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Dropwise Condensation and Heat Transfer

R. Yuvaraj

Abstract

The dropwise condensation is obtained on a copper surface by modifying the texture of the bare surface using the thermo-solution immersion method. In this method, the solution of 0.003–0.007 M of ethanol and myristic acid is used, and heating the plate in the solution at 40–65°C for 2–5 h using hot plate apparatus. The heat-transfer coefficient of the dropwise condensation is increased on the prepared superhydrophobic surface that exhibits very low surface energy causing the non-wetting nature of the water droplet on the prepared surface. The contact angle of the water droplet is measured on the obtained superhydrophobic copper surface, giving the average value of $160^\circ \pm 2^\circ$ with a low-inclination angle of 2° . The maximum contact angle of 162° is obtained by adjusting the composition of the solution, the temperature of the solution, and immersion time at 0.005 M, 45° , and 3 h, respectively. Further, the prepared superhydrophobic surface is experimented with for dropwise condensation, which provides a high heat-transfer coefficient of $196 \text{ W/m}^2 \text{ K}$ over the bare surface providing around $186 \text{ W/m}^2 \text{ K}$. The condensation rate of water droplet fall-off time is about 1 s on the superhydrophobic surface, and 2 s for bare surface is obtained against the mass flow rate of 300 lph.

Keywords: superhydrophobic, copper surface, contact angle, dropwise condensation, heat transfer

1. Introduction

The water vapour normally condenses on a bare surface by film-wise mode of condensation. The larger surface energy of the bare surface results in higher wetting nature of the water on the bare surface and forms a water film throughout the bare surface. This water film causes higher resistance to heat flow across the film. To overcome this, the surface texture is modified to offer lower surface energy, resulting in the non-wetting nature of water on the modified surface and forming many water droplets on the surface to reduce the resistance to heat flow across the surface. For the same temperature difference between the vapour and the surface, dropwise condensation is much more effective than film-wise condensation about more than times. In dropwise condensation, the water droplets initially formed on the nucleation sites and grow up by condensation and coalescence of nearer droplets and then flow downwards, accumulating static droplets below them along the way. By increasing the

contact angle of the water droplet, the heat flow resistance between the substrate and the vapour decreases, the heat-transfer coefficient increases, and the condensation rate also increases.

In dropwise condensation, the heat-transfer coefficient is several times larger than that of film-wise condensation. To obtain dropwise condensation, the texture of the surface needs to be modified to offer lower surface energy. This can be implemented by introducing a non-wetting chemical into the vapour, by special physical treatment of the condensation surface/substrate, or by the chemical coating of the solid substrate with a low-surface-energy substance to promote dropwise condensation [1–3]. Among the many processes of promoting dropwise condensation, the chemical method offers superhydrophobic nature on the given surface with a simple process involved. Marto et al. [4] tested several polymer coatings, gold, and silver for sustaining dropwise condensation of steam and reported the heat-transfer coefficients in dropwise condensation as high as six times when compared with film-wise condensation. Zhao et al. [5] reported that the heat-transfer coefficients of dropwise condensation on Langmuir-Blodgett treated surfaces are more than 30 times higher than that of film-wise condensation on bare surfaces. Vemuri et al. [6] experimentally investigated the effects of various chemical coatings and their long-term durability on the dropwise mode of heat transfer. They reported a decrease in heat-transfer coefficient with the elapsed condensation time, suggesting possible leaching of the chemical coating. Rausch et al. [7] reported that the heat-transfer coefficient on an ion-implantation surface is more than five times that of film-wise condensation. In recent years, with the advent of newer coating/manufacturing and nanoscale fabrication techniques, promoting the long-term sustainability of dropwise condensation by chemical coating now holds the considerable prospect for enhancing heat transfer in a variety of industries [2, 6, 8]. An example of enhanced performance of compact steam condensers having chemically coated flow passages of only a few millimetres width is demonstrated by Majumdar and Mezic [9].

In this work, the superhydrophobic copper surface is prepared in a quick time of 2–5 h by using the thermo-solution immersion technique. The maximum contact angle of 162° is obtained by adjusting the composition of the solution, the temperature of the solution, and immersion time at 0.005 M, 45° , and 3 h, respectively. The prepared surface is then experimented with for analysing the nature of dropwise condensation, temperature variation on the substrate, heat-transfer coefficient variation, and condensation time variation. Also, the condensation on the prepared surface is compared with that of the bare copper substrate for the same conditions.

