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Surface Tension Effects on Micro Gravity Boiling

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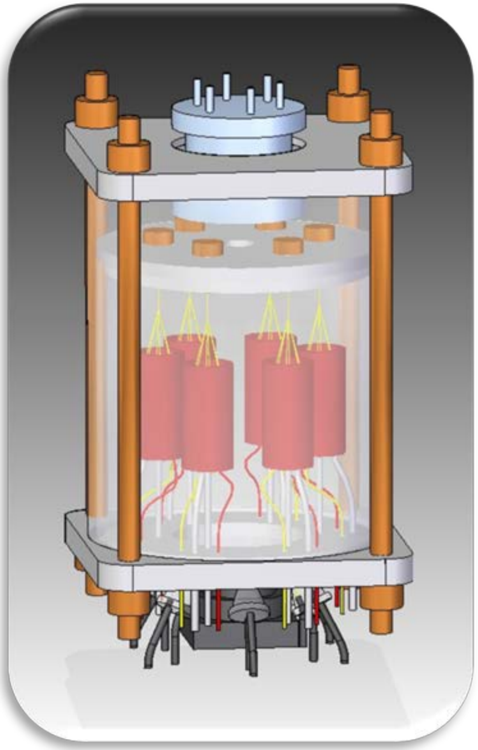

Figure 1: The Boiling Tube instrument, assembly

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Boiling Regimes[1]

- Free Convection
  - Buoyancy driven fluid convection at heated surface
  - Exists until bubble formation begins
- Nucleate
  - Isolated vapor bubble formation
  - Bubble interference and coalescence
  - Bubble departure
  - Exist until critical heat flux is reached
- Film Boiling
  - Vapor blanket

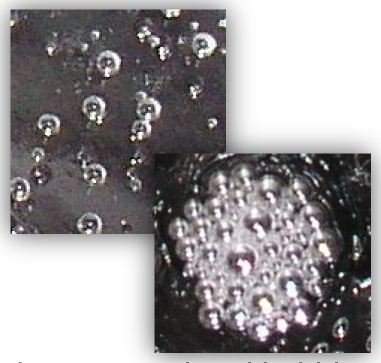

Figure 2: Isolated bubbles and bubble interference

[1]Incorpera, Frank P., Davis P. Dewitt, Theodore L. Bergman, and Adrienne S. Lavine. "Fundamentals of Heat and Mass Transfer" John Wiley & Sons, Inc. (2007).

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Effect of Micro-Gravity

- Minor free convection and conduction
  - Primary mode of heat transfer is limited convection due to small movement at the surface along with conduction through the fluid
- Nucleate
  - Bubble formation
  - Bubble coalescence
  - Surface Roughness
    - Higher surface roughness increases heat transfer rate

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Intent of Instrument

- To test six samples, each with a different surface roughness
- Bubble dimensions are driven directly by the change in surface roughness by altering the surface tension. Changing the bubble dimensions should have a direct and considerable effect on the heat transfer in micro-gravity.

