

Heaters Size and Orientation Effect on Pool Boiling of FC-72

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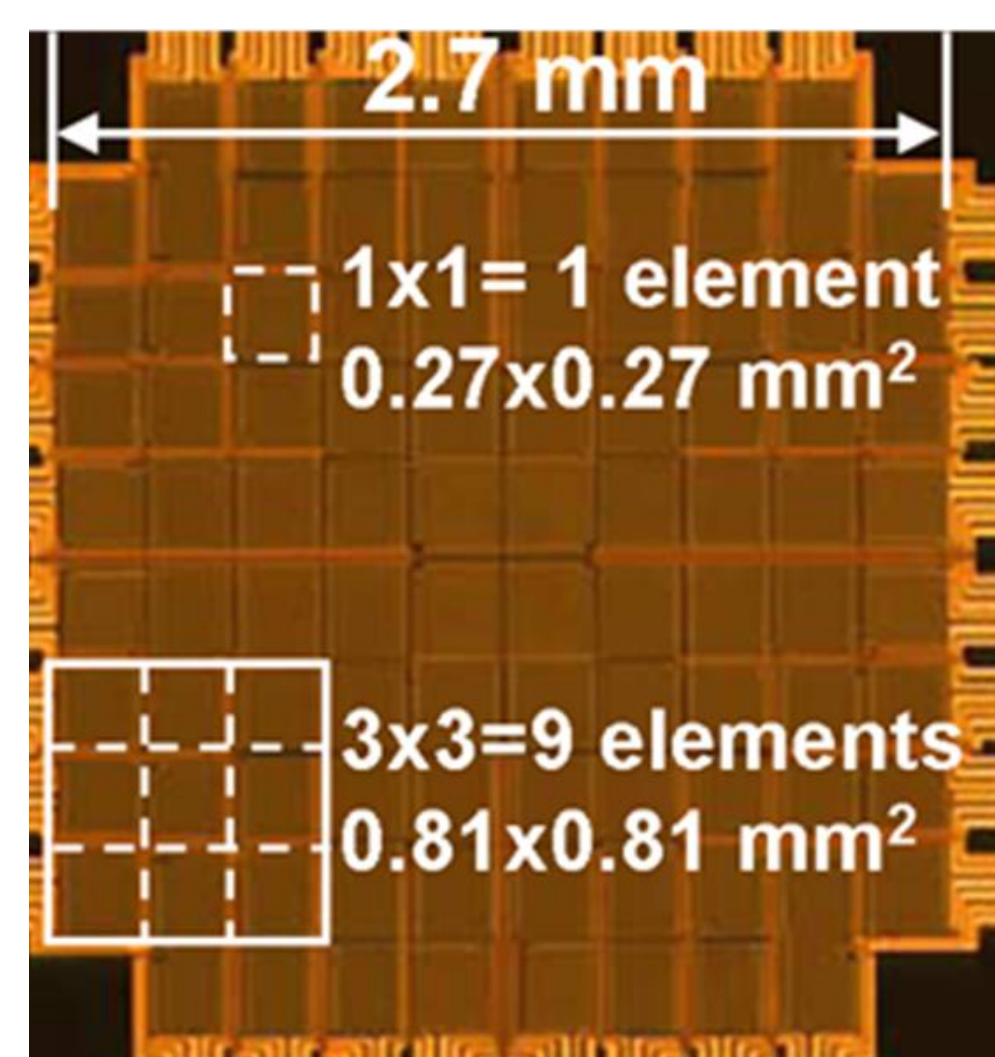
Introduction

Boiling under different gravity conditions and various heaters sizes is important for design of space based hardware.

➤ Effects of orientation on the balance between buoyancy and surface tension forces is discussed.

➤ 2.7 mm microheater array was used to vary the heater size.

➤ The test chamber was mounted on a rotating platform and experiments were performed at 4 orientations (0°, 45°, 90°, and 135°).



Heater Size Effect – Earth Gravity Results

Capillary length is a good parameter for studying heater size effect:

