CHAPTER 7

Conclusions and future work scope

The present work primarily focuses on the development of hydrophobic thin film composite coatings on copper substrates and the investigation of boiling heat transfer performance characteristics in a pool of water. Hydrophobic composite surfaces were developed using the electrophoretic deposition technique. Three different combinations of hybrid nanofluids (TiO_2-SiO_2, TiO_2-Al_2O_3, and SiO_2-Al_2O_3) were used as the deposition medium. For each combination, four distinct samples were prepared by varying the coating duration. The concentration of the hybrid nanofluid was kept at 0.1 wt. % in each case so that the effects of coating materials and coating duration could be studied separately.

The surface morphology of polished copper (bare) and composite samples were analysed using FESEM images. The surface morphology of composite surfaces differs from the polished surface. The surface texturing pattern changes with the coating duration, as well as the coating medium. For the same coating duration, textured patterns are different for different materials. A profilometer was used for the surface roughness measurements. The composites surface roughness (R_a) depends on the coating duration. It has been observed that, the surface roughness (R_a) of composites samples keeps on increasing as the coating duration increases. The highest surface roughness obtained for SiO_2-Al_2O_3 coatings (CS3-20), and lowest for TiO_2-Al_2O_3 coating (CS2-2.5). The static contact angle of polished Cu and textured surfaces were measured for wettability analysis using a Goniometer. The static contact angle on the bare surface is acute and on composite textured surfaces, is obtuse.

A series of pool boiling experiments of polished Cu and all coated surfaces were conducted in demineralized (Milli-Q) water at atmospheric pressure conditions. The data obtained from the polished copper surface is used as reference data to compare the performance of the composites surface. Effects of composite textures, and coating layer thickness on pool boiling performance characteristics such as the onset of nucleate boiling (ONB), boiling curve, boiling heat transfer coefficients, and bubble visualisation have been examined at nearly saturation temperature.

7.1. Conclusions

The conclusions from the present study are drawn as follows: -

- The surface characteristics such as; morphology, roughness, and wettability, of a composite texture depend on the coating material and coating duration.
- All coated surfaces are hydrophobic (obtuse) in nature, whereas polished Cu is hydrophilic in nature (θ= 65.7°). For the coating materials TiO_2-SiO_2, and TiO_2-Al_2O_3, wettability increases with an increase in coating duration, whereas decreases for SiO_2-Al_2O_3.
- Roughness and coating layer thickness depends on coating time and coating materials at the same voltage supply. Coating layer thickness increases non-linearly with an increase in coating duration.
- Boiling curves for all three types of composites CS1, CS2, and CS3 shifted towards the left compared to a bare surface, provided the coating layer thickness was maintained below the critical limit.
- There is a significant reduction in ONB observed on most of the composite surfaces, which depends on surface wettability, surface textures, and coating layer

thickness as well. The maximum reduction in ONB is 4.4°C which has been realized on SiO_2-Al_2O_3 composite (CS3-15).

- The optimum value of coating layer depends on surface morphology, textures, and coating materials.

- The optimum range of coating layer thickness up to which HTC was found to be increasing is ~10, ~16, and ~24 microns for the composite of TiO_2-SiO_2, TiO_2-Al_2O_3, and SiO_2-Al_2O_3, respectively.

- The maximum enhancement in HTC is 62%, 63%, and 75%, for the case of TiO_2-SiO_2, TiO_2-Al_2O_3, and SiO_2-Al_2O_3 composites, respectively. These maximum enhancements were realized corresponding to the optimum coating layer thicknesses and in low heat flux region ($q'' < 300$ kW/m^2).

- Surface textures and morphology play an important role in nucleation sites and bubble size formation. On composite surfaces (hydrophobic), relatively higher nucleation sites and smaller bubbles are formed, whereas, fewer nucleation sites and larger bubble appears on the bare (hydrophilic) surface.

- Higher nucleation sites and larger bubble departure diameter leads to a higher HTC in isolated bubble region on a hydrophobic surface. However, due to higher nucleation sites and larger bubbles, it starts coalescing early with the surrounding bubbles, as a result isolated bubble regime converts to a mature boiling regime, and the boiling surface is covered with bubbles which limits the further enhancement in HTC. Hence an optimum combination of nucleation sites, and bubble departure diameter preferably gives better results even at moderate heat flux conditions.

7.2. Novelty of the thesis work

The following section delineates the principal distinctions between current and prior research on composite surfaces, which may be regarded as the novelty of this thesis.

- The present work focused on development of binary oxide composites and its effects on boiling heat transfer performances. Whereas in most of the other's work, the composite surface was prepared with metals like Cu and other elements such as metal, metal oxide, and graphene. For example, Gupta et al. [88] have prepared a composite of Cu and TiO_2, Shil et al. [89] have used graphene nanoparticles with Cu and Al_2O_3. In another study Gupta et al. [136] have used Cu and Al_2O_3 to fabricate porous composite on copper substrate.
- Most of the researchers have developed either hydrophilic [88, 137], or superhydrophilic [89] nanocomposite coating. As per the authors' knowledge, hydrophobic nanocomposite coating and its effects on pool boiling performances, very few have discussed.
- Shi et al. [112], prepared superhydrophobic and superhydrophilic surface using copper foam and experimentally showed that in low heat flux regime ($q'' < 200$ kW/m^2), superhydrophobic surface works well while medium to high heat flux ($q'' > 200$ kW/m^2) superhydrophilic was superior. In the present study a hydrophobic surface prepared on coper substrate which has good water repellent properties and also provide comparatively better heat transfer performance in medium heat flux regime ($q'' < 400$ kW/m^2).
- In literature [88, 89, 136], significance of optimum layer of coating thickness has not been discussed, which may be because of HTC was continuously increased with increased coating layer due to copper. While in the present work, effect of excess coating layer thickness has been discussed and an

optimum value of it found nearly to 10µm, upon which BHTC seems improving, and beyond that, it starts decreasing.

7.3. Keys benefits if apply this study in engineering applications

- Hydrophobic coating prevents the contamination which can reduce the maintenance cost of the equipment and devices.
- Composite coating layer of TiO_2 -SiO_2 and TiO_2 -Al_2O_3 between 8- 10 µm help to increase in BHTC and ONB, which indicates HTC deterioration can be prevent if coating layer thickness kept below 10 µm.

7.4. Scope for future work

- Single bubble tacking and focusing has not performed, so someone can perform this study separately on hydrophobic surface, and can explain the heat transfer, bubble ebullition cycle, bubble departure diameter and frequency can be a different study separately.
- The size of particles also affects the structure formation hence different combinations of particle size can be considered for further investigation separately.
- Generally low concentrations (0.01-0.1 % wt.) prefer for better control over the coating thickness layer, however, someone can investigate the different concentration effects on surface textures and boiling heat transfer performance.
- Compatibility of all three types of composite material has not checked, so someone can try on different substrates to check the compactivity, which is a another type of study can be carryout.

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