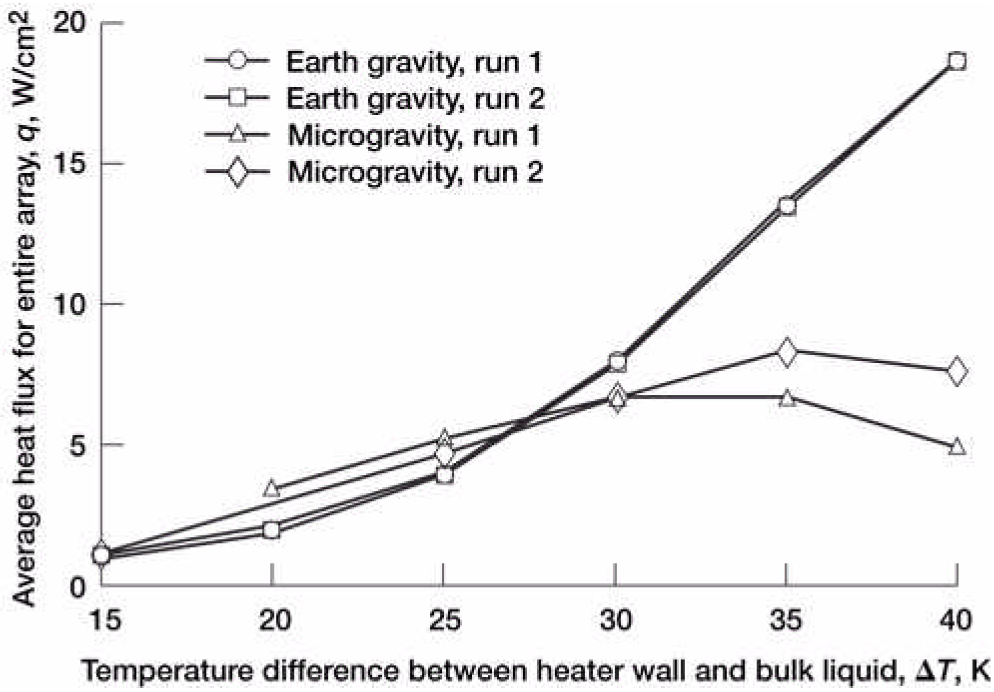
Microscale Heaters Detailed Boiling Behavior in Normal Gravity and Microgravity

Pool boiling in microgravity is an area of both scientific and practical interest. Conducting tests in microgravity, as well as lunar and Martian gravity, makes it possible to assess the effect of the density difference between the vapor and liquid phases on the overall boiling process and to assess the relative magnitude of these effects in comparison to other "forces" and phenomena, such as surface tension forces, liquid momentum forces, and microlayer evaporation. The microscale heater developed under a NASA Glenn Research Center grant serves as a unique tool to probe the fundamental mechanisms associated with pool boiling.

An experimental package was designed and built by the University of Maryland and tested on the NASA Johnson Space Center KC-135 experimental aircraft and a NASA WFF Terrier Orion Sounding Rocket under NASA Grants NAG3-2228 and NCC3-783. A square array of 96 microscale heaters was constructed and installed into a special boiling chamber. A fluorinert, FC-72, was used as the test fluid. A variety of tests were conducted at different pressures, heater wall temperatures, bulk fluid temperatures, and gravity levels.

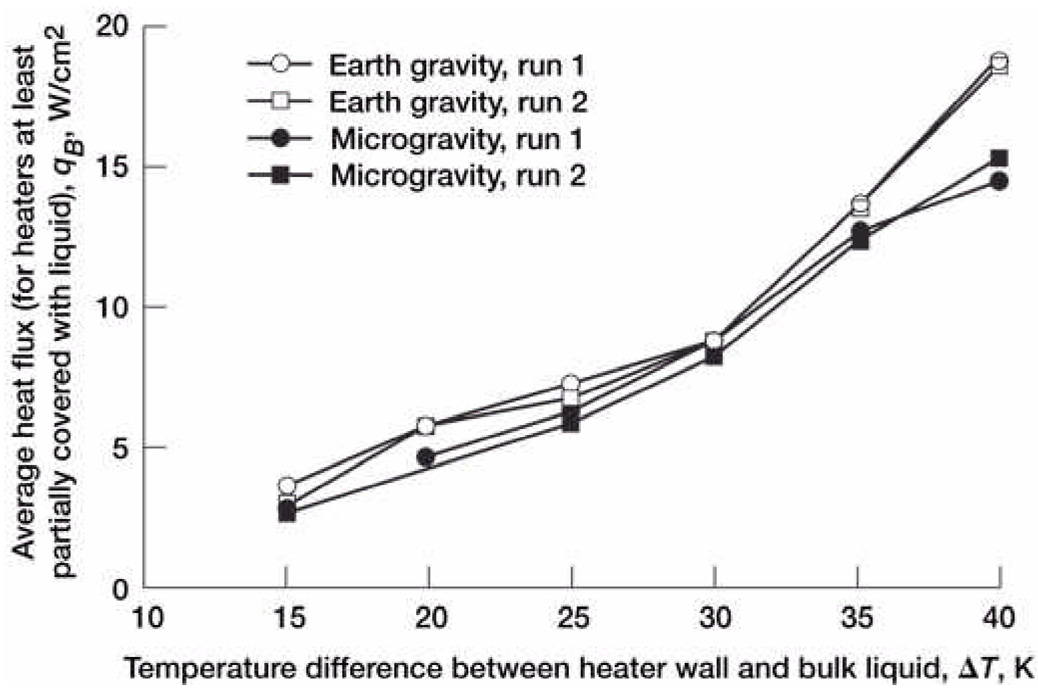


Array-averaged boiling curves at various gravity levels.