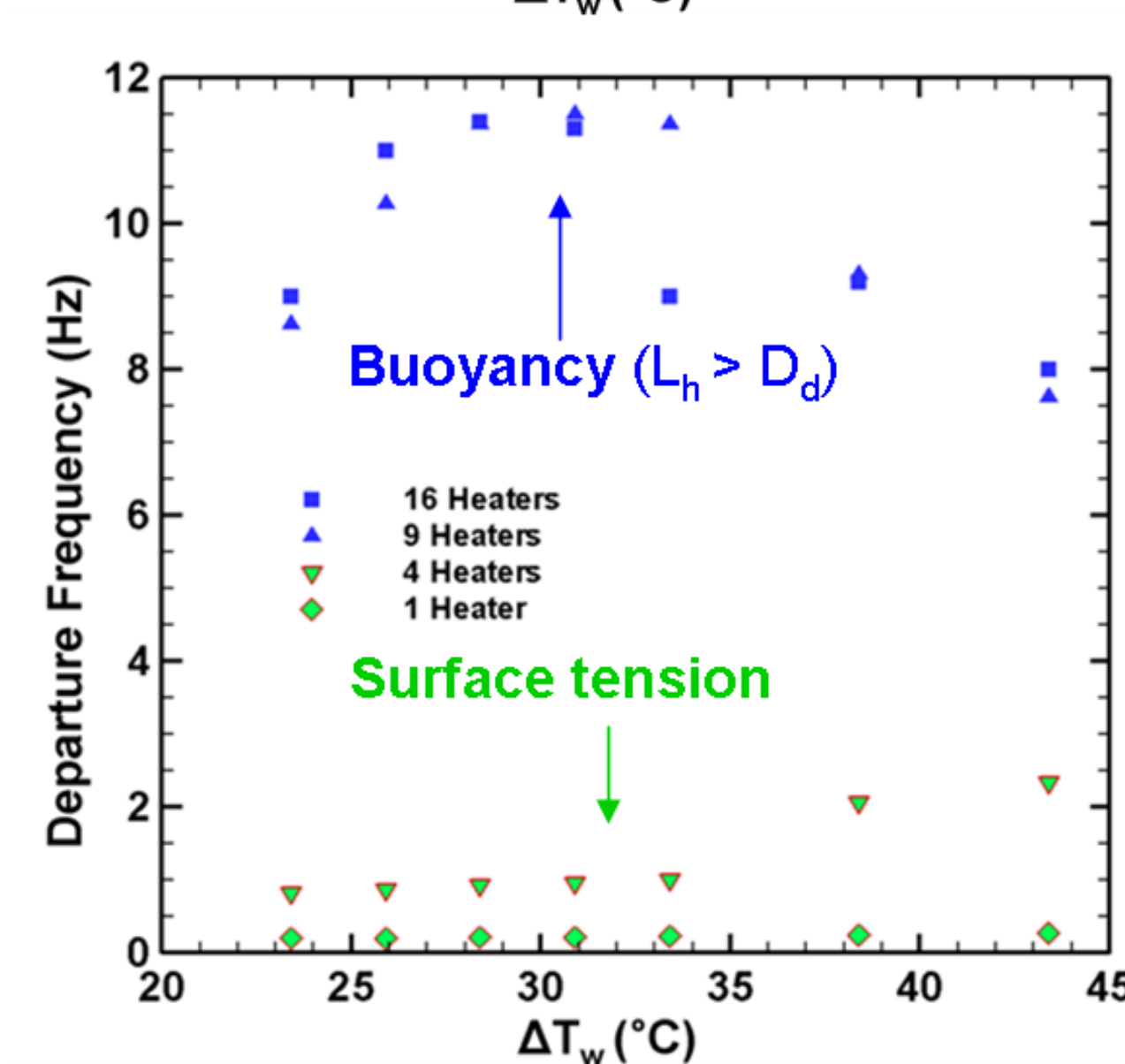
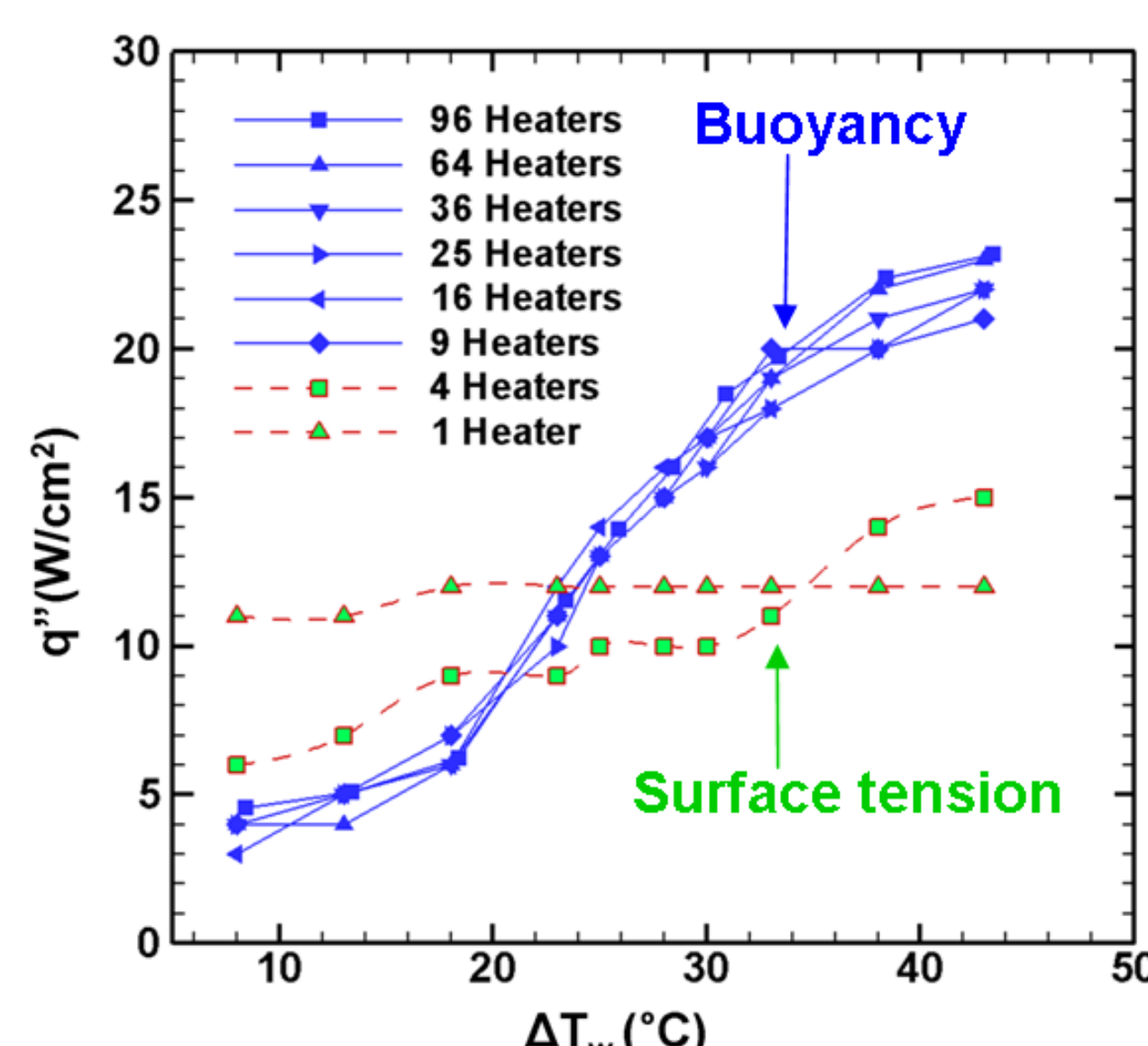
