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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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

CHF

Free Convection  Nucleate  Transition  Film

Surface Heat Flux, W/m²

10³  10⁴  10⁵  10⁶  10⁷

1  5  10  30  120  1000

Excess Temperature, °C

Nucleate boiling

Film boiling

Photos courtesy of Incropera
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

SOURCE: The Zero Gravity Corporation

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TRANSIENT WIRE BEHAVIOR

Saturation Temperature, 94°C

Wire Temperature

Superheat
Onset
Transition
Steady State

Time, ms

Wire Temperature, deg C

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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 to Total Surface Area</td>
<td>1:1</td>
<td>1:6</td>
<td>1:4</td>
</tr>
</tbody>
</table>

![Diagram showing surface area ratios](image)
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></th>
<th>TC 1</th>
<th>TC 2</th>
<th>TC 3</th>
<th>TC 4</th>
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<tbody>
<tr>
<td>Distance from wire</td>
<td>1 mm</td>
<td>6 mm</td>
<td>11 mm</td>
<td>16 mm</td>
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</table>
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
**Future Research**

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

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Photo courtesy of Deng

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<table>
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<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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