Long description Heat flux averaged over the entire array is plotted versus the temperature difference between the heater wall and the bulk liquid for two test conditions at normal and microgravity. At the lower temperatures, the four curves increase together; however, at a temperature difference of about 30 K (or 30 °C), the microgravity curves level off while the normal gravity curves continue to rise.

Data reduction indicates that gravity has little effect on boiling heat transfer when the wall temperature is no more than 25 °C above the average liquid temperature (see the preceding graph), even though there were vast differences in bubble behavior between gravity levels. At all these temperature differences in microgravity, a large primary bubble moved over the surface, occasionally causing boiling to occur. Smaller satellite bubbles surrounded this primary bubble. Once formed, the primary bubble's size remains constant for a given condition, indicating a balance between evaporation at the bubble base and condensation on the bubble cap. The size of the primary bubble increased with increasing temperature differences between the wall and liquid.

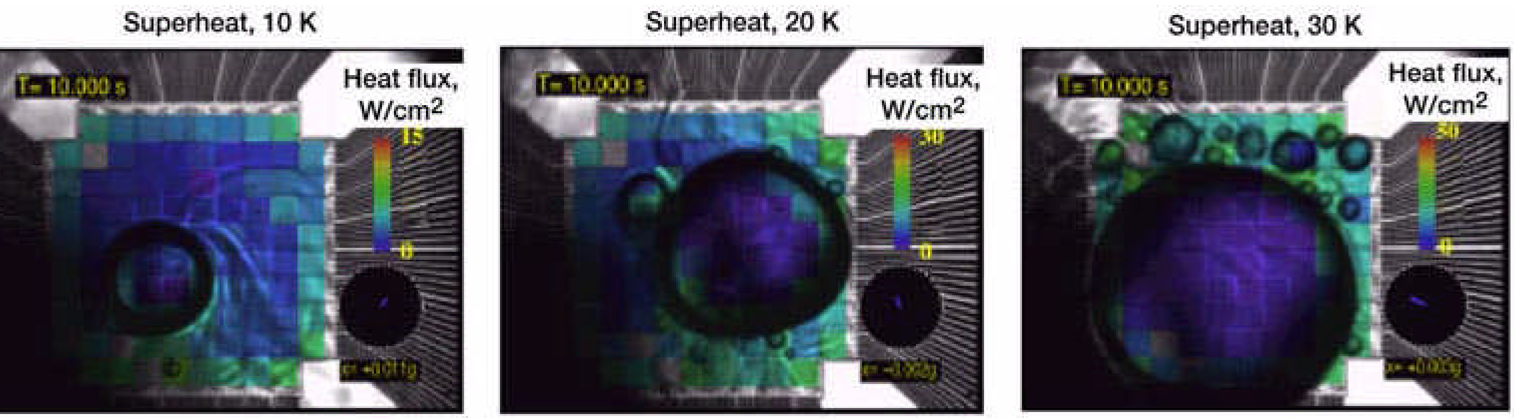
Modifying the preceding plot by averaging the heat flux from only heaters that had liquid contact produced boiling curves that were independent of the gravity condition (see the following graph). This suggests that the small-scale bubble behavior is not affected by gravity. Heat transfer from the heater surface occurred primarily through these small bubbles, and not much heat transfer was associated with the large bubble that occasionally formed on the surface when many small bubbles coalesced.



Modified-array-averaged boiling curves at various gravity levels using only heaters that were in contact with liquid or a liquid-vapor mixture.

Heat flux averaged over only those heaters in the array either totally or partially covered with liquid is plotted versus the temperature difference between the heater wall and the bulk liquid for two test conditions at normal and microgravity. All four curves increase together, unlike in the first figure.

In the final figures, color-coded maps that display the amount of local heat transfer are superimposed over photographic data. Blue indicates negligible heat transfer and red indicates significant amounts of heat transfer. The bubble itself is an area of moderate heat transfer. Most of the heaters under the primary bubble indicated low heat transfer, suggesting that liquid dryout occurred on the heater surface. Almost all the power was consumed by the test fluid during periods when the heater was immersed either in liquid or in a two-phase mixture of vapor and liquid. Because of a surface-tensioninduced flow in microgravity, a "jet" of fluid formed above the bubble into the bulk liquid and kept the bubble on the heater. As the superheat or temperature difference between the liquid and heater increased, the primary bubble became larger and more satellite bubbles were formed. By comparing these data, one can assess how the position and movement of the liquid and vapor phases affect the local heat transfer.



Spatially resolved heat transfer distributions relative to the position of vapor bubbles.
Long description Local heat flux is color-coded and superimposed over visual data of vapor bubbles on the heater array for three cases. Top: The temperature difference between the heater and the bulk liquid is 10 K (or 10 °C), and a single "large" bubble is present with some distortion in the fluid because of a change in the refractive index that is due to local temperature differences in the liquid. Center: With a temperature difference of 20 K (or 20 °C), there is a larger primary bubble and a few smaller satellite bubbles around it. Bottom: Temperature difference of 30 K (or 30 °C), with an even larger primary bubble and several satellite bubbles. The color coding indicates that there is no heat transfer under the primary bubble and moderate heat transfer in the liquid phase around the bubble.

Find out more about this research:
Journal of Heat Transfer article, *Subcooled Pool Boiling Heat Transfer in Microgravity and Hi-g*
Phase Change Heat Transfer Lab at University of Maryland http://www.glue.umd.edu/%7Ekimjh/
Pool Boiling Heat Transfer Mechanism in Microgravity Using an Array of Surface-Mounted Heat Flux Sensors http://microgravity.grc.nasa.gov/6712/multiph/kim.htm

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