REWETTING OF MONOGROOVE HEAT PIPE IN SPACE STATION RADIATORS

S. H. Chan, Ting Rong Shen and John Blake
Department of Mechanical Engineering
University of Wisconsin-Milwaukee
Milwaukee, Wisconsin 53211

ABSTRACT

Experimental investigation of the rewetting characteristics of a uniformly heated grooved surface was performed, the results of which are presented in this work. It was found that, for a rewetting fluid of 2-propanol, the rewetting temperature was 93~96 °c for the upward-facing case and about 2 °c lower for the downward-facing case. When the initial plate temperature was higher than the rewetting temperature, the rewetting speed decreased with the initial plate temperature. The rewetting speed is also faster in the upward-facing case than in the downward-facing case for the same initial plate temperatures, which indicates a gravitational effect on rewetting. This trend is found to be consistent with the previously investigated end heating condition. The rewetting distance that is predicted by the conduction controlled model is found to be in fair agreement with the experimental data. Also, an apparatus that enables experiments to be performed in a reduced gravitational environment has been built and experiments are currently being performed. The design of this apparatus is presented along with preliminary data.

INTRODUCTION

The design of space station radiators uses efficient two-phase monogroove heat pipes (ref. 1), the inner surfaces of which are made up of capillary grooves. Such capillary grooved surfaces are widely used in other space-based applications as well. When the heat pipes are thermally overloaded, dryout of the grooved surface occurs. It is essential that the dry surface be rewetted in a timely manner to prevent the malfunction of the related thermal management system.

The section of the circumferential grooves in the monogroove heat pipe that is located away from the region of two-phase thermal loading was the subject of our *prior* investigation (ref. 2). It was equivalent to rewetting of a grooved plate with one end heated and maintained at a constant elevated temperature. The objective of *this* work is to investigate the rewetting characteristics of the groove section that is in direct contact with the thermal loading. The equivalent to this is the rewetting of a grooved plate that is subjected to uniform heating throughout its length. The effects of gravity are examined by placing the grooved plate in upward and downward-facing positions. Both the theoretical and experimental results are presented and compared. In addition, the design of the newly completed drop tower are also reported and preliminary data is presented.

REWETTING WITH UPWARD AND DOWNWARD ORIENTATIONS

Experiment. -The experimental apparatus consists of the following components (fig. 1); a grooved copper plate with a flexible silicone rubber heater (10 W/in^2) glued to the bottom, ten surface thermocouples spaced along the groove direction with spring loading towards the groove land, a multiplexed data acquisition system to simultaneously read and record the thermocouple signals, a temperature controller and a by-pass switch that allows electric power to go either through the controller or directly to the heater, a variable flow rate liquid supply system and a video recording system for recording the liquid movement.

The plate was chemically cleaned and then uniformly heated to the desired initial temperature. The video camera was activated and a signal was recorded to indicate the commencement of computer data acquisition. The heater was turned on to allow the plate to undergo a continuous uniform heat flux during the rewetting process. Working fluid (2-propanol) was then introduced to the plate and the rewetting process was recorded. Rewetting experiments were conducted with the grooved plates at various initial temperatures and with the plate facing upward or downward.

Results and Discussion. -Experiments were first performed at high initial plate temperatures (>130 °c) for different flow rates in both the upward and the downward orientations to investigate the flow rate effect, as the fluid delivery system is such that there is overflow from the end of the plate. Thus, only fluid that was carried by the capillary action rewetted the plate. It was found that increasing the flow rate to above 41 ml/min. had little effect on the rewetting of the plate for both the upward and downward orientations. After this finding, the rewetting tests were performed at the flow rate of 41 ml/min.

