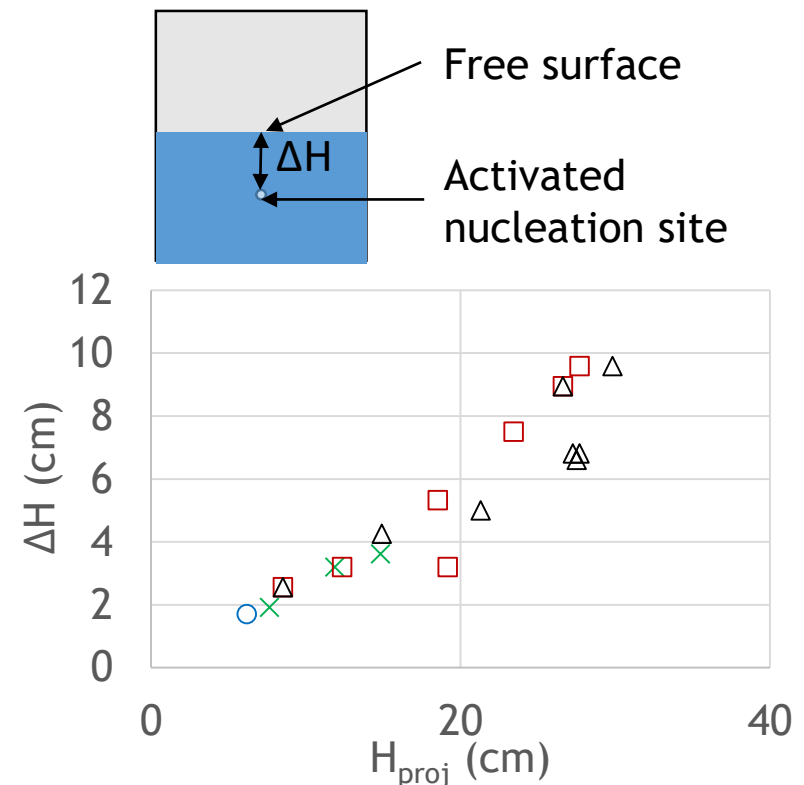
## Height up to which the liquid is plashed:

Parameters impacting on the height up to which the liquid is splashed ?

- Location of the bubble

➔ Relation between  $\Delta H$  and  $H_{proj}$  quasi linear

- Volume of the bubble ?
- Growth velocity ?



# Conclusions and Perspectives

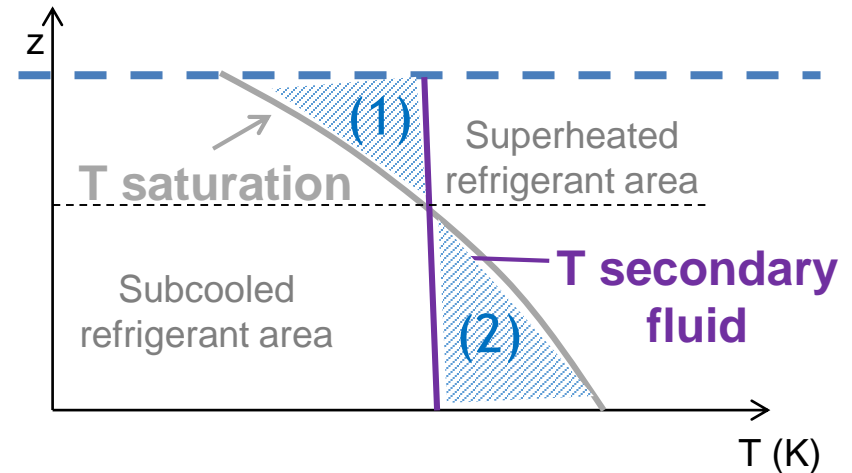
## We observed that:

- ✓ High influence of the filling ratio where the subcooling area is null for  $T_{fs} = 15\text{ °C}$  and  $T_{fs} = 20\text{ °C}$
- ✓ Impact of (1)-(2) on the cooling capacity

$$\checkmark \nearrow H_l \rightarrow \begin{cases} \nearrow H_{proj} \\ \searrow f_{bubble} \end{cases}$$