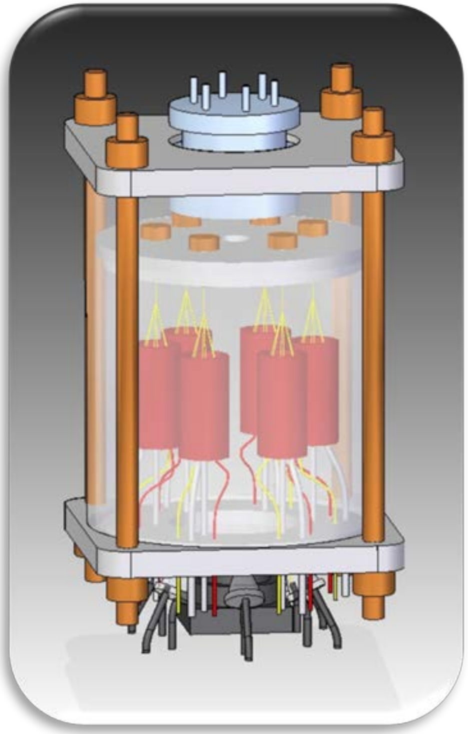

Figure 3: The Boiling Tube instrument, assembly

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Measurements

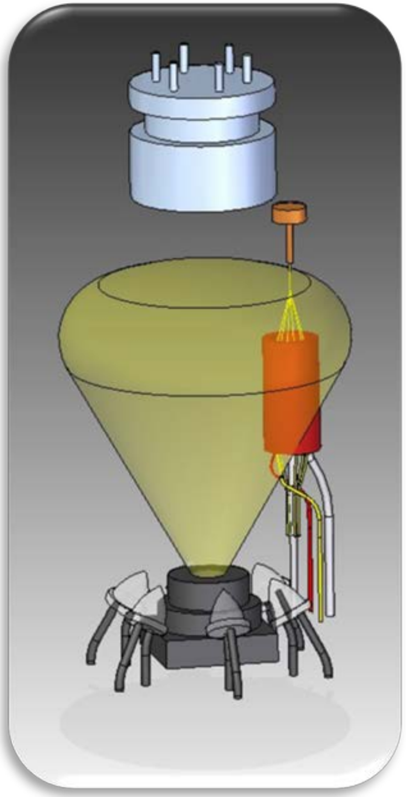

Figure 4: The Boiling Tube instrument, sensor configuration

- Fundamental
  - Fluid Pressure
    - Derive saturation temperature
  - Surface temperature
  - Input voltage and Current
    - Derive surface heat flux
- Additional
  - Fluid temperature
  - Images
    - Understand conditions during bubble formation and coalescence

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Why Test in Orbit?

Pros

- Mission life allows time to stabilize and perform longer tests
- Lower acceleration than sub-orbital options
  - Aerodynamic drag
- Test multiple samples, multiple times

Cons

- Limited data downlink
- No instrument recovery

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CubeSat Parameters[2]

- Constrained
  - Mass ~ 1kg
  - Size ~ 10cm Cube
- Pressure vessels
  - Must be under 1.2 atmospheres (atm)
  - Factor of safety greater than 4
- Experiment dimensions
  - Sample dimensions
    - 5mm diameter an 10mm tall
  - Overall Instrument
    - Exterior is 30 x 30 x 56 mm
- Water for working fluid
  - Liquid at 1 atm within the expected temperatures of storage and launch.
  - Availability

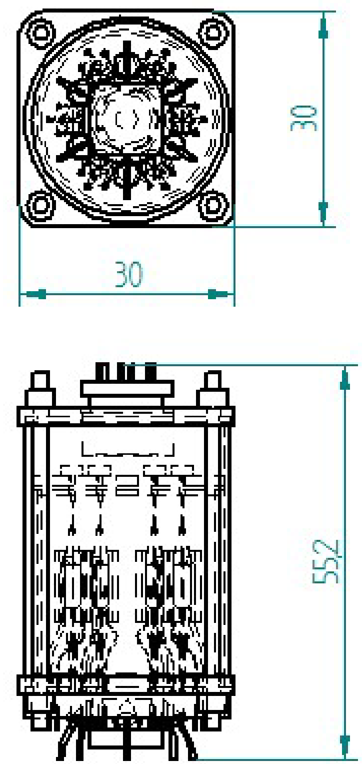

Figure 6: The Boiling Tube instrument, dimensions (mm)

