Topical:

Numerical Modeling of Boiling and Two-Phase Flow Under Microgravity Conditions

Vijay K. Dhir

Department of Mechanical and Aerospace Engineering, University of California at Los Angeles,

Los Angeles, CA, United States

Email: vdhir@seas.ucla.edu , Ph. 310-825-8507

Abstract.

In this white paper, it is emphasized that numerical simulation tool/tools be developed to analyze pool boiling, flow boiling and two-phase pressure drop and condensation under microgravity conditions. This approach will lead to a predictive tool that could be used to design thermal management and power systems to be employed in space. The development of the tool/tools should have strong coupling with reduced gravity experiments that are conducted using various platforms.

Introduction.

Boiling is an efficient heat removal process at earth normal gravity as such it can be considered as a preferable process for heat removal in space as well where gravity levels can be very small. Boiling can take place under pool or forced flow conditions. The application in space are in the area of thermal management and power systems. Over the last half century, a number of experiments having been conducted in reduced gravity starting with the work of Siegel [1]. These experiments, conducted in drop towers, sounding rockets, space shuttle and ISS, have shed light on different aspects of phenomenon and have even yielded contradictory results, see for example [2], [3], [4]. Having obtained data from experiments conducted at $1 \leq g/g_e \leq 10^{-6}$, supported by NASA, no systematic assessment has been made as to how the effect of gravity on nucleate pool boiling and maximum heat flux can be scaled. It should be noted that because of the stretching of the length and time scales of boiling with reduced gravity, at low gravity the heater size starts to influence the boiling phenomena. As such correlations that have been proposed in the literature for small heaters are of a limited value. To recover all of the investment NASA has made in carrying out the experiments in space, there should be a complimentary analytical and numerical effort to assess and model the phenomenon and use the existing experimental data or design new experiments to validate the critical phenomena modeled in the numerical simulations. Such an approach would lead to development of tools for design of heat rejection systems for space applications.

Flow boiling, two-phase flow and condensation are extremely important processes for their application in heat rejection and power systems for space. As present our knowledge base of these processes under microgravity condition is minimal.

It is recognized that a Flow Boiling Facility has been designed and built and it is currently on ISS. This facility will no doubt provide valuable data on flow boiling, two-phase pressure drop and condensation, however, it is not that clear as to how these data will be used to develop analytical and numerical models for simulation of flow boiling, two-phase flow and condensation under microgravity condition. It is this investigator’s view that experiments, modeling and numerical simulation should be carried out simultaneously with experiments informing the modeling effort and models at the same time identifying the critical needs that could be fulfilled with the observations from experiments. In the following an approach in this direction is outlined.

Approach.

The suggested approach is divided into three distinct areas: pool boiling; flow boiling and two-phase flow and forced flow condensation.

a) **Pool Boiling**: (i) All of the data from experiments conducted over last half of a century should be reviewed and assessed to delineate the physical understanding that has been gained from these experiments; (ii) A framework for a numerical simulation tool should be developed; (iii) Key phenomenological details necessary to improve the fidelity of the numerical simulation tool be identified; (iv) Data available from previous microgravity experiments be used to validate the numerical model results or new experiments be proposed to provide the needed information; (v) Numerical tool should be exercised to predict expected behavior in a variety of thermal management scenarios under microgravity conditions. Figures 1 and 2 respectively show strength of the numerical tool developed at earth normal gravity and extended to microgravity.

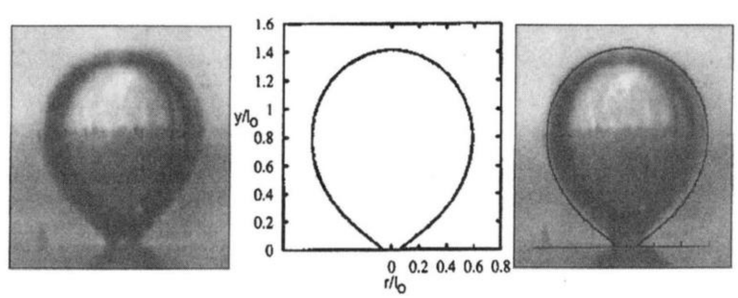

Figure 1 Comparison of prediction of bubble shape at departure with data for ΔT = 8.5 K and φ = 50 deg, g/g_e = 1.