➔ High fluctuations of the heat transfer coefficient

- ✓ Impact of  $\Delta H$  on  $H_{proj}$



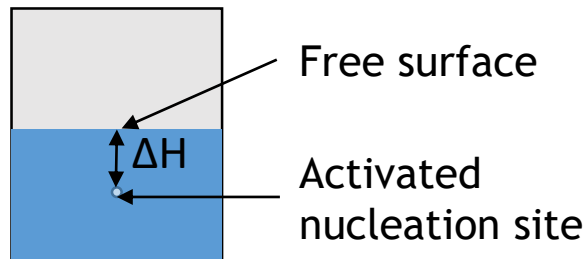


# Conclusions and Perspectives

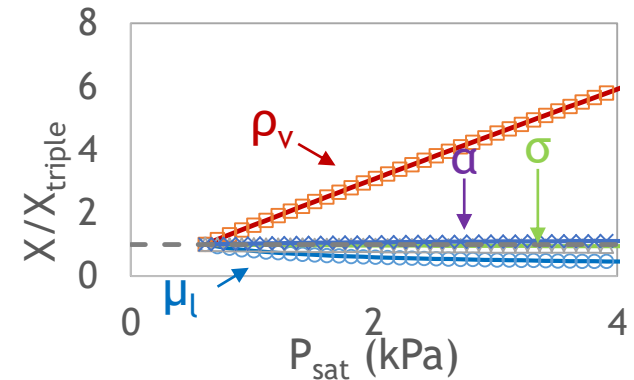
➔ Further effort must be done in order to :

✓ Understand phenomena observed

➔ Why the bubble is not generated closer to the free surface ( $\Delta T_{\text{sat, max}}$ )?



If  $\Delta H$   $\nearrow$   
 $\Delta T_{\text{sat}}$   $\searrow$



$\sigma$  and  $\mu_l$   $\searrow$  when  $P$   $\nearrow$

➔ There still remains mainly questions !!!