Figure 2 and figure 3 show the rewetting front profiles and plate temperature profiles with initial temperature larger than 110 °c, 120 °c and 130 °c for the grooved plate facing upward and downward respectively. The presented temperature profiles are contour plots that depict the plate temperature in relation to time and location. The location of the liquid front, as observed from the video, is superimposed on these plots. From figure 2 and figure3 it can be seen that, with initial plate temperatures greater than 110 °c and 120 °c, the rewetting temperature (the plate temperature at the liquid front) is about 93~95 °c for the upward facing case and about 2 °c lower for the downward facing case. It can also be seen from that in the case of an initial plate temperature greater than 130 °c, the rewetting temperature is about 94~96 °c for the upward facing case and is, again, about 2 °c lower for the downward facing case. Figure 2 and figure 3 also give the experimental data of rewetting distance versus time for the upward and downward facing cases with continuous uniform heating at different initial temperatures. It is clear that the rewetting velocity decreases with the initial plate temperature and that rewetting is faster in the upward facing case than in the downward facing case for the same initial plate temperature. This trend is consistent with the previously investigated end heating condition (ref. 2). The results of research that has been performed under much lower than 1-g_e conditions can help explain why the downward facing cases show a lower rewetting velocity. When the grooved plate is flipped from the upward to the downward-facing orientation, the gravity force exerted on the liquid in the groove is switched from a compressive to an expansive effect against the groove bottom surface. This is equivalent to switching from a positive to the negative gravity condition. Thus, analogous to previous finding (refs. 3-5), the boiling heat transfer rate should be lower in the negative gravity case and consequently the transient rewetting distance should be lower in the downward-facing condition as is shown in figure 2 and figure 3.. The difference in boiling heat transfer rates may also account for the slight difference between the upward and downward-facing rewetting temperatures.

Predictions. -Prior study (ref. 2) has shown that rewetting goes from a hydrodynamically controlled to a heat conduction controlled mechanism when the initial plate temperature exceeds its rewetting temperature. The experimental data that is reported in figure 4 depicts a case in which the initial plate temperature exceeded the rewetting temperature. Thus, the heat conduction controlled model was used to predict the rewetting distance versus time for a grooved plate facing upward under continuous uniform heating with different initial temperatures. The rewetting temperatures and heat transfer coefficient must be prescribed when using the model to make calculations. The actual measured rewetting temperatures were used in calculations. The heat transfer coefficient is estimated in terms of the pool boiling diagram of 2-propanol by (ref. 6). It is noticed that the Leidenfrost temperature (temperature at CHF) from the diagram is about 102 °c, while the measured rewetting temperature is much lower than 102°c. Therefore, it was necessary to make some adjustments in the evaluation of the average heat transfer coefficient. The value of the average heat transfer coefficient is such that the actual heat transfer rate in the wet region is in accordance with the boiling diagram. The values are given in table I.

The predicted distances are given in figure 4. The predicted rewetting distances are found to be in fair agreement with experimental data, with (maximum) discrepancies of about 20%. From both experimental and calculated results it can be seen that the transient rewetting distance decreases with the plate initial temperature.

DROP APPARATUS DESIGN AND REDUCED GRAVITY EXPERIMENTS

Introduction. -The research that we are currently involved with is the study of the wetting characteristics of heated capillary grooved surfaces under various environmental conditions. In our previous studies, the plate orientation and temperature were the varied conditions. The current phase of our research involves the study of wetting characteristics in various accelerational reference frames. To achieve this, it is necessary to devise experiments and equipment that will perform as needed to yield good data under these conditions. To this end, we have built a device that achieves an average relative accelerational frame of about 0.1 g for a period of ~0.9 sec. This is sufficient time to observe and measure the transient temperature and wetting velocity under some thermal conditions. This also allows us to test our experimental designs prior to attempting to run them in more expensive and hazardous environments such as NASA's microgravity research aircraft.

Drop Apparatus.-The purpose of a drop apparatus is to perform experiments at a near free-fall for as long as possible. Also, the experiments should be repeatable and non-destructive. Figure5 is a schematic of the drop apparatus design. A rigid cage encloses the experimental device(s). The cage can be raised to a height of up to 4.3 meters from where the cage is released. The cage's descent is guided by four cables and at the bottom of travel is an airbag to cushion the cage's impact and bring it to rest. The drop apparatus consists of five major components: the lifting and dropping mechanism, the guide and anchoring assembly, the airbag, the state logic controller and the experimental platform. The lifting and release mechanism consists of: a rectangular frame that carries the platform along the guide cables to the top anchor bracket and a latch that connects to the experimental platform. When the latch is released, the platform falls away from the lifting mechanism. After the platform is dropped, the lifting mechanism is lowered and reconnected to the platform. As the platform drops, the frame experiences a change in relative gravitational acceleration from $\ddot{x} = g_e$ prior to the drop to $\ddot{x} \approx 0.1g_e$ during the drop. When the platform impacts with and is slowed by the airbag, it goes through a deceleration $\ddot{x} \approx -3g_e$ until it comes to rest at $\ddot{x} = g_e$. Since the experiments are to be performed at a reduced acceleration frame $\ddot{x} \approx 0.1g_e$,, a mechanism has been devised to initiate the experiment just after the platform and lifting mechanism de-couple, and terminate the experiment just prior to impact with the airbag. The controller contains a Set-Reset flip flop for the logic operation and receives inputs from the operator and the position of the cage. The control signals interface with and operate the experimental apparatus through a series of relays and solenoids. A block logic diagram of the controller is shown in figure 6.