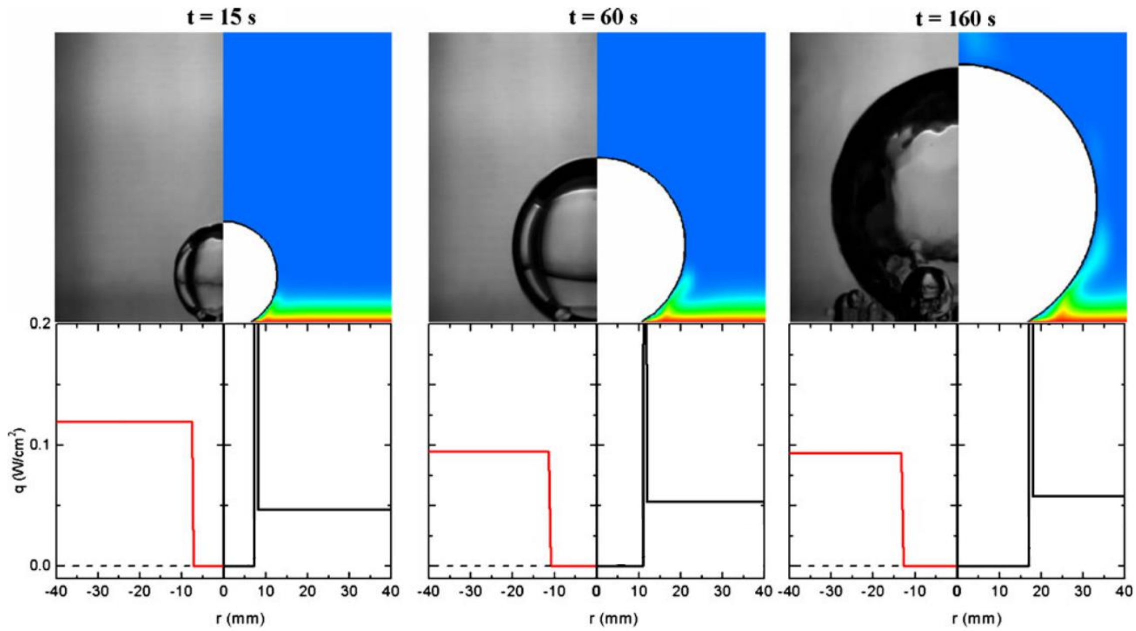

Figure 2 Comparison of bubble size and shape and wall heat flux with data obtained from experiments at g/g_e at 10^{-7} .

b) **Flow Boiling and Two-Phase Pressure Drop**: Development of numerical simulation tool for Flow Boiling in tubes and associated pressure drop is of critical importance in order to make a headway in advancing thermal management in space and for power production in space systems based on Rankine cycle. The proposed effort is broken up into several steps: (i) A framework should be developed for a numerical simulation tool. Advantage can be taken from the work that has been performed over last half a century by Nuclear Regulators and Industry ([5], [6]); (ii) The framework should identify key constitutive relations and physical phenomenon that will be affected by lack of gravity in space; (iii) Microgravity experiments should be proposed that will provide the needed information. The proposed experiments should have sufficient justification for the importance of the phenomena in the modeling effort and the detail to which instrumentation should be provided so that the effect of magnitude of gravity on constitutive relations can be delineated; (iv) Reduced gravity platforms should be identified that could provide needed data with sufficient fidelity; (v) Numerical simulations tool should be exercised to simulate a variety of perceived scenarios, that could be validated with data from experiments; (vi) An iterative process would be needed to improve the predictive tool.

c) **Forced Flow Condensation in Tubes**: At earth normal gravity, horizontal or vertical position of the tube greatly influences the development of the flow regimes. Thus, it is of significant importance to develop a flow regime map for condensation in the absence of gravity. As such the proposed numerical simulation tool should include: (i) The modeling of flow regimes for film condensation in tubes under microgravity conditions; (ii) Development of models and constitutive relations for heat transfer in each regime; (iii) Identification of the effect of turbulence in high shear scenarios; (iv) Development of models and predictive tools for two-phase pressure drop; (v) Development of guidelines for space based condensation experiments that will provide the needed information; (vi) Use of the numerical simulations tool to predict a variety of practical scenarios for condensation in space based thermal management and power systems.

References.

1. Siegel, R. (1967). Effects of reduced gravity on heat transfer. In *Advances in Heat Transfer* (Vol. 4, pp. 143-228). Elsevier. https://doi.org/10.1016/S0065-2717(08)70274-0
2. Lee, H. S., Merte Jr, H. (1997). Pool boiling curve in microgravity. Journal of Thermophysics and Heat Transfer, 11(2), 216-222. https://arc.aiaa.org/doi/pdf/10.2514/2.6225
3. Raj, R., Kim, J. and McQuillen, J., 2012., "On the scaling of pool boiling heat flux with gravity and heater size." *Journal of heat transfer*, vol. *134*. https://doi.org/10.1115/1.4004370
4. Warrier, G. R., Dhir, V. K., & Chao, D. F. (2015). Nucleate pool boiling experiment (NPBX) in microgravity: International Space Station. International Journal of Heat and Mass Transfer, 83, 781-798. https://doi.org/10.1016/j.ijheatmasstransfer.2014.12.054
5. Mesina, G. L. (2016). A history of RELAP computer codes. Nuclear Science and Engineering, 182(1), v-ix. https://doi.org/10.13182/NSE16-A38253
6. Bajorek, S. M., Bernard, M., Gingrich, C., Hoxie, C. L., Ireland, A., Kelly, J., Whitman, J. (2015, August). Development, validation and assessment of the TRACE thermal-hydraulics systems code. In *Proceedings of the 16th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Chicago, IL, USA* (Vol. 14). http://glc.ans.org/nureth-16/data/papers/13476.pdf