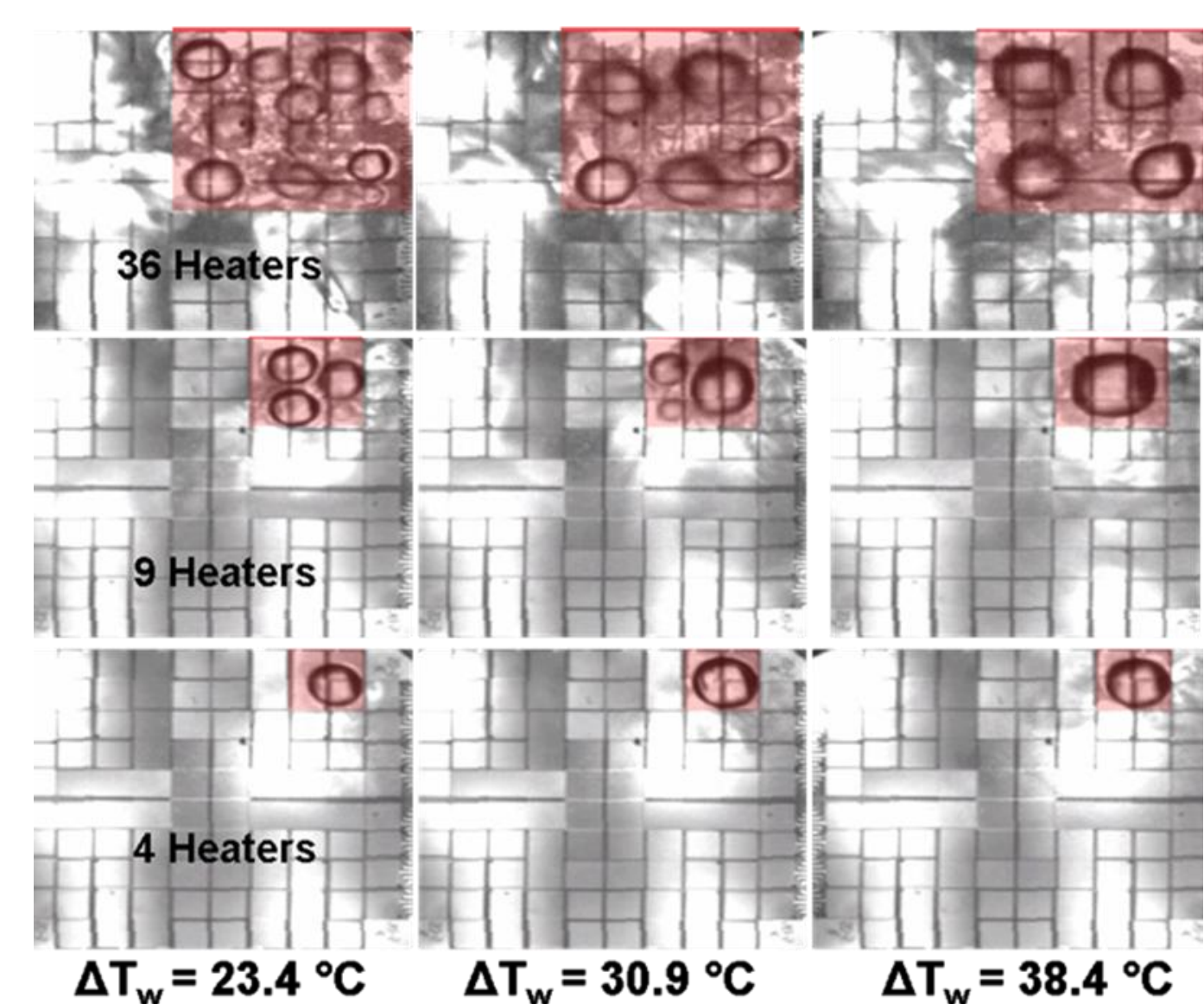
$$L_c = \sqrt{\frac{\sigma}{g(\rho_l - \rho_v)}}$$

