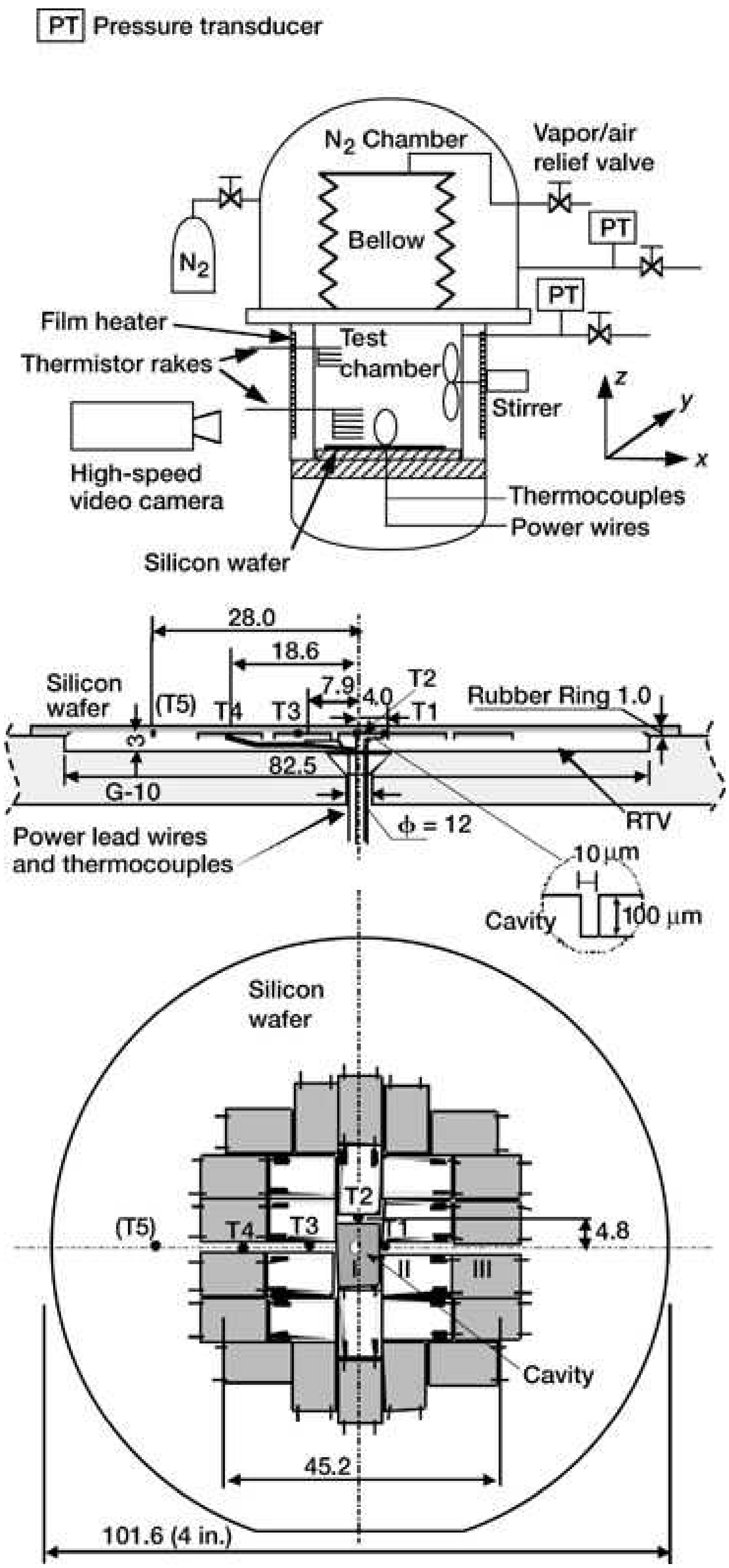
Nucleate Boiling Heat Transfer Studied Under Reduced-Gravity Conditions

Boiling is known to be a very efficient mode of heat transfer, and as such, it is employed in component cooling and in various energy-conversion systems. In space, boiling heat transfer may be used in thermal management, fluid handling and control, power systems, and on-orbit storage and supply systems for cryogenic propellants and life-support fluids. Recent interest in the exploration of Mars and other planets and in the concept of in situ resource utilization on the Martian and Lunar surfaces highlights the need to understand how gravity levels varying from the Earth's gravity to microgravity ($1g \geq g/g_e \geq 10^{-6}g$) affect boiling heat transfer.