2. Surface preparation

The various methods for the preparation of superhydrophobic surfaces, as shown in **Figure 1**, have been reported, such as electrochemical deposition, plasma method, crystallisation control, chemical vapour deposition (CVD), wet chemical reaction, sol-gel processing, lithography, and solution immersion processes.

Wang et al. [10] conducted an experiment to produce superhydrophobicity on the copper plate using a solution immersion process in which a copper plate was immersed in an ethanol solution of n-tetradecanoic acid (0.01 M) at room temperature for 3–5 days. The immersed copper plate was rinsed with deionised water and ethanol thoroughly and then dried in air. The prepared films were immersed in common solvents (water, acetone, ethanol, and toluene) for 5 days at 25°C . The same

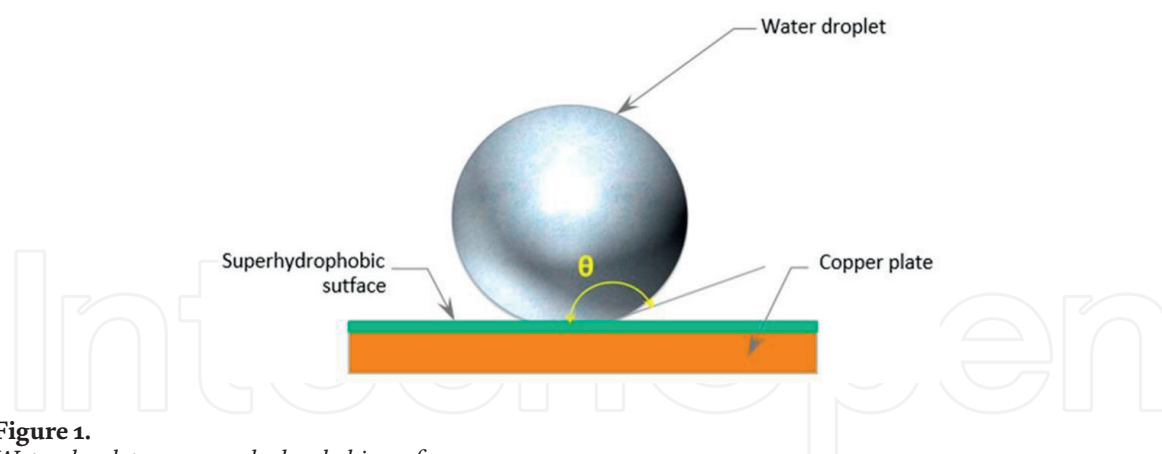


Figure 1.
Water droplet on a superhydrophobic surface.

treatment was also carried out using hot water at 80°C. The contact angle was measured for the dried films. After immersion, the contact angle of the droplet slightly decreases in water, acetone, ethanol, and hot water. The contact angle is slightly increased in solution immersion with toluene. Their experiments suggest that a concentration of around 0.01 M is ideal for the formation of stable flower-like clusters. When the concentration is about 0.001 M, a self-assembled monolayer of tetradecanoic acid is formed on the copper substrate and the contact angle is only about 124°. At above 0.02 M, the microclusters or nanosheets prefer to form in solution rather than on the copper plates. Thus, the concentration of tetradecanoic acid is crucial for the formation of flower-like clusters. They concluded with a concentration of 0.01 M that gives a high contact angle of about 160°. The prepared superhydrophobic surface reliability is checked by immersing the substrate in water, acetone, ethanol, and toluene for 5 days, its superhydrophobic nature remains unaffected.

The drawback of their work is it requires a high concentration of 0.01 M and 5 days to form a superhydrophobic surface on a copper plate compared with our work, which required only 0.003–0.007 M low concentration and less time of around 2–5 h. After immersing the superhydrophobic surface in water, acetone, ethanol, and toluene for 5 days, we obtained an unchanged contact angle of about 162°.

In this work, the superhydrophobic surface is obtained on a copper plate by using the thermo-solution immersion process. **Figure 2** shows the process diagram of preparing a superhydrophobic surface on a copper plate. At first, the plate is cleaned to remove the impurities on the copper plate using an emery sheet. The plate is immersed in acetone for an ultrasonic bath for about 15 min. The plate is washed with deionised water and dried with air. Then, the solution is prepared for the different compositions and the concentration varies from 0.003 to 0.007 M of ethanol and myristic acid. The cleaned copper plate is then immersed in the solution, and the plate within the solution is heated by a hot plate for different temperatures varying from 40° to 65° with atmospheric pressure. After heating, the plate is taken out from the hot solution and cleaned with deionised water and dry air; the self-assembled monolayer is formed on the copper plate that produces superhydrophobic nature.