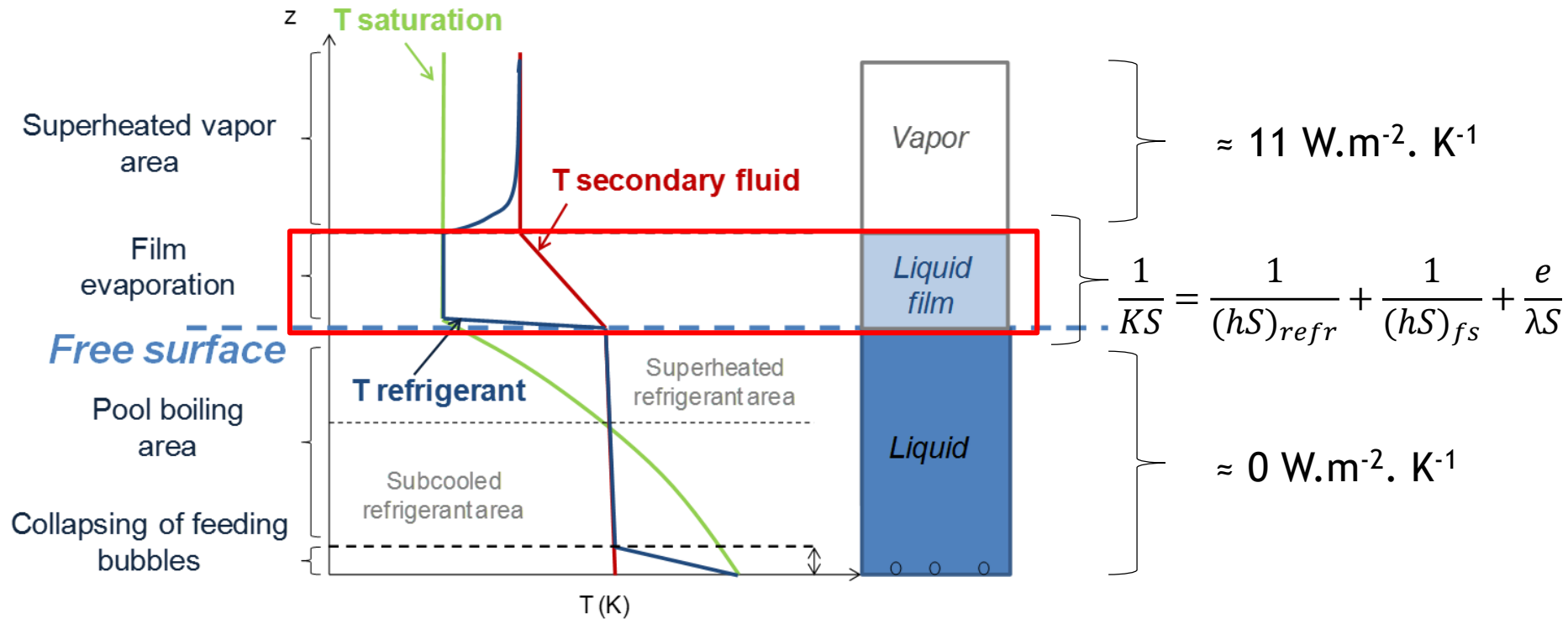
➔ Facilitate the bubble growth

✓ Control the bubble frequency and the location of the bubble growth

✓ Control conditions to obtain the widest liquid film area

# Thank you !

# Global heat transfer coefficient

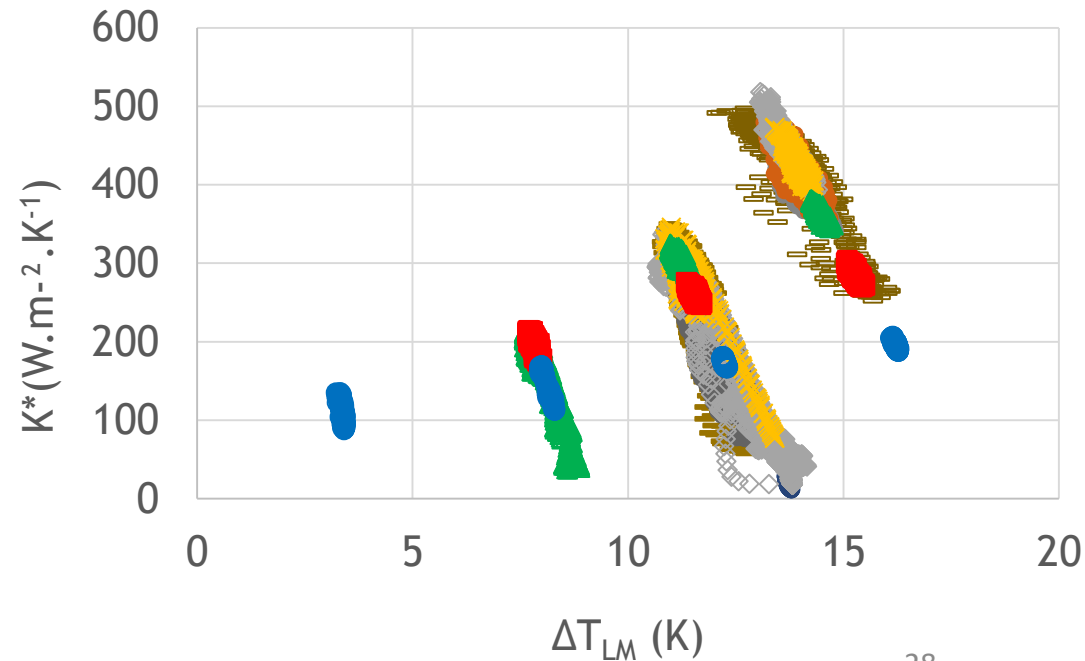
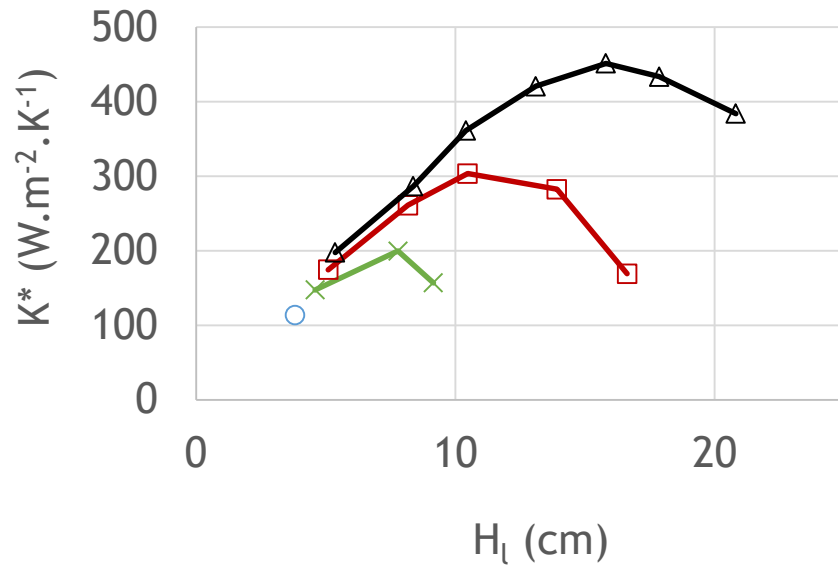