Experimental Apparatus.- The current experiments observe the wetting velocity under reduced acceleration frames with the plate at various temperatures. In addition, equipment designs are being tested for functionality and resilience. The components in the current experiment are: a positioning mechanism, grooved plates that are heated either at the end or on the bottom, a temperature controller, a fluid reservoir which is also being tested for functionality, a data acquisition system to record the signals from thermocouples arrayed along the bottom of the plates, a video camera to monitor the fluid position within the grooves and laser line generator which provides a height measurement on the video data. The positioning mechanism is a two state system that operates through solenoids which are selectively activated by the controlling logic system. The mechanism positions the plate in the reservoir while the experimental platform is dropping and removes the plate from the reservoir as the platform ends its descent. The grooved plate is fashioned from oxygen free copper and has 0.4 mm capillary grooves machined into the surface. Flexible heaters are glued either to the plate's bottom or end, the power to which is controlled by a PID temperature controller. An array of T-type thermocouples (36 gauge) is located on the bottom of the plates and the corresponding temperature signals are gathered by the data acquisition system. The reservoir contains the fluid (2-propanol) and is slotted on top to accommodate the plate. The slot is gasketed with condom latex. The video camera is a pinhole micro chip CCD. A laser line generator provides a non-invasive reference point for determining vertical position during close up video observations.

Discussion.-Experiments are currently being performed with this apparatus. A preliminary example of the data that is obtained from these experiments is given in figure 7, which depicts the change of the rewetting front position and the plate temperature profile with time.

CONCLUSION

The rewetting of a grooved plate that is subjected to uniform heating with an initial temperature that is higher than the rewetting temperature was investigated and the completion of a drop apparatus design and construction was reported. The following conclusions can be reached; (i) The rewetting temperature is 93 °c~ 96 °c for the upward-facing case and about 2 °c lower for the downward-facing case when 2-propanol is used as a rewetting fluid. The rewetting temperature is a few degrees lower than prior findings for the end heating case. (ii) The rewetting speed decreases with the initial plate temperature. (iii) The rewetting speed is also faster in the upward-facing case for the same initial temperature conditions, thus indicating a gravity effect on rewetting. (iv) The prediction of the transient rewetting distance using the conduction controlled model is in fair agreement with experimental data. (v) A drop apparatus is ready to conduct rewetting tests under a reduced gravity environment (~0.1 g_e) for a duration of ~0.9 s.

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REFERENCES

1. Alario, J; Brown, R.; and Kosson,R.: Monogroove Heat Pipe Development for the Space Constructable Radiator System. AIAA paper 83-1431, 1983.

2. Chan, S.H.; Blake, J.D.; Shen, T.R.; and Zhao, Y.G.: Effects of Gravity on Rewetting of Capillary Groove Surface at Elevated Temperatures-Experimental and Theoretical Studies. ASME Journal of Heat Transfer, Vol. 117, Nov. 1995, pp. 1042-1047.

3. Kawaji, M.; and Westbye, C.J.: Microgravity Experiments on Two Phase Flow and Heat Transfer During Quenching of a Tube and Filling a Vessel. AIChE Journal, Vol. 11, 1991, pp. 403-419.

4. Lyon, D.N.; Jones, M.C.; Ritter, G.L.; Chiladakis, C.; and Kosky, P.G.: Peak Nucleate Boiling Fluxes for Liquid Oxygen on a Flat Horizontal Platinum Surface at Boyancies Corresponding to Acceleration Frames Between -0.03 and 1 g. AIChE Journal, Vol. 11, 1965, p. 773.

5. Merte, H.; and Clark, J.A.; Boiling Heat Transfer with Cryogenic Fluids at Standard, Fractional and Near-Zero Gravity. ASME Journal of Heat Transfer, Vol. 86, 1964, pp.351-359.

6. Ungar, E.K.; Saturated Pool and Flow Boiling From Horizontal Cylinders. PhD. dissertation, University of Wisconsin-Milwaukee, 1987, p. 71.