The copper plate of the required size (25 × 25 × 3 mm) is first rubbed with a rough emery sheet and later with a fine emery sheet. Then, the plate is kept in an ultrasonic bath with acetone for 10–15 min. After being rinsed with deionised water, the plate is dipped in hydrochloric acid for 2–3 min. After being rinsed with deionised water and dried with air, the plate is immersed in a solution of 0.003–0.007 M of ethanol and myristic acid. The solution immersed plate is heated in a hot plate at 40–65°C for 2–5

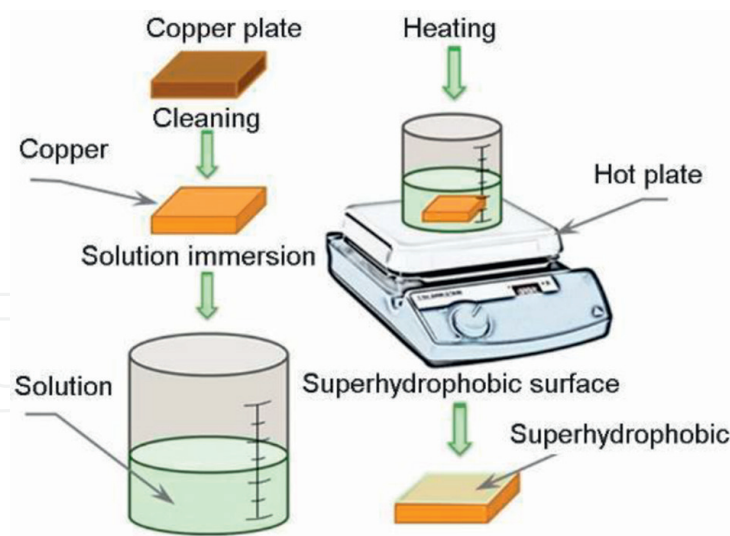


Figure 2.
Surface preparation processes.

h and rinsed with deionised water and ethanol. The superhydrophobic layer is formed on the surface that produces the average contact angle of about $160^\circ \pm 2^\circ$.

Figure 3 shows scanning electron microscopy (SEM) images of the prepared superhydrophobic copper surface. In **Figure 3(a)**, the SEM image is obtained with $\times 500$ and $50 \mu\text{m}$ magnification, which shows the ribbon clusters are formed and randomly spread over the copper substrate. In **Figure 3(b)**, the SEM image is obtained with $\times 10,000$ and $1 \mu\text{m}$ magnification, which shows clusters of a copper compound are formed on the substrate with an air gap between the ribbon clusters. These air gaps will play a vital role to promote the superhydrophobic nature of water droplets on the prepared surface. When the water droplet is dropped on the prepared surface, the water droplet traps the air between the ribbon clusters and reduces the surface energy, which causes an increase in the contact angle of the water droplet. When the contact angle approaches more than 90° , the hydrophobic nature of the prepared surface is formed, and for the contact angle of more than 150° , a superhydrophobic nature of the prepared surface is formed.

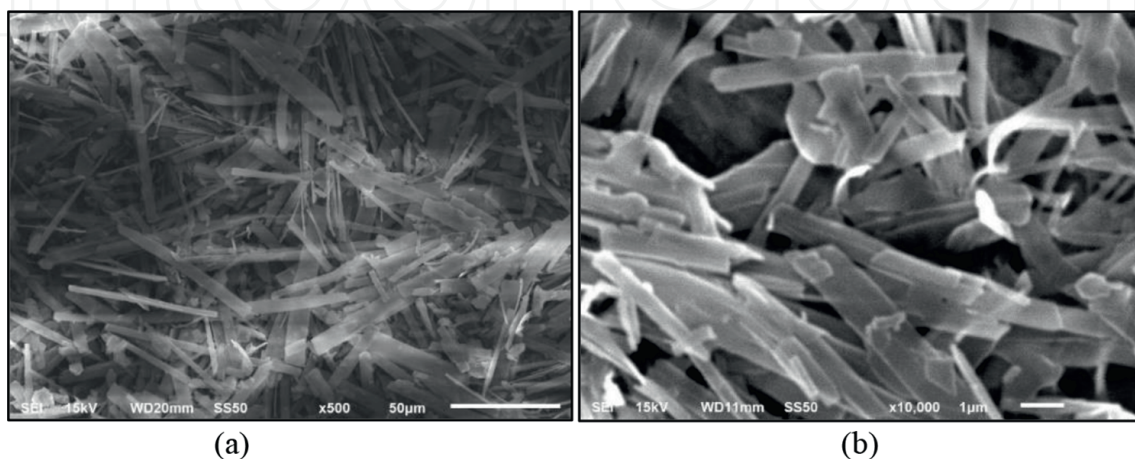


Figure 3.
(a) SEM image with $50 \mu\text{m}$ magnification and (b) $1 \mu\text{m}$ magnification.

