Comparative Study of Heat Transfer Performance and Visualization Images of Superfluid Helium Boiling in Narrow Two-Dimensional Channel

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Background

He II is applied as cooling media through narrow channels to cooling superconducting magnets.

Research Objective
What is the difference between He II boiling phenomenon in narrow channels and in open space?
Our Previous Researches; thermal measurements

In saturated pressure condition, the heat transfer coefficient is much higher than that in the case of pressurized He II. Quasi nucleation boiling region appears in narrow channel

H. Kobayashi et. al., Proc. of ICEC22, 2008, pp.341-346
H. Kobayashi et. al., Cryogenics 49, 2009, pp.700-706
Our Previous Researches; Explanation based on the visualization study

Visualization study proved;
the metastable state of superheating readily generated in narrow channel in saturate He II

We have focused on the appearance of metastable state in narrow channel.

In this study,
We tried to get more information from visual image for understanding thermal performance depending on pressure.
For wide pressure range, the visualization study and thermal performance data were compared.

S. Takada et. al, Cryogenics 49 (2009), pp. 576-582
Experimental Results; Thermal performance in Film boiling region

Peak heat transfer coefficient appears at lambda pressure.

"P \lambda = 5 \text{kPa}"

- \(10.61 \text{ W/cm}^2\)
- \(12.73 \text{ W/cm}^2\)

Picked up two point of heat flux

\(T_b = 1.95 \text{ K}\)
Experimental Results; Visualization in Film boiling region

Film boiling modes in narrow channel

**Strongly** subcooled film boiling

- $101.3 \text{ kPa}$
- $q = 9.68 \text{ W/cm}^2$

**Weakly** subcooled

- $9.2 \text{ kPa}$
- $q = 35.48 \text{ W/cm}^2$

**Noisy** film boiling

- $9.2 \text{ kPa}$
- $q = 35.48 \text{ W/cm}^2$
- $5.5 \text{ kPa}$
- $q = 11.21 \text{ W/cm}^2$

$T_b = 2.0 \text{K}$
In narrow parallel channel, area of stable boiling mode are larger than that in an open bath.

This mode only appears in narrow parallel channel.
The diagram illustrates the heat transfer coefficient (W/cm$^2$ K) and pressure (kPa) relationship for different film boiling modes. The pressure dependence varies corresponding to the film boiling modes, similar to the case of an open channel.

Pressure dependence varies corresponding to the film boiling modes, same as in the case of an open channel. Peak heat transfer coefficient appears at the transition pressure between weakly subcooled and noisy film boiling mode.

The transition pressure shifts to the lower pressure side in the case of a wire heater in an open bath.
Experimental Results; Thermal performance at Quasi nucleation boiling region (Bubble generation and collapse)

The bubble generation and collapse repeated when constant heat load applied.
Visualization Result;
Quasi nucleation boiling = bubble generation and collapse intermittently

① initial condition
② sHe II-sHe I < $P_{\lambda}$
③ sHe II-sHe I > $P_{\lambda}$
④ vapor expansion +Vapor
⑤ collapsing

Q. Why heat transfer getting smaller when heat flux increase?

A. The time duration of bubble covering the heater surface increases with heat flux.
   (i.e Frequency of generation and collapse increase.)

The frequency increase with heat flux.
Q. Why heat transfer coefficient jump at lambda point?

A. Visual image look similar. Vapor expansion speed increase when pressure decrease below $P_{\lambda}$. However shrinking speed is similar.
Summary

In this study, thermal measurement and visualization study results were compared for the case of narrow parallel channel in He II.

- Film boiling modes exist even in narrow channel. Stable film boiling mode region is larger than that in an open bath.

- The tendency of pressure dependence of heat transfer coefficient in narrow channel agree with that in an open bath.

- Around $P_\lambda$, the peak heat transfer coefficient appears.
  - $P_\lambda$ is the transition pressure between weakly subcooled and noisy film boiling mode in narrow channel.

- High heat transfer coefficient appears when bubble repeats generation and collapse intermittently accompanying with metastable state of superheating below $P_\lambda$. Rapid vapor expansion in the superheated He I caused the high heat transfer coefficient.
Backup slides
\[ T_b = 1.95 \text{ K} \quad \text{gap 0.15 mm} \]