→ Physical meaning ?

$$K^* = \frac{\dot{Q}}{S \Delta T_{LM \text{ film}}}$$

$$\Delta T_{LM \text{ film}} = \frac{T_{fs,in} - T_{fs,out}}{\ln \left( \frac{T_{fs,in} - T_{sat}}{T_{fs,out} - T_{sat}} \right)}$$

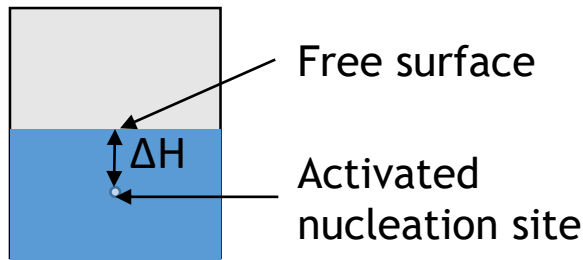
# Global heat transfer coefficient



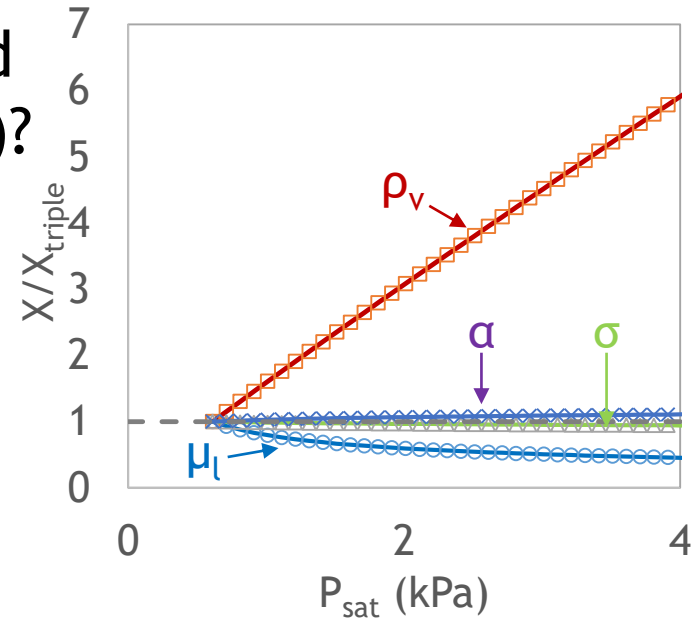
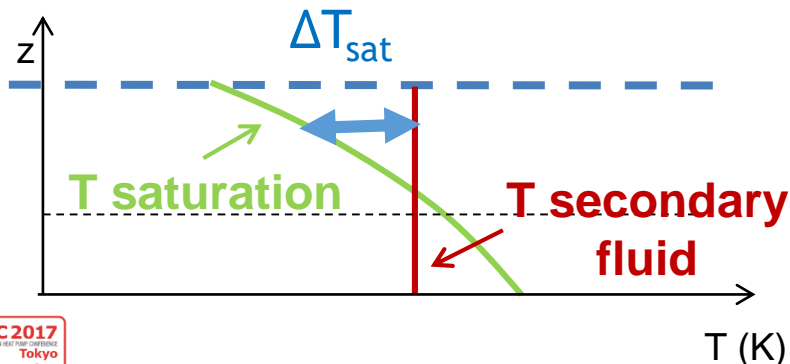
# Results obtained

## Height up to which the liquid is plashed:

→ Why the bubble is not generated closer to the free surface ( $\Delta T_{\text{sat, max}}$ )?



