Gravity Scaling Parameter for Pool Boiling Heat Transfer – IMECE2009-12624

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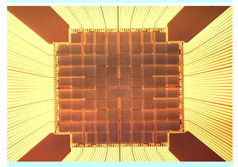
Introduction

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

- Parabolic flight experiments were performed to simulate the variable gravity condition (0.01g<a <to 1.7 g)
- Constant temperature microheater array was used for heat flux measurements and for varying heater sizes


Airbus 300 – "ZERO-G"

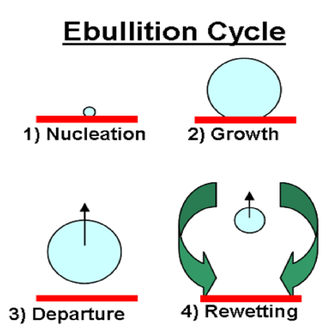

Constant-temperature microheater array

Gravity Effect

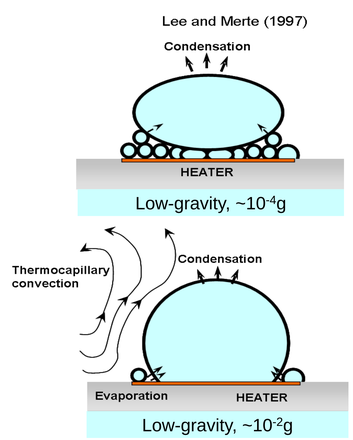
Nucleate boiling correlations are of the form:

$$q''_{b,NB} = f(\mu, c_p, h_{lv}, \alpha, \rho_l, \rho_v, \sigma, p, \Delta T_{sub}) * \Delta T_w^n \left(\frac{a}{g}\right)^m$$ ← Constant?

Is it physical to correlate earth and microgravity data?



Earth gravity, 1g

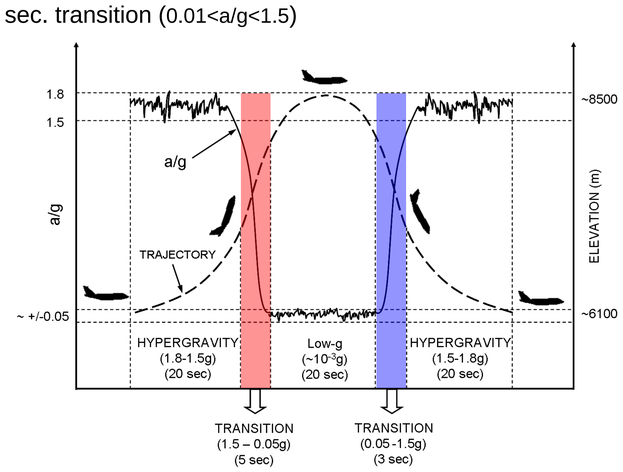


Variable Gravity Experiment

98.9 % n-perfluorohexane, P = 1 atm, ΔT_{sub} = 26°C.

48th ESA Parabolic Flight Campaign, 3/08

- 20 sec. hypergravity (>1.5g)
- 20 sec. low-g (<0.01g)
- 3-5 sec. transition (0.01<a/g<1.5)

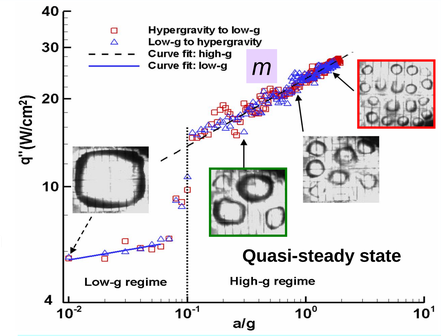


Schematic of Parabolic Flight

Variable Gravity Boiling Curve

Observations

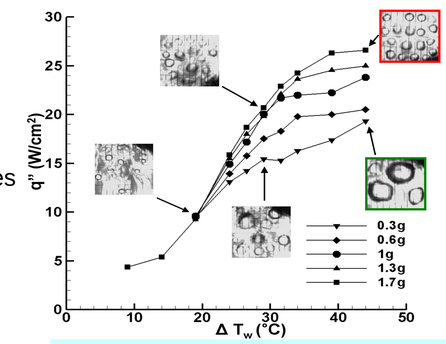
- Slope m is not constant
- $m = f(T_w)$
- Jump in heat flux at transition between regimes (~0.1g)



Heat flux vs. acceleration, ΔT_w=44° C, ΔT_{sub}=26°C

High-g regime

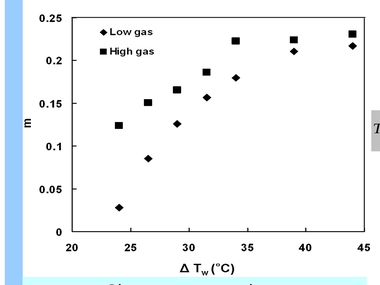
- Bubble departure diameter decreases with gravity
- Departure frequency increases with gravity
- Heat transfer by bubble growth, departure and rewetting



Boiling curves at different gravity level for high gas case, ΔT_{sub}=26° C

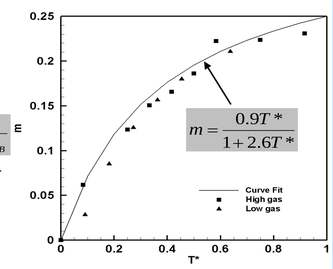
Development of Scaling Parameter

Slope *m* is not constant and increases with superheat.