[2]"CubeSat Design Specification" The Cubesat Program, Cal Poly SLO

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Heated Sample

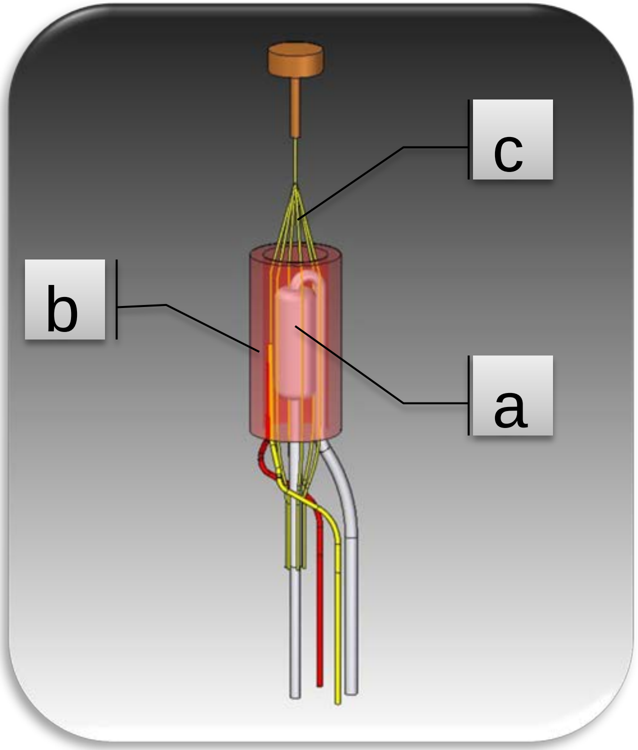

Figure 7: The Boiling Tube instrument, heating sample

a) Heated resistor
   - Produces heat for heated sample
b) Thermistor
   - Measured to derive the surface temperature
c) Suspending polymer strings
   - Mount the cylinder in the chamber securely

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Chamber

a) Aluminum bulkheads
b) Upper support ring
  - Aluminum mounting ring for samples in tension
c) Glass walls
  - Ease of inspection for assembly and testing
d) Electrical pass-through
  - Epoxied wires for insulation and seal
e) Lens
  a) Camera port for image

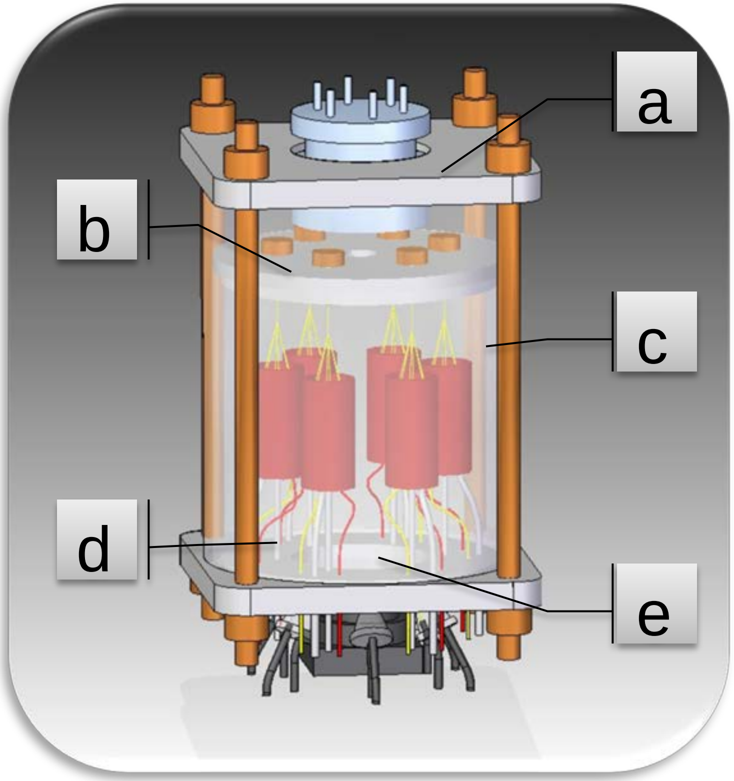

Figure 8: The Boiling Tube instrument, assembly

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Boiling Curve

Critical heat flux is reevaluated at microgravity to determine maximum heat dissipation during the experiment.

$$q''_{\max} = C h_{fg} \rho_{\upsilon} \left[\frac{\sigma g \left(\rho_l - \rho_v \right)}{\rho_{\upsilon}^2} \right]^{1/4}$$

Equation 1: Critical heat flux[1]

