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

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Introduction

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

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

Gravity Effect

Nucleate boiling correlations are of the form:

\[ \dot{q}_{\text{w},*} = f \left( \dot{m}, c_p, h_l, \rho, \alpha, \sigma, \Delta T_{\text{w}} \right) \]

Is it physical to correlate earth and low gravity data?

Ebullition Cycle

1) Nucleation
2) Growth
3) Departure
4) Rewetting

Earth gravity, 1g

Low-gravity, ~10⁻³ g

Variable Gravity Experiment

98.9 % n-perfluorohexane, P = 1 atm, \( \Delta T_{\text{sub}} = 26 \, ^\circ\text{C} \).

48th ESA Parabolic Flight Campaign, 3/08
• 20 sec. hypergravity (>1.5g)
• 20 sec. low-g (<0.01g)
• 3-5 sec. transition (0.01-g < g < 1.5 g)

Variable Gravity Boiling Curve

Observations

• Slope m is not constant
• \( m = f \left( T_{\text{ONB}} \right) \)
• Jump in heat flux at transition between regimes (~0.1g)

High-g regime

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

Development of Scaling Parameter

Slope \( m \) is not constant and increases with superheat.

\[ q_{\text{w}} = q_{\text{w,*}} \left( \frac{\Delta T_{\text{w}}}{\Delta T_{\text{ONB}}} \right)^m \]

\( q_{\text{w}} \) vs. \( \Delta T_{\text{w}} \)

\( m \) vs. non-dimensional temperature \( T^* \)

\[ \Delta T_{\text{ONB}} = \left( \frac{\dot{q}_{\text{w,*}}}{\dot{m}} \right) \left( \frac{\rho_l c_p \Delta T_{\text{ONB}}}{\Delta T_{\text{sub}}} \right) \]

\[ q_{\text{w}} = q_{\text{w,*}} \left( \frac{\Delta T_{\text{w}}}{\Delta T_{\text{ONB}}} \right)^{m-1} \left( \frac{\Delta T_{\text{w}}}{\Delta T_{\text{sub}}} \right) \]

Scaling Parameter

Given the \( q_{\text{w,*}} \) at one gravity level and a superheat \( \Delta T_{\text{w}} \), heat flux at any other gravity level \( q_{\text{w}} \) can be predicted.

Earth gravity correlations can also be used to get \( q_{\text{w,*}} \).

Results

• Good agreement at various gravity levels (Errorrms < 0.35 w/cm²).
• Scaling parameter is independent of gas concentration \( c_g \).

Conclusions

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

The scaling parameter is independent of:
• Gas concentration
• Heater surface morphology
• Subcooling
• Heater size

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