

CHAPTER 7

CONCLUSIONS AND FUTURE SCOPE

7.1 Conclusions

In the present investigation, upward flow boiling through a vertical quartz tube has been investigated experimentally using pure water and nanofluids (Al_2O_3 -water, TiO_2 -water and SiO_2 -water) with different concentrations. The effect of supplied heat flux ($30\text{-}250\text{ kW/m}^2$), mass flux ($3\text{-}20\text{ kg/m}^2\text{s}$), inlet subcooling (20, 40 and 60K) and particle volume fraction (0.001%, 0.005% and 0.01% v/v) on heat transfer characteristics have been investigated. Visualization studies on the flow boiling heat transfer of water and nanofluids (0.001% and 0.01% v/v) have been conducted. Bubble growth, departure and the flow pattern evolution during flow boiling have been investigated with the aid of high-speed photography. The test conditions were set under various thermal hydraulic conditions in order to study the effects of several parameters that affect the bubble dynamics.

Results show that, various nanofluids have different optimum volume concentration in which the heat transfer characteristics show the maximum enhancement. The heat transfer coefficient for various nanofluids increases up to optimum volume concentration, and decreases thereafter. The maximum HTC enhancement of alumina/water nf occurs at 0.005% particle volume concentration and is approximately 28% compared to water. For silica/water nf, the maximum HTC enhancement is observed at 0.001% volume concentration and 37.5% as compared to water. For titania/water nf, the maximum HTC enhancement is observed at 0.005% volume concentration and 20% as compared to water.

Based on results and discussions, the following conclusions can be made:

- In case of nanofluids, DNB has been delayed in comparison with water. The nanoparticle deposition on the heater caused by microlayer evaporation keeps modifying the heater surface and alter the boiling phenomenon. This phenomenon is predominant at higher heat fluxes which causes delayed flow regime.
- Heat transfer coefficient is enhanced in case of nanofluid as compared to water, however with increasing concentration, enhancement in heat transfer coefficient decreases. The reason may be attributed to increased thermal resistance caused by excess deposition of nanoparticles on the heater wall at higher concentration of nanofluid during boiling.
- Bubble size increased with increase in heat flux in both water and nanofluids, but the growth was more in pure water at higher heat flux resulting larger and irregular bubbles which initiated flow oscillation earlier than nanofluids.
- It was observed that addition of nanoparticles delays the flow oscillation and the extent of suppression is proportional to nanoparticle concentration. The amplitude of oscillation was less in nanofluids as compared to pure water. The presence of nanoparticles modified the bubble dynamics and reduced the void fraction at a given heat flux and thereby suppressed the oscillation.
- Under the same condition, the bubble in nanofluid departs from the heating surface earlier. This illustrates that using nanofluid can supplement the new coolant to ensure bubble departure on time before the bubble becomes a gas film.
- The bubble size before the bubble departure is smaller for nanofluid than that for pure water. This effect causes frequent miniature bubble departure, causing the

enhanced heat transfer for the mechanisms due to the interchange of hot and cold liquids, and the micro convection heat transfer by the disturbance of the boundary layer during the bubble departure process for nanofluid.

- Nanofluids can be used to stabilize flow boiling in channels which will mitigate channel dryout and thereby attenuate the oscillation of surface temperatures.

7.2 Scope for future work

1. Investigations similar to the current study may be carried out with a complete closed loop system that quickly causes the escaping vapor to condense, in order to maintain the nanoparticle concentrations.
2. Different orientations of the boiling surface can provide insight to how boiling would occur under different conditions.
3. Nano-textured surface can be prepared and water can be used instead of nanofluids for flow boiling analysis.
4. Heat transfer analysis for rod bundle using nanofluids can be performed.
5. Analytical and numerical model can be developed for flow boiling heat transfer in channel flow for nanofluids.