But if  $\Delta H \nearrow$ ,  $\Delta T_{\text{sat}} \searrow$

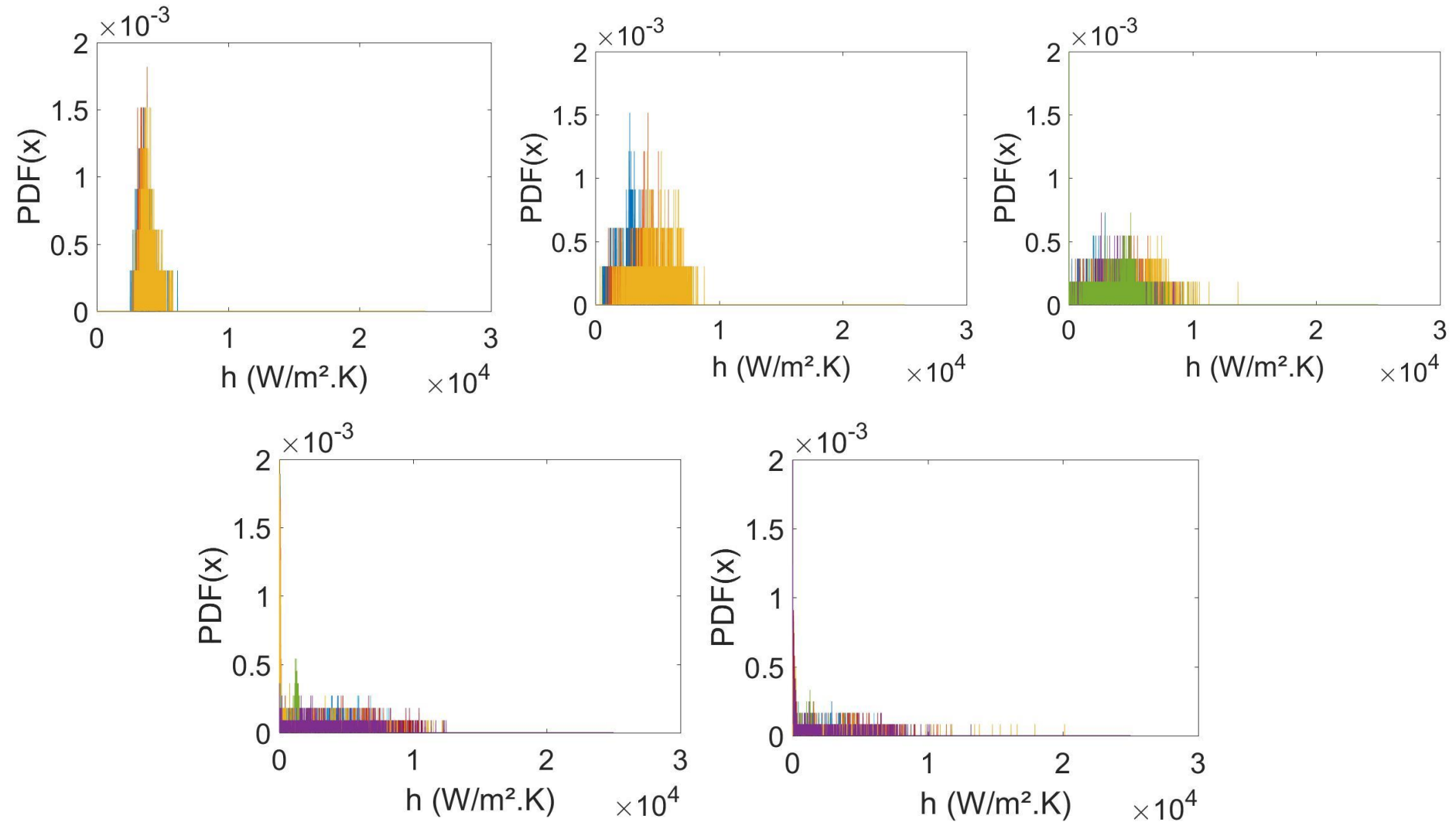


$\sigma$  and  $\mu_l \searrow$  when  $P \nearrow$

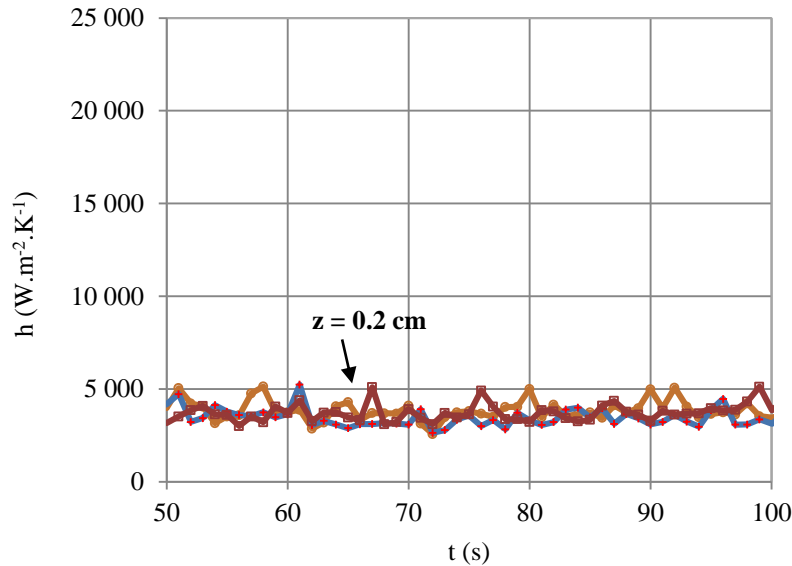
→ Facilitate the bubble growth

➡ There still remains mainly questions !!!