Table 1 Average Heat Transfer Coefficients Adjusted for Different Rewetting Temperatures

Rewetting Temperature (°c)	91	92	93	94	95	96
Average Heat Transfer Coefficient (W/m^2 °c)	29,682	26,558	24,028	21,939	20,184	18,689

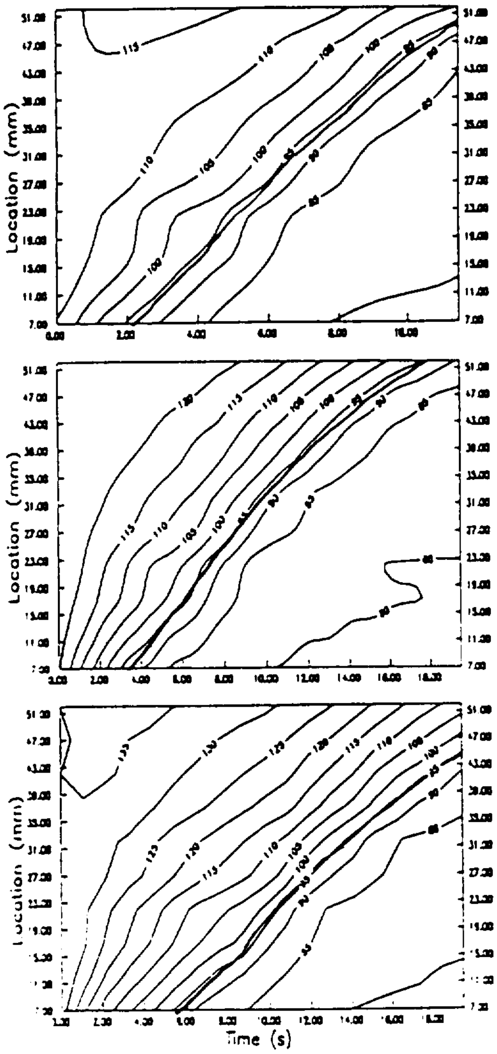

Figure 2. Rewetting Front and Temperature Profiles for the Grooved Plate Facing Upward Under Uniform Heat Flux (10 W/in^2).

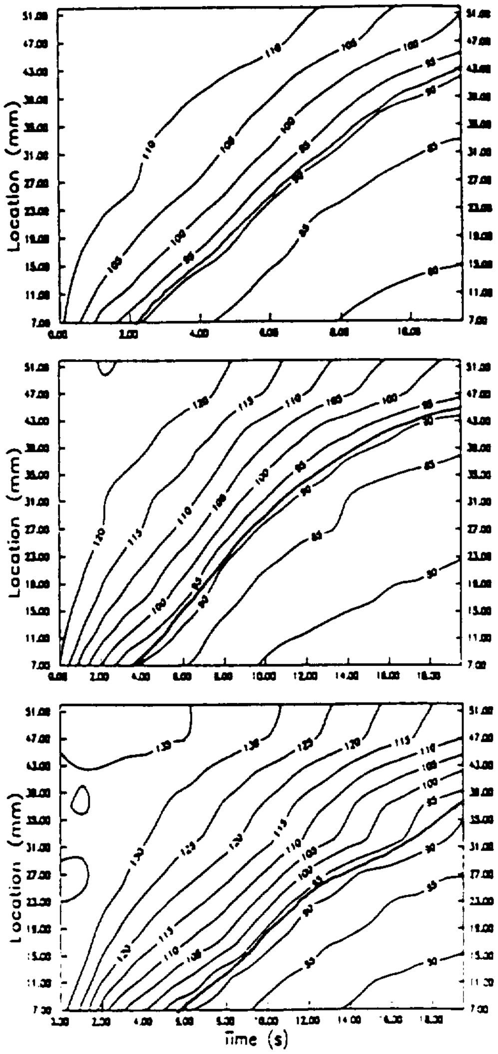

Figure 3. Rewetting Front and Temperature Profiles for the Grooved Plate Facing Downward Under Uniform Heat Flux (10 W/in^2).