Slope *m* vs. superheat

$$T^* = \frac{T_w - T_{ONB}}{T_{CHF} - T_{ONB}}$$



Slope *m* vs. non-dimensional temperature T*

$$q''_2 = q''_1 \left(\frac{a_2}{a_1}\right)^{\frac{0.9T^*}{1+2.6T^*}}$$ ← Scaling Parameter

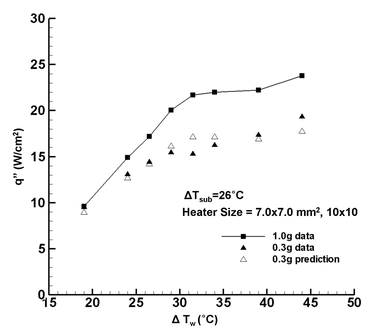
- Given the q_1'' at one gravity level and a superheat ΔT_w, heat flux at any other gravity level q_2'' can be predicted.
- Earth gravity correlations can also be used to get q_1''.

Prediction

$$q''_{0.3g} = q''_{1.0g} \left(\frac{0.3g}{1.0g}\right)^{\frac{0.9T^*}{1+2.6T^*}} \leftarrow T^* = \frac{T_w - T_{ONB}}{T_{CHF} - T_{ONB}}$$

△ ■

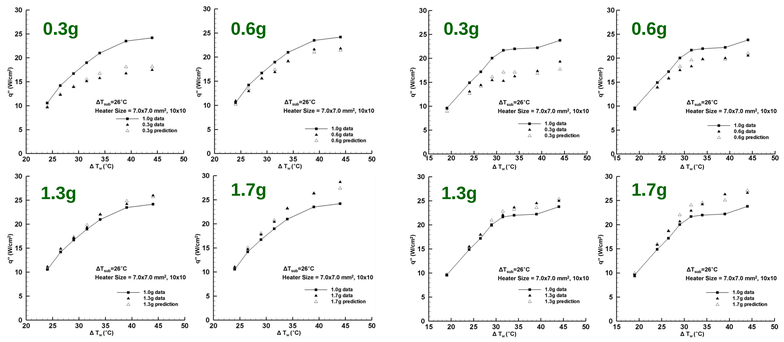
- T_{CHF} and T_{ONB} known from 1-g experimental data



Comparison of prediction and experimental data

Results

- Good agreement at various gravity levels ($Error_{RMS}$< 0.35w/cm²).
- Scaling parameter is independent of gas concentration c_g.

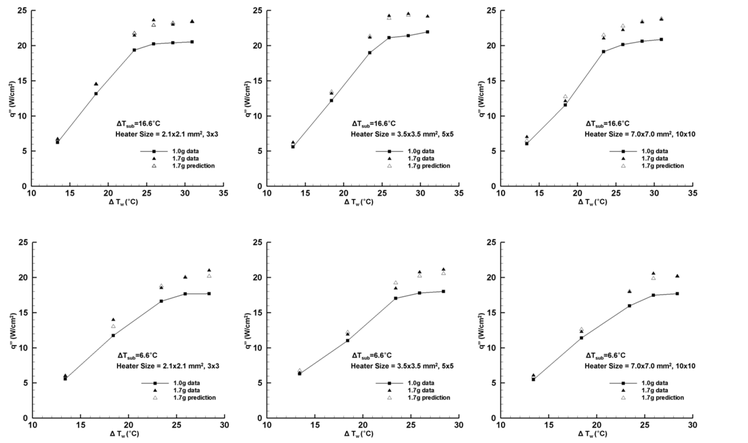


Low gas c_g~220 ppm, ΔT_{sub}=26°C

High gas c_g~1216 ppm, ΔT_{sub}=26°C

- Validated at various subcoolings.
- Applicable to all heater sizes if L_h/L_c>2.1

$$L_c = \left(\frac{\sigma}{g(\rho_l - \rho_v)}\right)^{1/2}$$ is the capillary length and L_h is heater width


Comparison of the prediction and experimental result for three sizes and two subcoolings at 1.7g

Conclusions

A gravity scaling parameter for pool boiling was developed for high-g buoyancy dominated boiling regime (L_h/L_c>2.1).

The scaling parameter is independent of

- Gas concentration
- Heater surface morphology
- Subcooling
- Heater size

Acknowledgements

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