The Constrained Vapor Bubble Experiment – Interfacial Flow Region

Akshay Kundan, Peter C. Wayner Jr., Joel L. Plawsky
Rensselaer Polytechnic Institute

Introduction

- A bubble constrained by the walls of a solid.
- A transparent wickless heat pipe flown in the ISS
- 3mm x 3mm ~ 20 - 40 mm long (inside dimensions), size developed to have low Bond number.
- Study the fluid physics and determine the liquid and vapor distribution.
- Completely modular design.

Experimental Results

- Heat pipes are predicted to dry-out as power is increased. [1-2]
- Opposite behavior of dry-out i.e. flooding observed at heater end from 0.7W onwards in microgravity [3].
- Formation of a thick layer of liquid near heater starts from 0.7 W – 3 W called Interfacial flow region
- Beyond 2.2 W, the interfacial region reaches a constant length, arresting further penetration of liquid down the axis of the heat pipe.

Experimental set-up

- Higher Temperature Lower surface tension
- Marangoni flow driven by surface tension gradient
- Low Temperature High surface tension
- Critical drop
- Liquid flow driven by pressure gradient
- Liquid film driven by Marangoni force
- Wall of the container liquid back flow

Experimental Results

- Extra heat input is compensated by back flow and then evaporation of liquid in the vapor region.

Mathematical Analysis

$$\frac{\alpha_{in} = \alpha_{law} + \alpha_{uprad}}{\alpha_{out}}$$

- Maximum internal heat transfer coefficient at 0.7 W
- Interfacial flow starts from 0.7 W, results in increased resistance to heat transfer and thus, decrease in internal heat transfer coefficient.
- A constant internal heat transfer coefficient from 2.2 – 3W is consistent with the arresting of interfacial flow region.
- Bending curve near the heater end - a signature of "interfacial flow region".
- The Marangoni signature coincides well with the location of central drop at high power inputs.
- Beyond 2.2 W heat input, the temperature gradient at 10-12 mm of heat pipe is not sufficient to offset the capillary flow and movement of the junction vertex down the axis is arrested.
- Increased heat input is dissipated to the surroundings as outside radiation.
- A balance between an increased evaporation rate due to thick liquid film and outside radiation results in a constant heat transfer coefficient.

Conclusions

- The internal heat transfer coefficient of the CVB can be correlated to the presence of the Interfacial flow region.
- The competition between capillary and Marangoni flows causes ‘flooding’ near the heater and not a ‘Dry-out’ region.
- The growth of the interfacial flow region growth is arrested at higher power inputs.
- 1D heat model confirms the presence of ‘Interfacial flow region’ and its growth.
- Visual observations are essential to understanding the heat pipe’s performance.

References


Future Work

- Understand the role of cooler temperature on the growth of the interfacial flow region and the magnitude of the interfacial forces
- Develop higher dimension model to predict the interface temperature gradient and the velocity profile in the interfacial flow region.
- Improve theoretical models [1,2] to predict the flooding behavior observed in CVB experiments.

Final goal is to cool critical space craft components to enable long-term manned missions.

Applications

- LED lamps, Desktops, laptops.
- Hubble Space Telescope, Mars Rovers.
- Very important for space applications.

Acknowledgements

This work is supported by the National Aeronautics and Space Administration under grant number NNX13AQ78G and 04555-009 USRA. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of NASA.