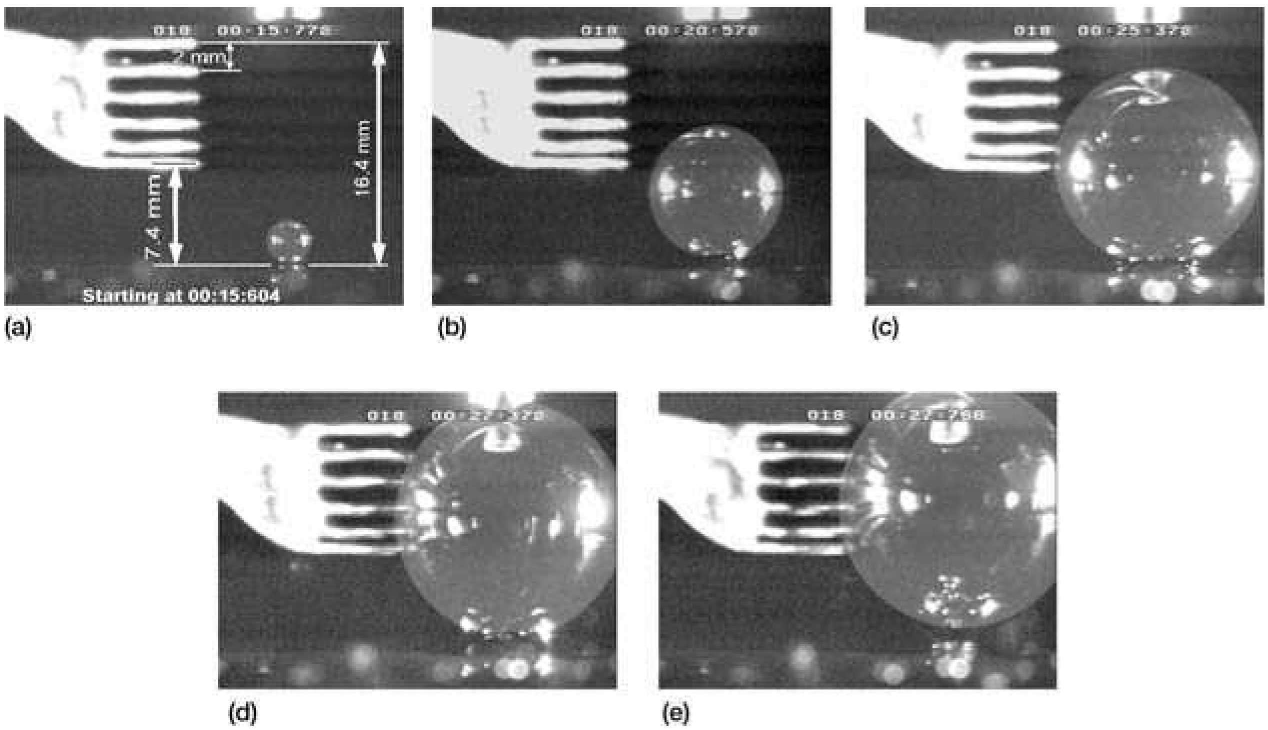
Because of the complex nature of the boiling process, no generalized prediction or procedure has been developed to describe the boiling heat transfer coefficient, particularly at reduced gravity levels. Over the last three decades, a limited number of experimental studies performed in short- and long-duration low-gravity environments provided valuable insights into the boiling phenomena. However, these studies produced nonconclusive findings and often yielded contradictory data that could not provide sufficient understanding of the phenomena so that models or correlations could be developed. Recently, Professor Vijay K. Dhir of the University of California at Los Angeles proposed a novel building-block approach to investigate the boiling phenomena in low-gravity to microgravity environments (see ref. 1 and Dhir, V.K.; and Hasan, M.M.: Science Requirement Document for a Mechanistic Study of Nucleate Boiling Heat Transfer Under Microgravity Conditions. Unpublished document, NASA Glenn Research Center, Cleveland, Ohio, 1999). This approach experimentally investigates the complete process of bubble inception, growth, and departure for single bubbles formed at a well-defined and controllable nucleation site.

