



An Empirical Study on Dropwise Condensation Occurred on Surfaces Hydrophobized Using a Single-Step Electrodeposition

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ABSTRACT: Dropwise condensation occurs on hydrophobic and superhydrophobic surfaces. The rate of heat transfer depends mostly on the preparing process of hydrophobic surface. Two main features of hydrophobic surfaces are existing micro-nanostructures and their low surface energy. In this paper, a one-step electrodeposition process is used to produce the necessary micro-nanostructures on copper surfaces and a self-assembled mono-layer of 1-Octaethanethiol as surface energy reducing agent. Effects of different electrochemical cell parameters such as electrical current and time of process on the dropwise condensation heat transfer are investigated. The heat transfer experiments are performed in a device fabricated for this purpose. The surface of the specimens is analyzed using scanning electron microscopy images and X-ray diffraction analysis. The results show that some microstructures made from copper grow on the surface. The results show that current and process time have positive effects on the dropwise condensation heat transfer. It has been seen that surfaces fabricated at low electrodeposition time (15 and 45 sec) have a worse dropwise heat transfer rate than filmwise condensation heat transfer. On the other hand, higher electrodeposition times (135 sec) give 2-4 times higher heat transfer than filmwise heat transfer in the sub-cooling range lower than 10 Kelvin.

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1. Introduction

Improvement of heat transfer process including phase change phenomena such as boiling and condensation, due to their high heat exchange capacity and wide applications in different areas, has been in the center of attentions in the recent years [1]. Condensation occurs in two modes including Dropwise Condensation (DWC) and Filmwise Condensation (FWC). In FWC a condensate layer covers the surface while in DWC, discrete droplets with different diameters spread on the surface. Because of the low thermal conductivity of the condensate layer, the FWC has a lower heat transfer capacity than DWC. Therefore different theoretical and experimental studies have been done in recent years on DWC heat transfer. For example, Barati et al. [2] investigated DWC using a high speed camera. They studied the effects of the wall temperature and nucleation site density on the droplet distribution. Talesh Bahrami et al. [3] performed a numerical study on an inclined micro-nanostructured tube. They have shown that heat transfer rate of a vertical tube is greater than a horizontal one under DWC. DWC occurs on hydrophobic and superhydrophobic surfaces. These surfaces usually have micro-nanostructures which have a low surface energy. Different methods have been used in the literature to produce micro-nanostructures and an artificial hydrophobicity on the metal surfaces. However, electrochemical based techniques such as electrodeposition have a special advantage where

micro-nanostructures could be produced with very good accuracy and flexibility [4]. As well as, electrochemical-based methods are environmentally friendly [5] and could be performed with low cost and on complicated geometries. As well as, different methods have been used to reduce the surface energy in between self-assemble monolayers because of their low thermal resistance are suitable for heat transfer applications [6].

In this paper an electrodeposition technique as an electrochemical-based method is used to produce micro-nanostructures on the copper surfaces in order to be used in

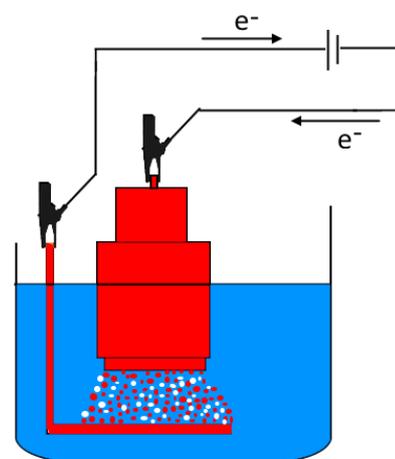


Fig. 1. Electrodeposition system

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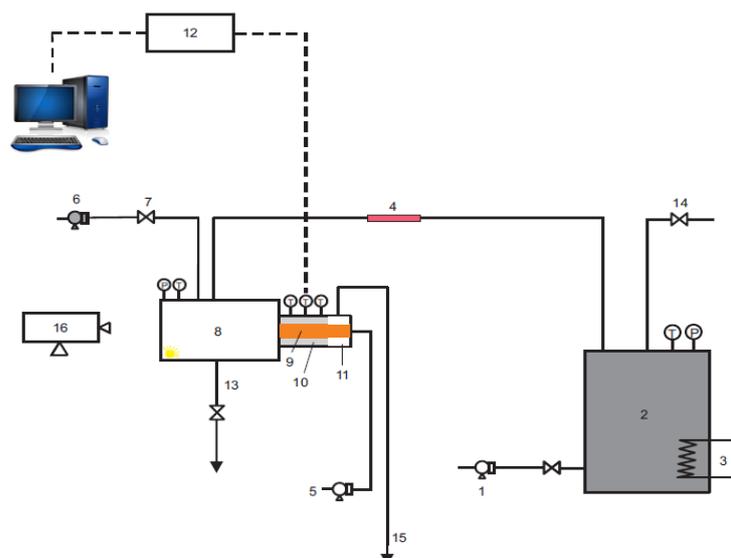


Fig. 2. The schematic view of the experimental setup; 1- water inlet to the boiler, 2-boiler, 3- heater, 4- vapor heater, 5- cooling flow 6- vacuum pump, 7- one-way valve, 8- test chamber, 9- test sample, 10- PTFE cover, 11- cooling section, 12-data acquisition system, 13- condensate exit, 14- emergency drain valve, 15- cooling flow exit, 16- camera

DWC experiments. In the experiments cathode and anode are copper where the cathode is workpiece. Ethanolic solution of 1-Octanethiol is used as a self-assembled monolayer to reduce the surface energy of the samples. Scanning electron microscopy and X-ray diffractometry are used to study the roughened surfaces.