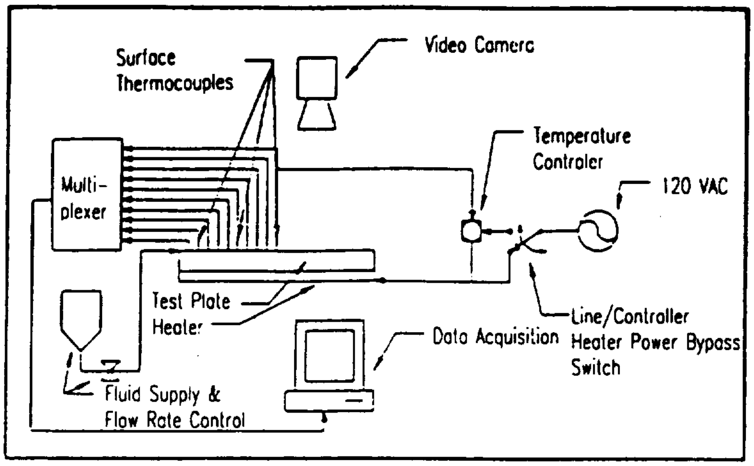

Figure 1. Schematic Diagram of Experiment Setup.

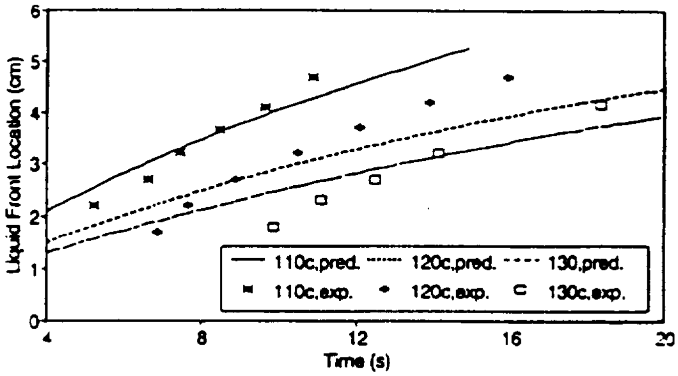

Figure 4. Predictions and Experimental Data of the Rewetting Front Locations Versus Time for the Grooved Surface Facing Upward at Different Initial Temperatures Under Uniform Heat Flux (10 W/in^2).

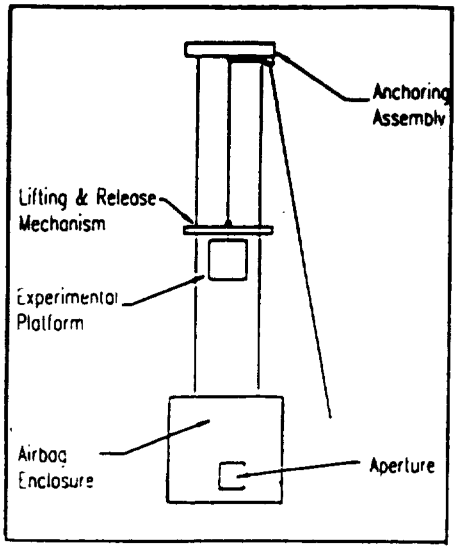

Figure 5. Drop Apparatus Schematic.

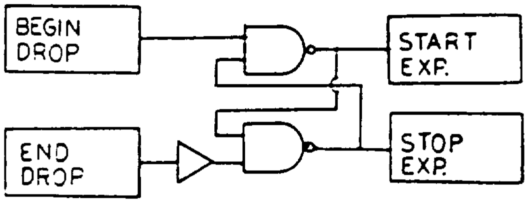

Figure 6. Controller Block Logic Diagram.

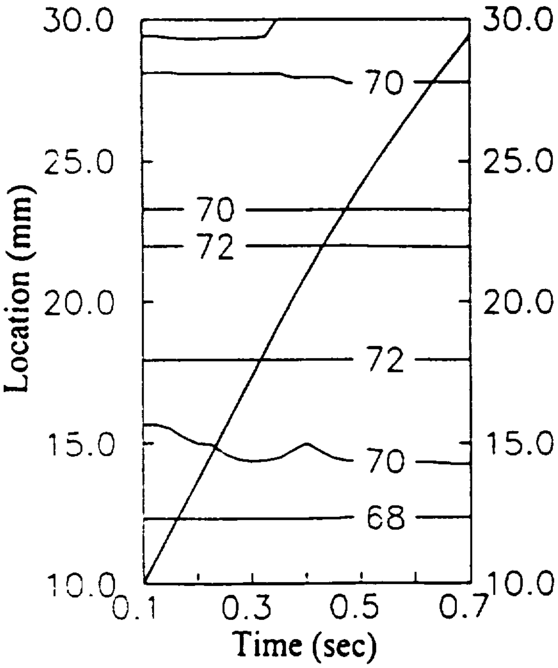

Figure 7. Preliminary Drop Data.