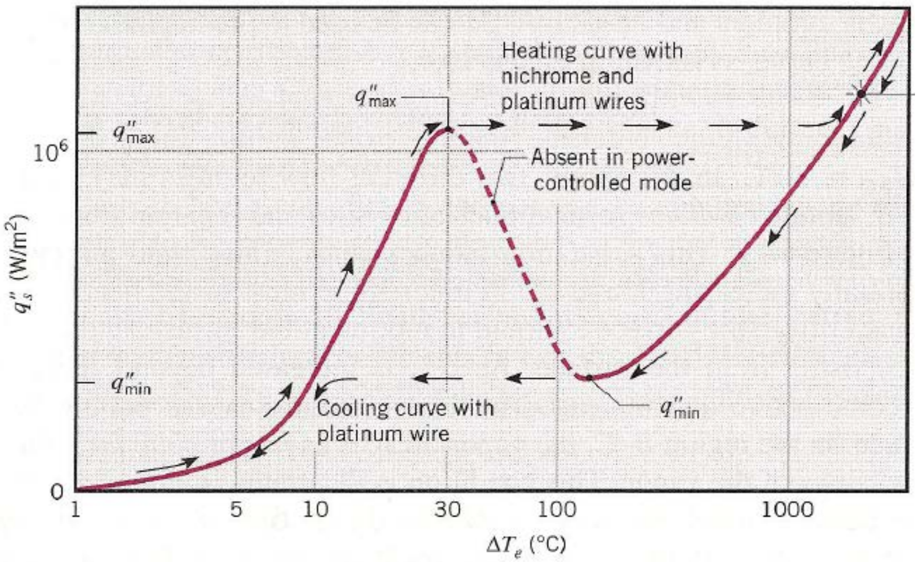

Figure 9: Typical boiling curve at 1atm and 1gravity.[3]

[3]Nukiyama, S., J. Japan Soc. Mech. Eng., “Int. J. Heat Mass Transfer, 9, 1419, 1966”.

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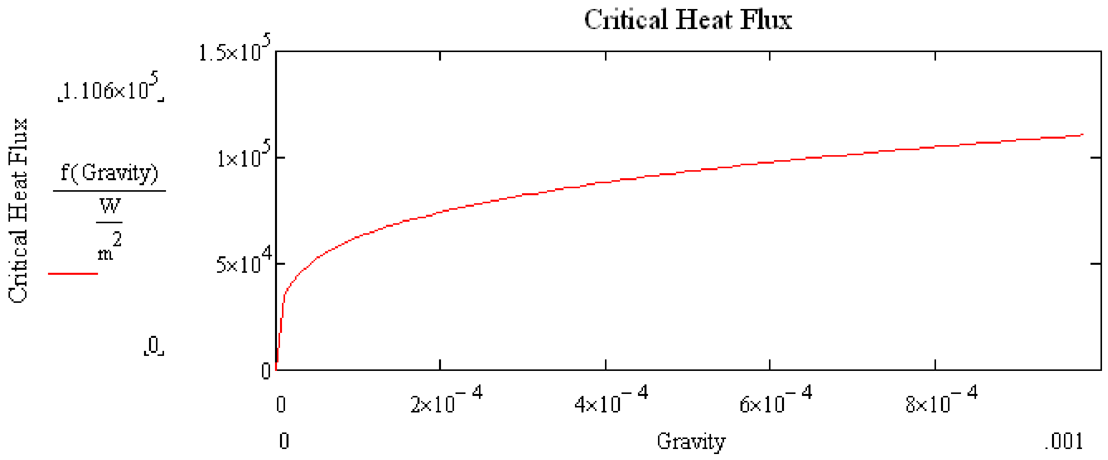
Performance on Orbit

- Initial approximations of on-orbit performance is significantly affected by the local acceleration.
- This local acceleration could be due to movement by satellite attitude changes or vibrations and can increase the critical heat flux.



Results

- The results of this experiment will expand the knowledge in the field of microgravity boiling.
- With a low cost experiment platform, variations of the fluid and material samples can be flown in a cost effective manor.

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