2. Experimental Setup

The samples, after cleaning, are electrodeposited in a setup shown in Fig. 1. Then the samples are placed in the designed and fabricated setup given in Fig. 2.

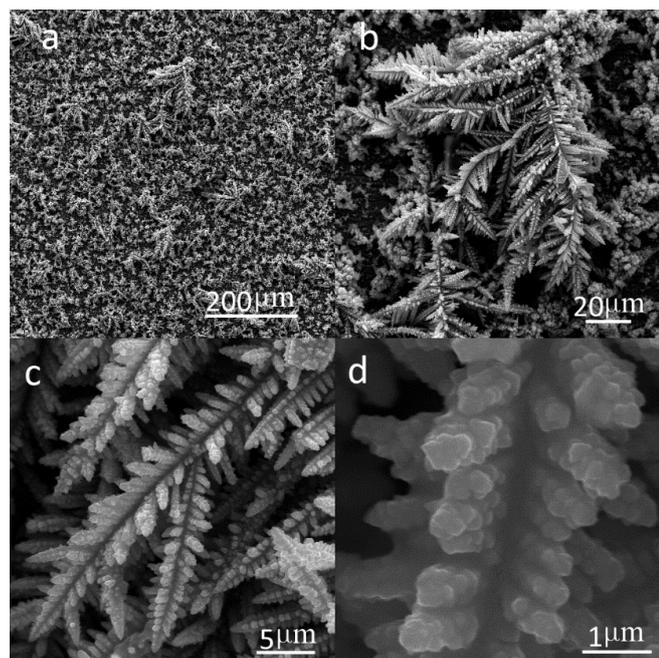


Fig. 3. The scanning microscopy image of the specimen surface after electrodeposition process

3. Results and Discussion

3.1. The surface structure

The scanning electron microscopy images of the specimen surface after electrodeposition process are given in Fig. 3. It can be seen that micro-nanostructures have grown on the surfaces. The X-ray analysis of the specimen after electrodeposition process is given Fig. 4. It can be seen that copper micro-nanostructures have grown on the surface under the electrodeposition process. The effects of electrodeposition time on the heat transfer coefficient are given in Fig. 5. The result of FWC is extracted from a correlation given in reference [7]. It can be seen that process time 75 and 135 sec have higher heat transfer rate than FWC respectively in subcooling temperatures lower than 12 and 20 K. In other cases flooding phenomenon occurs, droplets penetrates through micro-nanostructures and heat transfer coefficient becomes even lower than FWC in some conditions. This condition have also reported by other researchers [8].

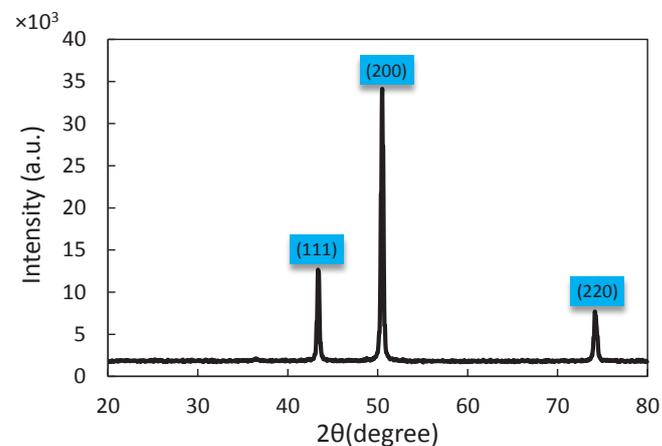


Fig. 4. X-ray analysis of the specimen after the electrodeposition process

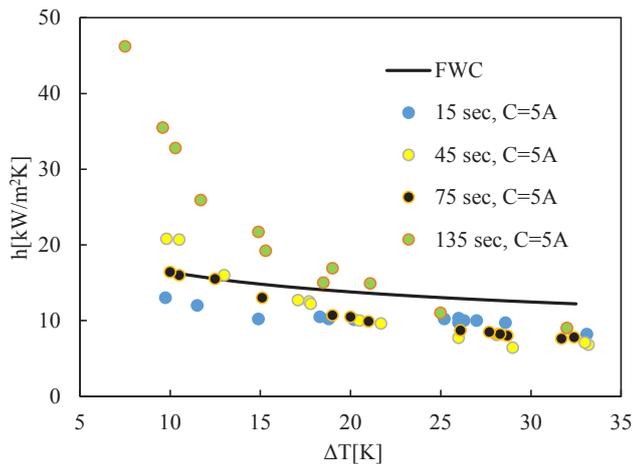


Fig. 5. The effect of electrodeposition time on heat transfer coefficient

4. Conclusions

An experimental study has been done to explore the function of surfaces micro-nanostructured by electrodeposition process. To do this, a condensation test setup is designed and fabricated. The specimens after electrodeposition process are immersed in the ethanolic solution of 1-Octadecanethiol to reduce their surface energy. The scanning electron microscopy images and X-ray diffractometry analysis of the processed specimens shows that copper micro-nanostructures have grown on the surface. Different experiments with constant current and different electrodeposition times have been done. The experiments show that in some conditions (time=135 and 75 sec) the heat transfer coefficient of DWC is greater than FWC and in other cases flooding occurs.

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