Principal investigator Professor Vijay K. Dhir, with support from researchers from the NASA Glenn Research Center at Lewis Field, is performing a series of pool boiling experiments in the low-gravity environments of the KC–135 microgravity aircraft's parabolic flight to investigate the inception, growth, departure, and merger of bubbles from single- and multiple-nucleation sites as a function of the wall superheat and the liquid subcooling. Silicon wafers with single and multiple cavities of known characteristics are being used as test surfaces. Water and PF5060 (an inert liquid) were chosen as test liquids so that the role of surface wettability and the magnitude of the effect of interfacial tension on boiling in reduced gravity can be investigated.

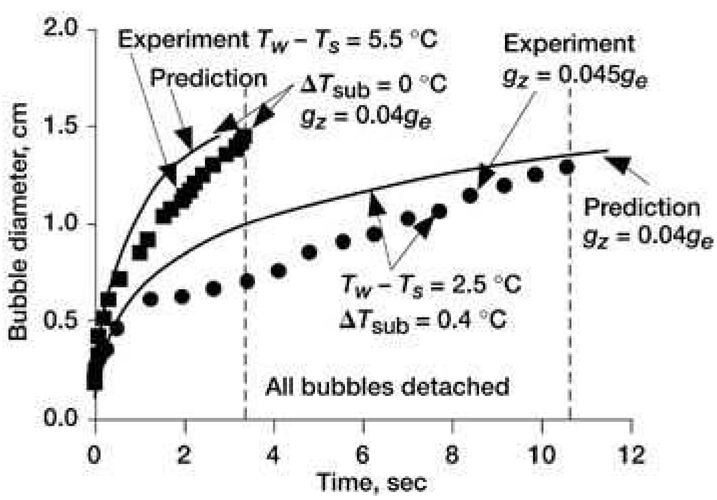


Top: Experimental setup. Center and bottom: Configuration of silicon wafer heater. (Dimensions in millimeters unless marked otherwise.)

The left drawing shows a schematic of the KC–135 apparatus, and the right drawing shows the location of the heaters and thermocouples on the silicon wafer. To date, we have obtained data on the growth and departure of bubbles from a single nucleation site in the low-gravity environments of KC–135 as a function of the wall superheat from 2.5 to 8 °C and of the liquid subcooling of less than 1 °C. The next figure shows selected pictures of a complete cycle of bubble growth with nucleation occurring at the designed cavity, and the graph compares the measured bubble diameter with the prediction of the numerical solution. The experimental findings are described in detail in reference 2.



Selected pictures of a single bubble during a growth-departure cycle inception of nucleation.



Comparisons of measured bubble diameter and numerical prediction in saturated water and in subcooled water at low gravity. Time, t, 0 sec; wall superheat, ΔT_{sub}, 0.3 °C; wall temperature minus the saturated liquid temperature, $T_w - T_s$, 4.2 °C; Earth's gravitational acceleration in the z-direction, $g_z \approx 0.02\ g/g_e$ (where g_e is Earth's normal gravitational acceleration).

References

1. Dhir, V.K.: Investigation of Mechanisms Associated With Nucleate Boiling Under Microgravity Conditions. Proceedings of the Third Microgravity Fluid Physics Conference. NASA CP–3338, 1996, pp. 153–158.

2. Qiu, D., et al.: Single and Multibubble Dynamics During Nucleate Boiling Under Microgravity Conditions. Microgravity Fluid Physics and Heat Transfer, United Engineering Foundation, Inc., New York, NY, Sept. 19–24, 1999.

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