CHAPTER 8

CONCLUDING REMARKS AND RECOMMENDATION FOR FUTURE WORK

8.1 Concluding Remarks

The experimental investigation has been conducted here to explore the saturated pool boiling heat transfer of dielectric fluid FC-72 on enhanced surfaces with various geometric structures (rectangular fin array surfaces and artificial micro-cavity surfaces) as well as orientations. Moreover, the bubble flow pattern observations have also been carried out to reveal the boiling characteristics of FC-72 on boiling enhanced surfaces. A summary of the major findings and given in the following:

1. It is rather clear that high boiling incipience superheat, high temperature excursion and low CHF on plain surface including the copper and silicon based surfaces result from the their rarer cavities with high polish treatment. Moreover, the boiling incipience superheat and temperature excursion on silicon based surfaces are more significant than that on metal based surfaces.
2. Extended fins, micro-cavities and orientation are found to be effective in eliminating the boiling incipience superheat and temperature excursion. Boiling incipience superheat decreases as the fin length increases and the fin spacing decreases. The denser fin array and higher fin length also eliminate the temperature excursion. Besides, the boiling incipience superheat and temperature excursion on vertical finned surfaces are smaller and unapparent because the extended fins can induce thicker thermal boundary layer on their downward-facing surface and can result early boiling initiation. Moreover, the boiling incipience superheat of micro finned surfaces is relatively low for both orientations and the temperature excursions of the pool boiling curves are quite unclear. The incipience superheat and temperature excursion of micro finned surfaces are significantly lower than those of mini finned surfaces.

3. For finned surfaces at horizontal orientation, boiling generally initiates at the fin tip. However, for the finned surfaces at vertical orientation, the boiling initiation occurs at the downward-facing surface of fins. Moreover, bubble departure and lift-off of the vertical finned surfaces are also different from those of horizontal ones. The initial bubbles are generated from the downward-facing surface of the horizontal fins on the vertical surfaces, the bubbles grow or accumulate to a certain size that are larger than fin width and then separate at fin edge, slip along the fin spacing and lift-off.
4. As the finned surface is at vertical orientation, the extended fin becomes a real obstacle to the bubble upward motion. At very low heat flux, there are only isolated bubbles. As heat flux increases, the bubbles coalescence and rise more rapidly. In the moderate heat flux region, the accumulated bubbles become continuous and the liquid phase can reach the surface only at the low edge of the fins. Moreover, the narrower fin spacing obstructs the leaving bubbles and traps the bubbles in the downward-facing surface of the fins. The increase in heat transfer performance at low heat flux region is due to the disturbance in thermal boundary layer, however, at high heat flux region, the horizontal fins obstruct the vapor mushrooms departing from the heating surface and reduce in boiling heat transfer coefficients.
5. It is noted that a short periodical vapor mushroom departure process is observed on horizontal mini and micro finned surfaces as heat flux approaches to CHF, and large vapor mushroom clouds are found to accumulate inside the fin spacing and then to split into several vapor clouds prior to lift-off.
6. Closer fin spacing and longer fin length provide higher heat transfer area per unit base area and result in better heat transfer rate. The test results show the enhancement in heat transfer rate by increasing the fin length is more significant than that by reducing the fin spacing. Moreover, the enhancement of heat transfer rate is not directly proportional to the total area enhancement of the finned surface. Lower aspect ratio fins, either lower fin length or larger

fin spacing, provide lower resistance to the departure bubble and re-wetting liquid as well as yield higher heat flux.

7. Reducing the fin spacing and increasing the fin length increase the flow resistance to bubbles departure and also induce an early decline or level-off of the overall heat transfer coefficient. Besides, the decline behavior in heat transfer coefficients for micro finned surfaces are shifted to lower heat flux region due to their larger re-wetting liquid and bubble departure resistance.
8. For horizontal micro-cavity surfaces, The CHF values are raised with the cavity density and area enhancement of the cavities surface. However, the overall heat transfer coefficient decreases as the cavity density increases especially at high heat flux region than that in low heat flux region because of the horizontal bubble/vapor coalescence near the heating surface.
9. The influence of the cavity diameter in heat transfer coefficients during low heat flux region can be ignored. However, in moderate and high heat flux region, the surfaces with larger cavity diameter show earlier decay and lower peak value in boiling heat transfer coefficient. Besides, increasing the depth of cavities can result early rapid decline of overall heat transfer coefficients due to the larger flow resistance in the deeper cavities to obstruct the re-wetting liquid from entering the these cavities.
10. The overall heat transfer coefficient of micro-cavity surfaces in vertical orientation during the high heat flux region decreases significantly due to the vapor coalescence along the heating surface and dry-out situation inside the cavity.

8.2 Future works

During the course of this study it is realized that dielectric fluid FC-72 has the potential to be used in electronics cooling. The surface structures exhibit significant influence on the bubble/liquid flow characteristics during the pool boiling process. Furthermore, it is found that many factors can influence the pool boiling heat transfer characteristics and flow pattern on enhanced surfaces. A summary of future work is given in the following:

1. The pool boiling heat transfer and associated bubble characteristics for FC-72 on staggered and inline finned surfaces on vertical orientation.
2. The effects of nano-particle on boiling heat transfer and associated bubble characteristics of FC-72 in plain and enhanced surfaces.
3. The pool boiling heat transfer and associated bubble characteristics for FC-72 on enhanced surfaces in confined channels.
4. The effects of different micro-cavity geometric structure and thermal conductivity of the silicon based surface on pool boiling characteristics.