Study of He II boiling flow field around a heater

M. Murakami\textsuperscript{a,b}, S. Takada\textsuperscript{c}, M. Nozawa\textsuperscript{d}

\textsuperscript{a}U Tsukuba, Japan, \textsuperscript{b}Mahasarakham U, Thailand,  
\textsuperscript{c}National Inst. for Fusion Sci., Japan and \textsuperscript{d}National Inst. of Tech., Akita College, Japan

Contents

1. Experimental Setup:
   Cryostat + PIV System  
   Heaters: Planar and Cylindrical Heaters

2. High-Speed Video Flow Visualization

3. PIV Measurement Results
   Transient Record of PIV Velocity \( U_{PIV}(t) \)  
   Time–Averaged Flow Velocity \(< U_{PIV} >\):
      Velocity Contour, Velocity–q, Velocity–T  
   Velocity Fluctuation \( \Delta U_{PIV} \)
Cryostat and PIV Experiment

L He Cryostat
- with 3 windows of 60 mm dia.
- 0 deg. : Entrance of Laser Sheet
- 90 deg. : Photographing

High Speed Video (Photron):
- 125~1000 fps

Field of View:
- 60 mm (y: horizontal)
- x 45 mm (x: vertical)

Laser (Kanomax):
- 5 W CW YAG
- Light Sheet (<2 mm)

PIV:
- Solid H-D Particles (Neutrally Buoyant)
- Direct Cross-Correlation Method

Significant improvement in Accuracy of calculating the the Average
as compared to the Previous results
Visualisation of Vapour Bubble + Tracer Particles

Noisy Boiling
Planar Heater

Heater (Horizontal)
10 mm (w) x 39 mm (depth)

Photographing time = 0.2 s
Temp. = 1.96 K
$q = 6.64E4 \text{ W/m}^2$
Visualisation of Vapour Bubble + Tracer Particles

Noisy Boiling
Cylindrical Heater

Heater (Horizontal)
5 mm (d) x 50 mm (Length)

Photographing time
= 0.1 s
Temp. = 1.95 K
q = 2.04E4 W/m²
Visualisation of Tracer Particles

Non–Boiling

No Vapour Film

Cylindrical Heater

Imaging time = 0.5 s
Temp. = 1.90 K
$q = 1.03 \times 10^4 \text{ W/m}^2$
Transient Velocity Record $U_{PIV}(t)$, Fluctuation Component

**Transient Velocity Record**

![Graph showing the transient velocity record $U_{PIV}(t)$ with time in s on the x-axis and velocity in m/s on the y-axis.]

- **Jumping up** Period: Bubble Expansion
- **Gradual Decrease**: Bubble Collapse

$\langle U_{PIV} \rangle$ at $x = 25.3$ mm, $y = 0.0$ mm (Outside the Vapour Area)

**Noisy Film Boiling**
- **Planar Heater**

$T = 2.00$ K, $q = 4.4e4$ W/m²

$\langle U_{PIV} \rangle = 0.045$ m/s, RMS = 0.147 m/s

**Fluctuation Component**

<table>
<thead>
<tr>
<th>Boiling Mode</th>
<th>Noisy ($\Delta U_{PIV}/\langle U_{PIV} \rangle$ (%))</th>
<th>Silent</th>
<th>He I</th>
<th>Non-Boiling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;100</td>
<td>$\leq 40$</td>
<td>$\leq 30$</td>
<td>$\leq 25$</td>
</tr>
</tbody>
</table>

Noisy Boiling: Extremely large
Time-Averaged Velocity $\langle U_{PLV} \rangle$: Velocity Vectors and Contour

**Noisy Boiling (Planar Heater)**
- Max Velocity = 0.19 m/s
- Averaging Time = 2.73 s
- Temp. = 1.96 K
- $q = 6.64E4$ W/m²

**Noisy Boiling (Cylindrical Heater)**
- Max Velocity = 0.019 m/s
- Averaging Time = 5.07 s
- Temp. = 1.78 K
- $q = 1.23E4$ W/m²
- Reverse Flow: at the lower right of the heater
Time-Averaged Velocity $\langle U_{PIV} \rangle$: Velocity Vectors and Contour

**Silent Boiling** (Planar Heater)
- Max Velocity = 0.052 m/s
- Averaging Time = 2.73 s
- Temp. = 1.96 K
- $q = 6.64E4$ W/m²

**Non-Boiling** (Cylindrical Heater)
- Max Velocity = 0.0081 m/s
- Averaging Time = 11.0 s
- Temp. = 1.90 K
- $q = 1.03E4$ W/m²
Time-Averaged Velocity $\langle U_{PIV} \rangle$ vs. Heat Flux $q$

$\langle U_{PIV} \rangle$ : Measured at Immediate Outside of Vapour Bubble Region

Thermal CF Theory : $U_{n,\text{theo}} = q/(\rho ST)$

**Planar Heater $\sim 1.8K$**

- Noisy Boiling
- Silent Boiling
- Non-Boiling
- Thermal CF Theory

**Cylindrical Heater $\sim 1.9K$**

- Noisy Boiling
- Silent Boiling
- Non-Boiling
- He I Boiling
- Thermal CF Theory

**Non-Boiling** : $\langle U_{PIV} \rangle \propto q$, and $\langle U_{n,\text{theo}} \rangle \leftrightarrow$ Interaction with Q Vortices

**Noisy** : Rapidly Rising Plume induced by Buoyant Bubble (> Silent)

**Magnitude of $\langle U_{PIV} \rangle$** : Noisy > He I > Silent > Non-Boiling
Temperature Dependence of PIV Velocity: \( \langle U_{\text{PIV}} \rangle / q \)

Noisy Boiling: \( \langle U_{\text{PIV}} \rangle \approx \) Thermal Counterflow Theory near \( T_\lambda \)
induced by Asymmetry of bubble expansion and collapse

Silent Boiling: \( \langle U_{\text{PIV}} \rangle < \) Thermal Counterflow Theory
Effect of Quantized vortices is predominant

He I Boiling: Nothing to do with Superfluidity, Temperature Independent
Conclusion

- Flow field around He II boiling
  - composed of thermal **counterflow** (DC background )
  - alternating flow of Total He II induced by boiling.
  - alternating flow component generated in the whole He II (Noisy)
    only near heater (Silent )

- Noisy Boiling
  - Bubble motion induced **Fluctuating Flow Component**
    is far larger than the **Average velocity**.
  - DC component resulting from the asymmetric bubble motion
    is as large as the theoretical thermal counterflow velocity

- Silent Boiling  : Quantized Vortices Dominant PIV Flow Field

- Non–Boiling : nearly **axisymmetric, no gravity effect**

- He I Boiling : rapidly rising buoyancy convective **Plume of He I.**