➤ $L_h/L_c > 2.1$

- Boiling is buoyancy dominated
- q'' is heater size independent
- Bubble departure frequency not affected by heater size

➤ $L_h/L_c < 2.1$

- Boiling is surface tension dominated
- q'' is heater size dependent
- Rarely departing or non-departing bubbles similar to microgravity



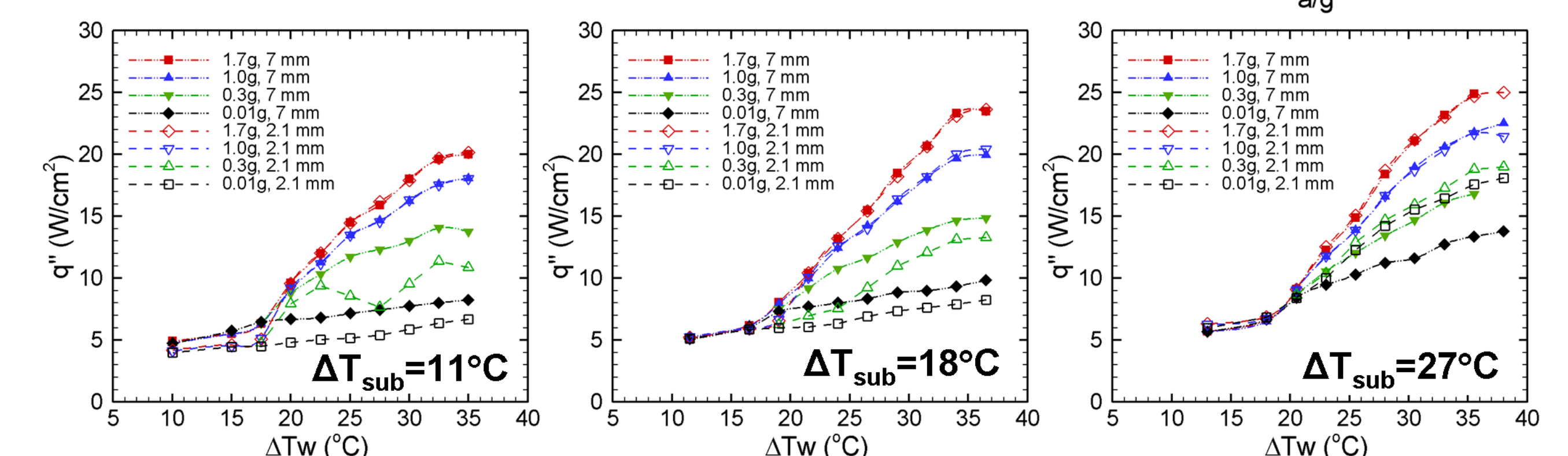
Heater Size Effect – Variable Gravity Results

➤ $L_h/L_c > 2.1$

- Boiling is buoyancy dominated
- q'' is heater size independent

➤ $L_h/L_c < 2.1$

- Boiling is surface tension dominated
- q'' is heater size dependent



Orientation Effect

For 45°, 90°, and 135°:

