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Surface Geometry and Heat Flux Effect on Thin Wire Nucleate Pool Boiling of Subcooled Water in Microgravity

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SURFACE GEOMETRY AND HEAT FLUX EFFECT ON THIN WIRE NUCLEATE POOL BOILING OF SUBCOOLED WATER IN MICROGRAVITY

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Utah State University
Heng Ban – Faculty Mentor

2011 AIAA Region VI Student Conference
Nucleate Boiling

- Characterized by presence of bubbles
- High heat transfer rates
- Governed by Newton’s law of cooling
- Wide range of terrestrial and possible space applications

\[ q'' = h(T_s - T_\infty) \]

- \( q'' \) - heat flux
- \( h \) – heat transfer coefficient
- \( T_s \) – temperature of surface
- \( T_\infty \) – bulk temperature of fluid

Photo courtesy of Incropera
**Heat Flux Effects**

![Diagram of Heat Flux Effects](image)

Photos courtesy of Incropera

Nucleate boiling

Film boiling

2011 AIAA Region VI Student Conference
SURFACE GEOMETRY EFFECTS

Photo courtesy of Fukada

Photo courtesy of Zhao

Photo courtesy of Chyu
Microgravity Observations

Photo courtesy of Fukada
OBJECTIVES

Investigate the effects of surface geometry, heat flux, and gravity on nucleate boiling by observing:

- Onset of nucleate boiling characteristics
- Steady state heat transfer characteristics
- Bubble dynamics
EXPERIMENTAL SETUP

Power Supply → Boiling Cell → DAQ

ΔV\text{wire}

TC

Wire Heater

 SOURCE: The Zero Gravity Corporation

AIAA Region VI Student Conference
Transient Wire Behavior
ONSET OF NUCLEATE BOILING

- Steady condition before boiling
- Range of three wire onset heat flux
- Average wire temperature below saturation (Bubble dynamic effects on wire temperature)
# Effects of Surface Geometry

<table>
<thead>
<tr>
<th></th>
<th>Single-wire</th>
<th>Three-wire</th>
<th>Four-wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Onset Heat Flux</td>
<td>825 kW/m²</td>
<td>Between 396 and 519 kW/m²</td>
<td>586 kW/m²</td>
</tr>
<tr>
<td>Concentrated Surface Area</td>
<td>1:1</td>
<td>1:6</td>
<td>1:4</td>
</tr>
</tbody>
</table>

- Concentrated Surface Area to Total Surface Area

\[
\frac{\text{Red Area}}{\text{Blue Area}} = \frac{1}{1} \quad \frac{\text{Red Area}}{\text{Blue Area}} = \frac{1}{6} \quad \frac{\text{Red Area}}{\text{Blue Area}} = \frac{1}{4}
\]
Steady State Heat Transfer

- Efficiency of boiling heat transfer in 1g and 0g are similar
- More effective area (more active nucleation sites) in microgravity
Bubble Dynamics - Jets

<table>
<thead>
<tr>
<th>Distance from wire</th>
<th>TC 1</th>
<th>TC 2</th>
<th>TC 3</th>
<th>TC 4</th>
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<tbody>
<tr>
<td>1 mm</td>
<td>6 mm</td>
<td>11 mm</td>
<td>16 mm</td>
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Relative Bubble Area Analysis (RBAA)
HEAT FLUX EFFECT - RBAA
CONCLUSIONS

- The unique twist of three-wires provides a surface geometry that reduces the required heat flux for onset boiling.
- In many instances, steady state heat transfer is enhanced in microgravity in the range of 5-10%.
- As heat flux increases, there is an increased tendency to form jets, which provide convective current normally absent in microgravity.
ACKNOWLEDGEMENTS

- SpaceX
- Rocky Mountain NASA Space Grant Consortium
- USU College of Engineering
- USU Department of Physics
- USU Undergraduate Research
- Space Dynamics Lab
- American Aerospace Advisors
- National Instruments
QUESTIONS
1) Extend input power range up to critical heat flux (wire burnout)

2) Further resolve onset conditions for boiling

3) 2-D Heater:
   • Electric pulses to ‘seed’ the bubbles
   • Bubbles grow as they accept heat
   • Possibility to control amount of cooling

Photo courtesy of Deng
<table>
<thead>
<tr>
<th>Geometry</th>
<th>“Power Level”</th>
<th>Input Current (A)</th>
<th>Average Power (W)</th>
<th>Average Heat Flux (kW/m²)</th>
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<td>2.48</td>
<td>599</td>
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