3-30-2010

A Systemic Study of Nucleate Boiling

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A SYSTEMATIC STUDY OF NUCLEATE BOILING IN MICROGRAVITY

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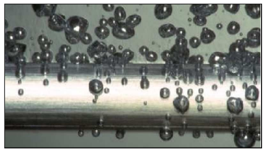


Nucleate boiling – individual bubbles forming on the heating element.

Abstract

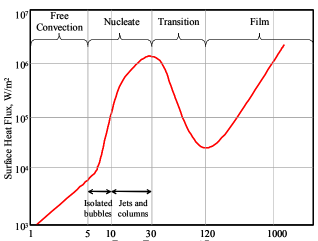
Nucleate boiling is a heavily researched form of heat transfer due to its associated high heat transfer rates. Applying two-phase heat transfer to space systems would allow these systems to become more capable, efficient, and compact. However, a fundamental understanding of boiling dynamics in the absence of buoyancy is yet to be developed. This study intends to analyze the effects of gravity, power input, and surface geometry during successive periods of microgravity provided by NASA's "vomit comet" through the Reduced Gravity Student Flight Opportunities Program.

Background

What is nucleate boiling?

Nucleate boiling is:

1. The most common mode of boiling
2. Characterized by the formation of individual bubbles on the heating surface
3. Different from free convection, transition, and film boiling based on the excess temperature
4. A highly efficient mode of heat transfer
5. Heavily researched both for terrestrial and space applications

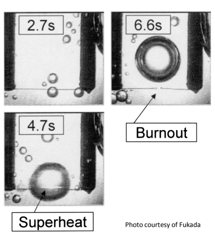


Boiling curve shows how heat flux varies with the temperature of the heater.

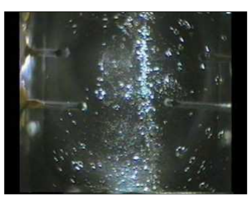
NASA's "vomit comet" simulates microgravity by flying a parabolic path.

Previous Research

In the absence of buoyancy, boiling behavior is heavily dependant on system characteristics such as power input, surface geometry, working fluid, and level of subcooling. Therefore, many experiments have been performed using drop towers, parabolic flight airplanes such as NASA's KC-135, the Space Shuttle and the International Space Station to try to develop a more fundamental understanding of this complex phenomenon.



Bubble coalescence leading to burnout.



Formation of individual bubbles that depart from the heating element, preventing burnout.

Results of these experiments have been contradictory. The are two very different common behaviors (shown in figures above), limiting the development of accurate simulations and predictive models for boiling in microgravity.

Research Goals

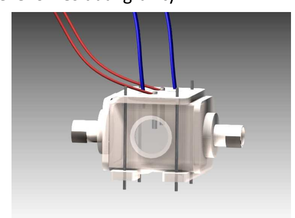
FUNBOE (**F**ollow-**U**p **N**ucleate **B**oiling **O**n-flight **E**xperiment) will provide the data needed to develop a more fundamental understanding of nucleate boiling in microgravity and on Earth. The dynamics of nucleate boiling to be studied are:

1. The effects of power input on bubble dynamics and boiling efficiency
2. The effects of heater surface geometry on bubble formation, growth, and departure as well as boiling efficiency
3. The repeatability of boiling dynamics via duplicate testing with the same system parameters

Methodology

Measurements to be taken to analyze the effects of power input and surface geometry on boiling dynamics are:

1. Resistance of the heating surface as a function of power input and time in order to calculate the aver heating element temperature
2. Thermocouple measurements of the radial temperature distribution
3. 3 axis age acceleration to monitor the level of residual gravity
4. 2 perpendicular HD video recordings to view bubble growth and departure dynamics in 3 dimensions



Fluid chamber – 30 identical chambers will be interchangeable during the two day experiment.

During each experimental run, 3 fluid chambers will boil water simultaneously for ~30 sec. For each run, 3 new chambers will be used to avoid changes due to heater degradation or subcooling. In total, there will be 60 independent sets of data.

The Program

GAS team students in the 2002 "vomit comet" campaign, holding the "We puke for Science" sign.

NASA's "vomit comet" is a part of the Reduced Gravity Student Flight Opportunities Program. During the flight, the plane will fly over 30 parabolas, each providing up to 30 sec of free fall followed by a period of hypergravity. The residual gravity on the plane during free fall is ~0.01g, causing the usually dominant buoyancy force during boiling to become negligible in comparison with other forces.

Acknowledgements

GAS Team
Dr. Jan Sojka
Dr. JR Dennison
Dr. Heng Ban

USU Physics and MAE
SpaceX
National Instruments
Space Dynamics Laboratory

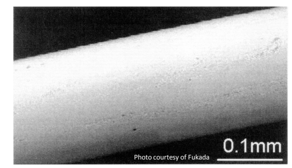
Gil Moore
Quality Plating Company
Rocky Mountain NASA Space Grant Consortium

Factors Affecting Boiling in Space

In the absence of the dominant buoyant force, other forces such as surface tension, pressure, inertia, and drag dictate bubble dynamics. These forces are heavily dependent on many factors of the boiling system such as surface geometry, power input, and subcooling (the initial temperature of the liquid below the boiling temperature at a given pressure).

Surface Geometry

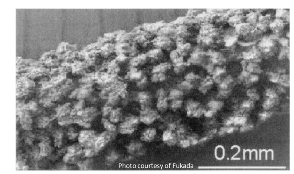
The surface of the heating element greatly effects the formation and departure of bubbles in microgravity.



Smooth platinum wire.

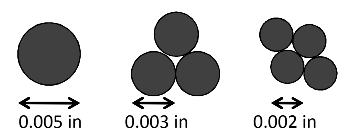
Smooth surfaces have been shown to increase the likeliness of forming one large coalescing bubble which causes the heater to burnout.

Roughened surfaces, either by fouling or machined micro-channels, improve the critical heat flux and delay burnout.



Platinum wire with calcium carbonate fouling.

FUNBOE will use a new approach to achieve the benefits of a roughened surface without the costs or inaccuracies of micro-channels and fouling. The single platinum wire is heavily researched and will act as the control. The twists of 3 and 4 wires will likely act like a micro-channel surface due to the internal areas of intensified heating.



Heating element wire diameters and configurations.

Power Input and Surface Heat Flux

FUNBOE will study to effects of power input by varying the power input and therefore the surface heat flux for each wire geometry. It is expected that the temperature of the heating element will rise as power input is increased and the critical heat flux will be determined.

Subcooling

The majority of microgravity boiling experiments are preformed at or near saturation, where the fluid is preheated to its boiling temperature before the experiment begins. FUNBOE will be performed with a high degree of subcooling, the difference between the boiling temperature and the temperature of the initial fluid. The water will be at "room temperature" initially, providing approximately 78°C of subcooling.