➤ $L_h/L_c > 1.8$

- Buoyancy dominated boiling
- q'' is heater size independent

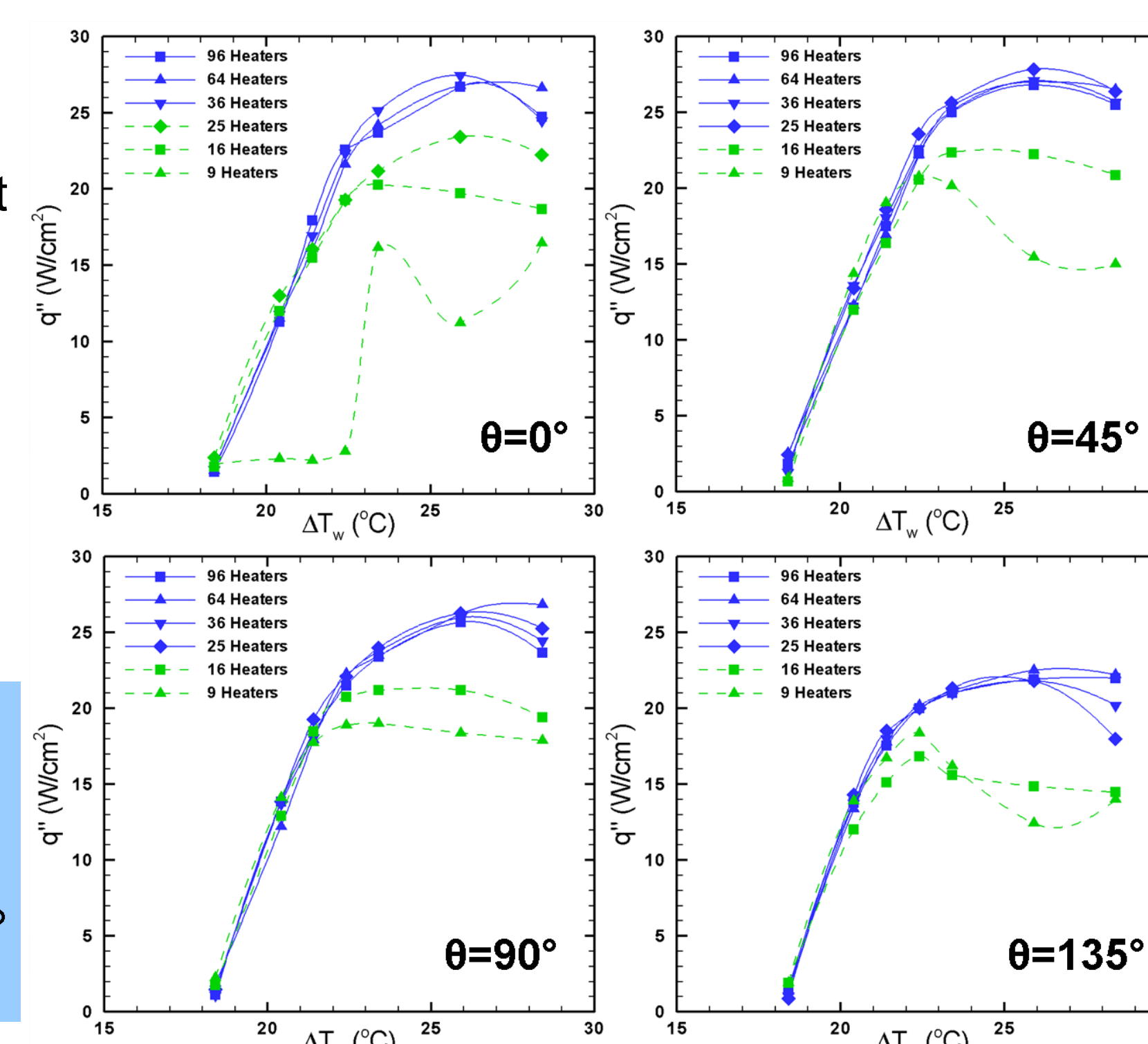
➤ $L_h/L_c < 1.8$

- Surface tension dominated
- q'' is heater size dependent

Transition Criteria

$$\frac{L_h}{L_c} = 2.1 \text{ for } 0^\circ$$

$$\frac{L_h}{L_c} = 1.8 \text{ for } 45^\circ, 90^\circ, 135^\circ$$

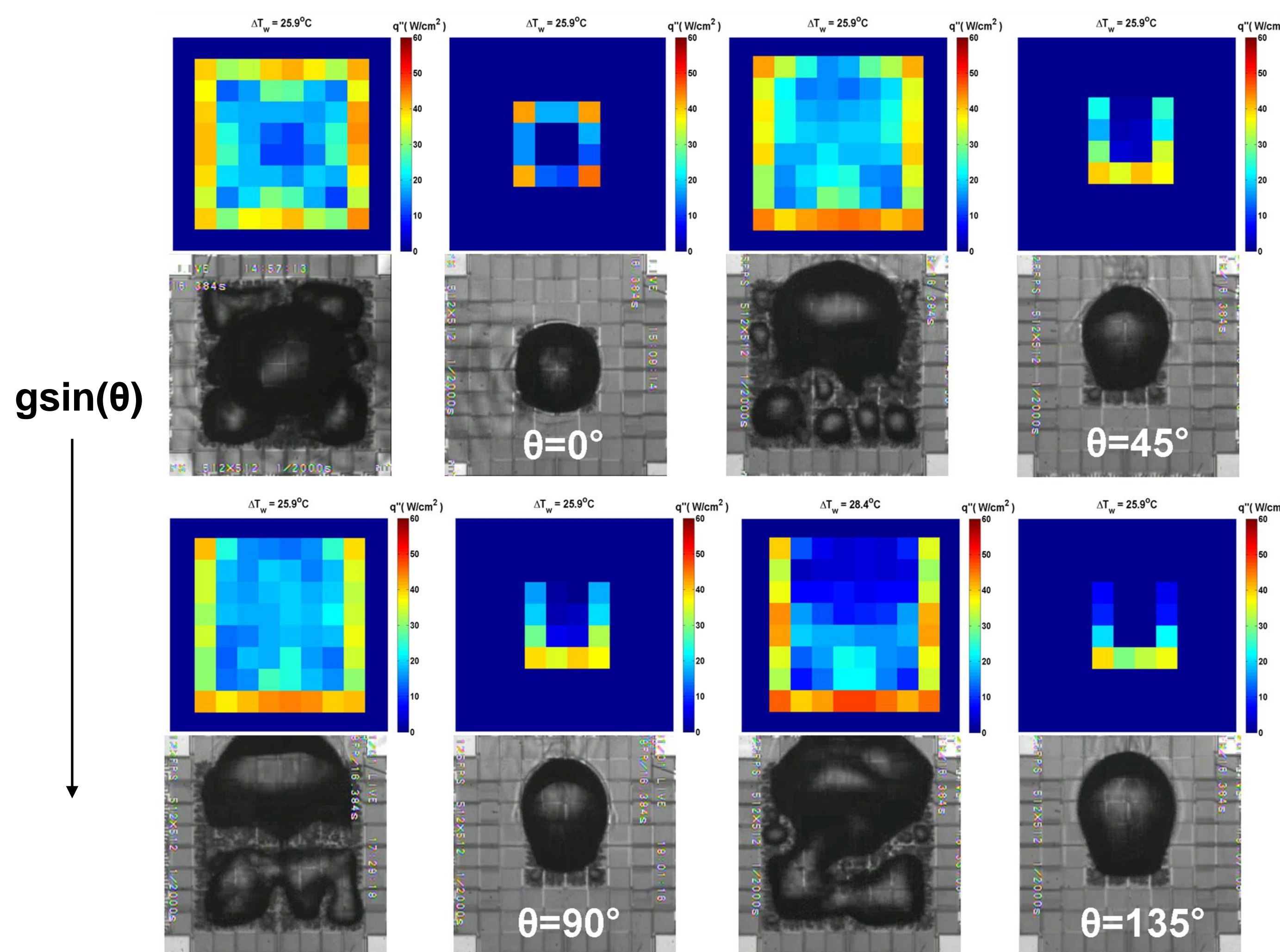


➤ ONB and CHF are not affected by heater orientation