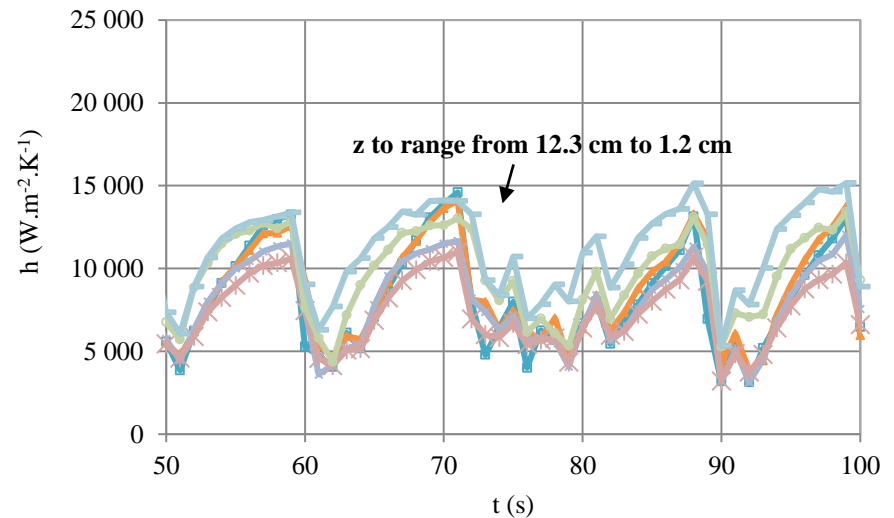
# Heat transfer coefficient



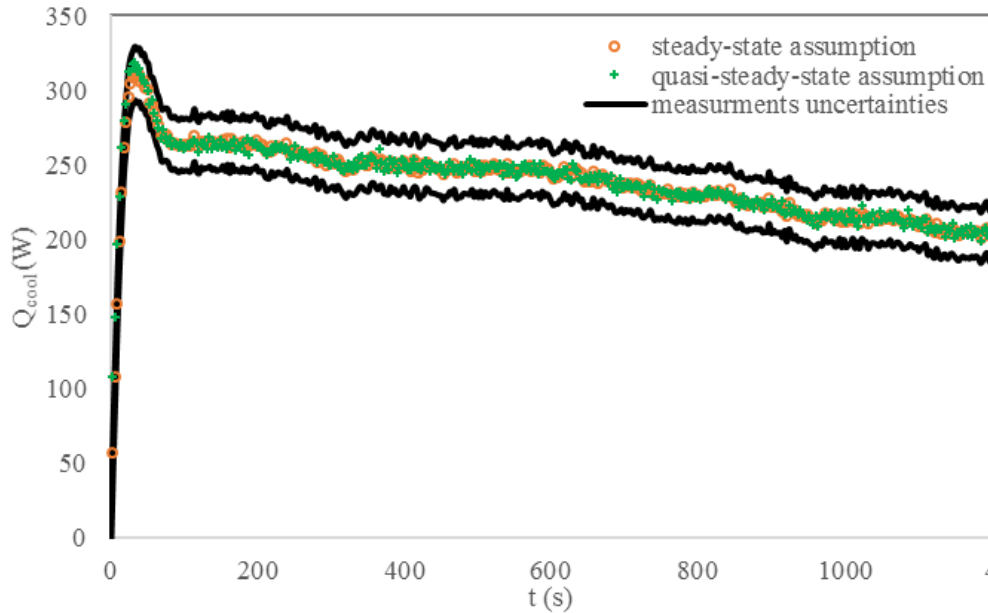
# Heat transfer coefficient



*Giraud F. et al., 2016. Experimental study of water vaporization occurring inside a channel of a smooth plate-type heat exchanger at subatmospheric pressure. Applied Thermal Engineering. vol 106, p. 180–191.*



# Inertial effect



*Giraud F. et al., 2017. Experimental study of water vaporization occurring inside the channel of a smooth-plate type heat exchanger connected to an adsorber and comparison with trends observed in absorption configuration. International Journal of Refrigeration. vol 77, p. 60-74.*