➤ Heat flux at higher superheats for the 135° is significantly lower than other orientations

- A component of gravity pushes bubbles on to the heater

➤ Similar heat transfer for 0°, 45° and 90° if $L_h/L_c > 1.8$



Fractal Pattern in Boiling

➤ A fractal pattern is observed for the upward facing heater case

- Primary bubble surrounded by satellite bubbles

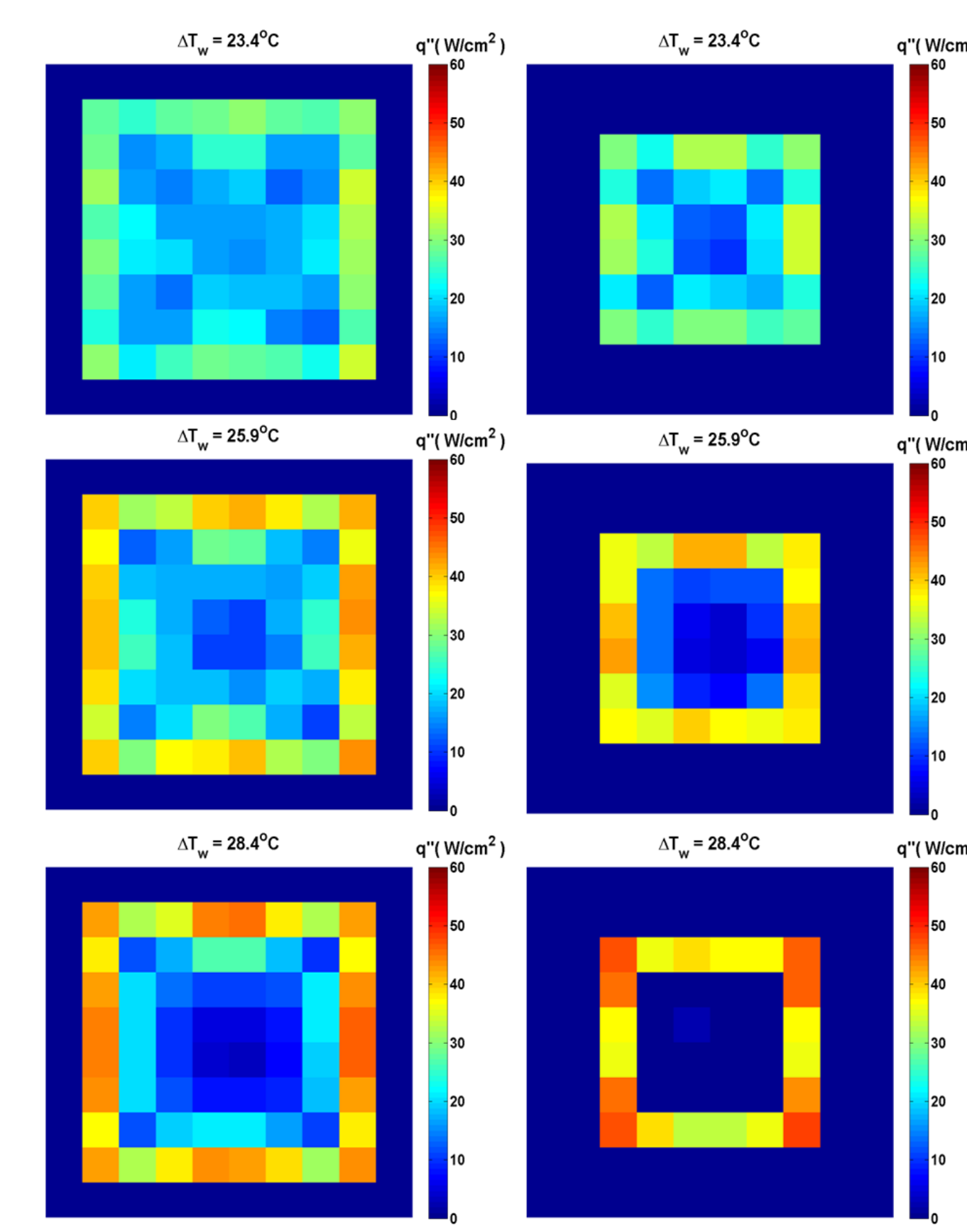
➤ Fractal pattern is observed in the video as well as confirmed by the local heat flux profile on the heater

➤ Fractal pattern becomes less prominent for smaller sizes

- Better spatial resolution required

➤ Fractal pattern is lost at other orientations

- Directional bias imposed by gravity



Critical Heat Flux (CHF)

Based on orientation, buoyancy dominated boiling can be divided into:

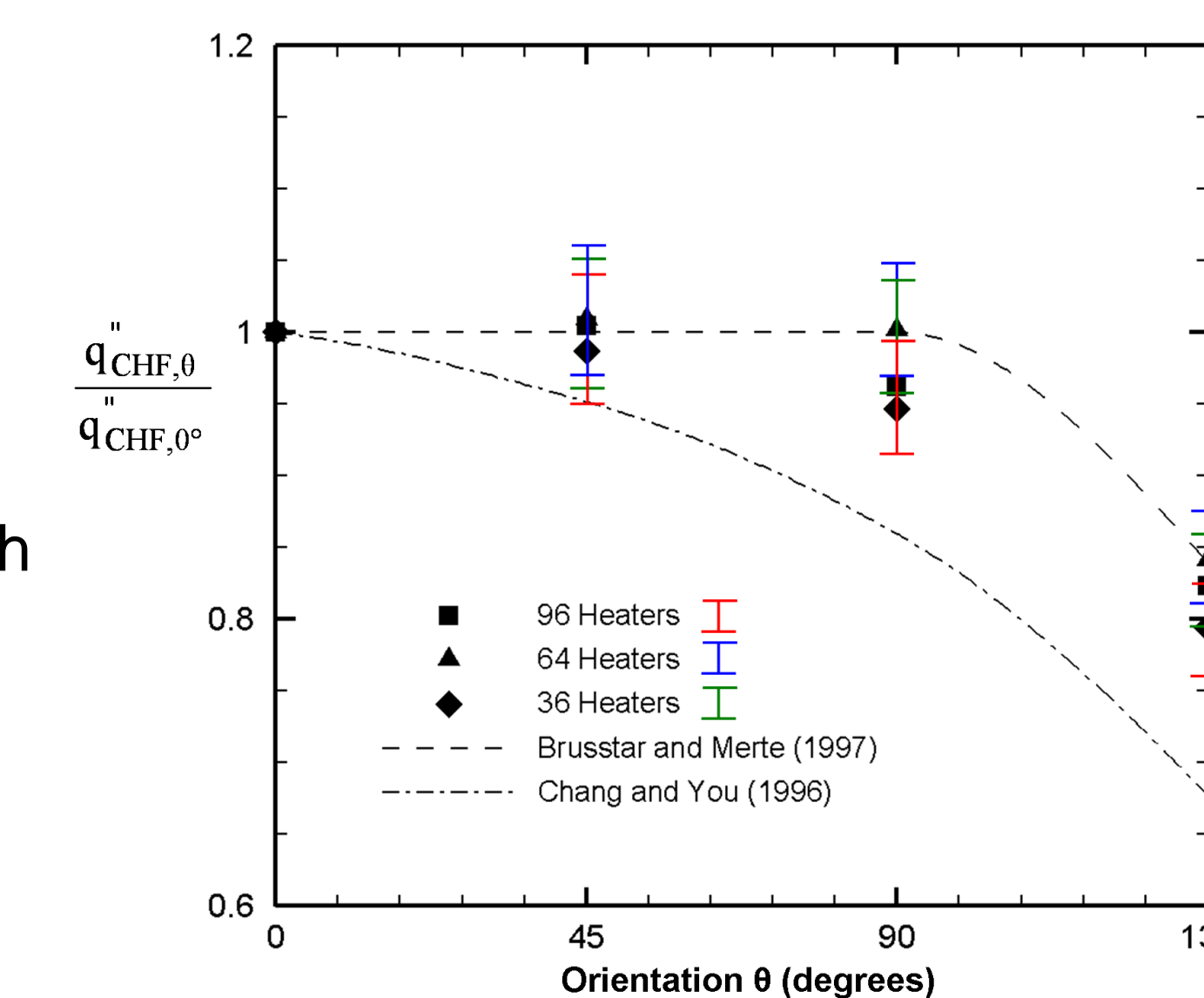
➤ Upward facing heater region

- $0^\circ \leq \theta \leq 90^\circ$
- CHF is independent of orientation

➤ Downward facing heater region

- $90^\circ < \theta \leq 180^\circ$
- CHF continuously decreases with orientation

➤ Better agreement with the model of Brusstar and Merte (1994)



Brusstar and Merte - R113 (1994)

$$\frac{q''_{CHF, \theta}}{q''_{CHF, 0^\circ}} = \begin{cases} 1.0 & 0^\circ < \theta < 90^\circ \\ |\sin \theta|^{1/2} & 90^\circ < \theta < 180^\circ \end{cases} \quad \text{Good agreement}$$

Chang and You - FC - 72 (1996)

$$\frac{q''_{CHF, \theta}}{q''_{CHF, 0^\circ}} = 1.0 - 0.00120 \tan(0.414\theta) - 0.122 \sin(0.318\theta)$$

➤ Buoyancy dominated regime

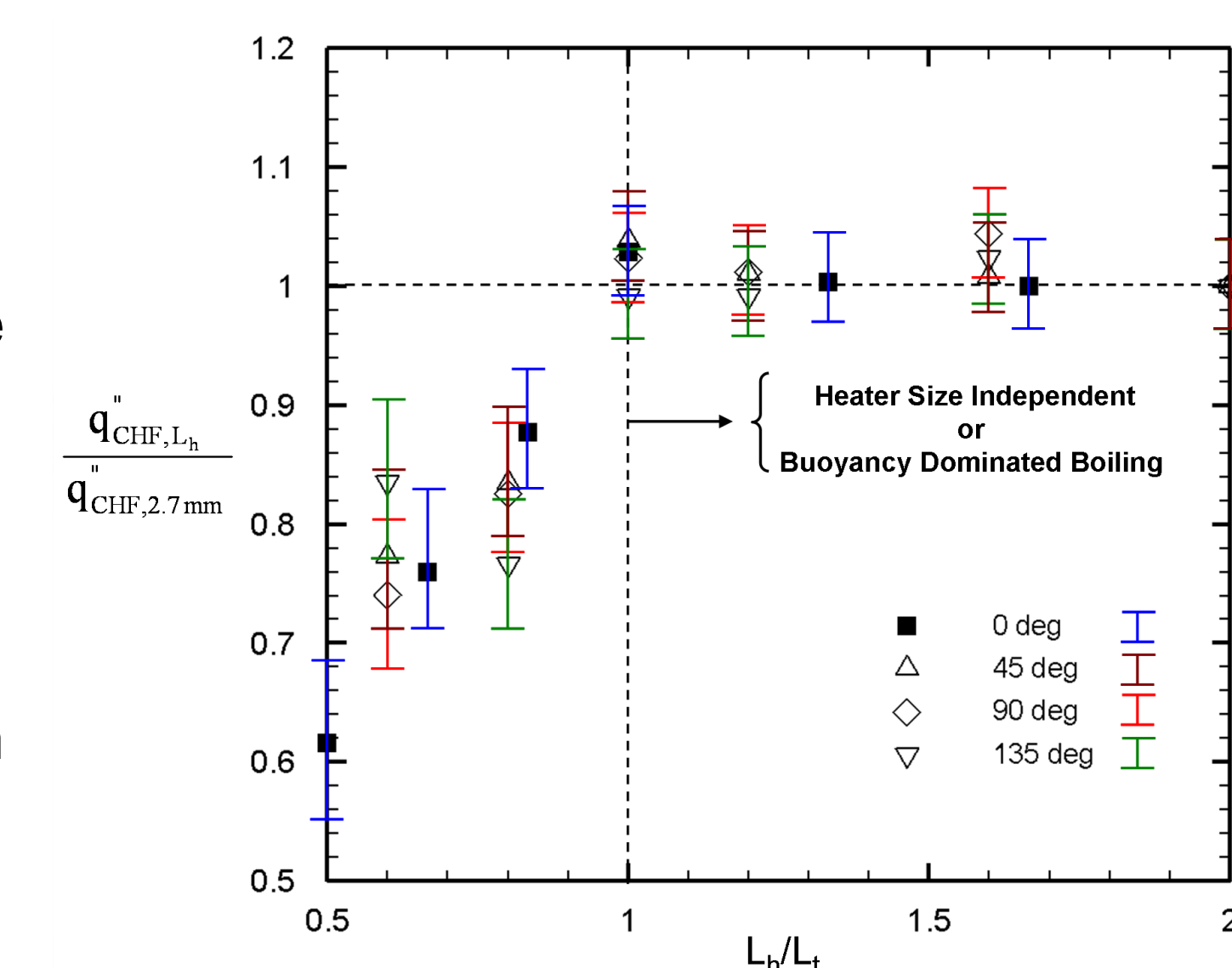
- $L_h/L_c > 1$
- CHF is independent of heater size

➤ Surface tension dominated regime

- $L_h/L_c < 1$
- CHF continuously decreases with heater size

where

$$L_t = 2.1L_c \text{ for } 0^\circ \text{ and } L_t = 1.8L_c \text{ for } 45^\circ, 90^\circ, 135^\circ$$



Conclusions

➤ Two pool boiling regimes similar to upward facing heater case were also observed for heater orientations of 45°, 90°, and 135°.

➤ Transition between the regimes was observed at a threshold value of $L_h/L_c \sim 1.8$.

➤ Heat transfer in the surface tension dominated boiling regime was smaller and boiling curves did not follow the classical boiling behavior at all four orientations.

➤ Heaters oriented at 135° showed significantly smaller heat transfer compared to the other three orientations.

➤ A fractal pattern in boiling was observed for the upward facing heaters.

Acknowledgements

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