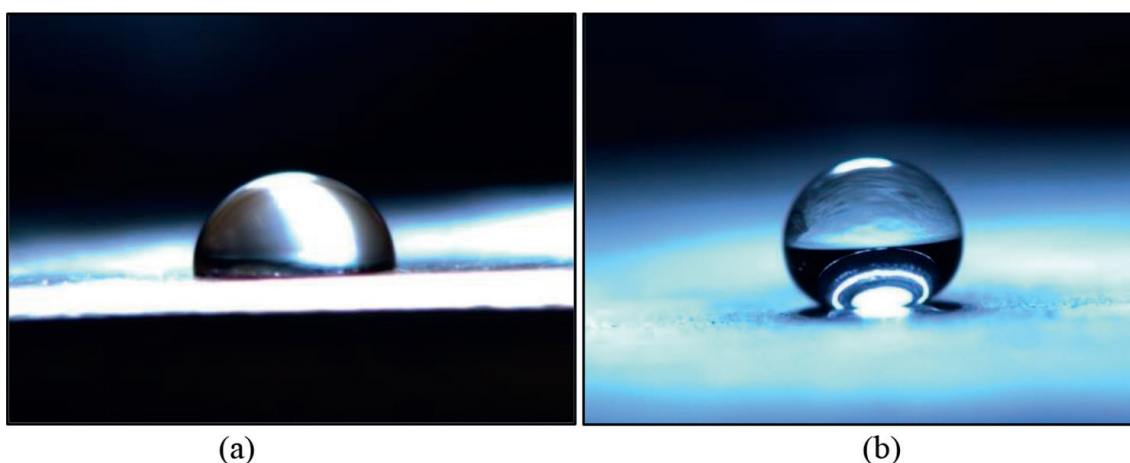


Figure 4.
(a) Droplet on the bare copper surface and (b) droplet on a superhydrophobic surface.

We have carefully monitored this solution immersion process. After immersion into the solution and heating the plate around 45° , a few copper carboxylate nanosheets and small clusters self-assembled from these nanosheets. Also, the surface is very sparsely covered with varying temperatures. Upon increasing the heating time to 60 min, the copper carboxylate nanosheets and self-assembled clusters grow bigger and longer. A further increase in the heating time and temperature leads to an increased surface density of the clusters and nanosheets, and the nanosheets start to grow upwards. For heating times close to 3 h, the ribbon-like clusters grow much bigger, become continuous, and almost completely cover the copper surface, as shown in **Figure 3**. Thus, an interesting continuous coating of ribbon clusters is formed on the copper surface. The ribbon clusters are the morphology that tends to provide the superhydrophobic behaviour.

Figure 4(a) shows the water droplet on the bare copper surface, and **Figure 4(b)** shows the water droplet on the prepared copper surface. On the bare surface, the morphology is not allowed to increase the contact angle due to higher surface energy and exhibits the Wenzel model of a water droplet with a contact angle $<90^{\circ}$. Whereas on the prepared copper substrate, the ribbon clusters offer the water droplet to exhibit the Cassie Baxter model for water droplet and offer a superhydrophobic surface with a contact angle $>150^{\circ}$ due to low surface energy. Further, the contact angle varies for different concentrations, temperatures, and times. The best value obtained is 162° with a concentration of 0.005 M at 45°C for 3 h of heating.

3. Experimental setup

The experimental apparatus was designed and developed to study dropwise condensation under controlled conditions underneath a copper surface shown in **Figure 5**. The setup primarily consisted of the main cylindrical stainless steel vacuum chamber of 180 mm inner diameter and 120 mm length. It was closed from the two ends by specially designed flanges. The lower flange was fitted with an optical viewing window.

In addition, it also had an annular space around this viewing window wherein the working fluid inventory of distilled and de-ionised water was stored. An electric heater is attached at the bottom of the vacuum chamber to heat the water and generate steam inside the vacuum chamber. **Figure 6** shows the cut sectional view of the

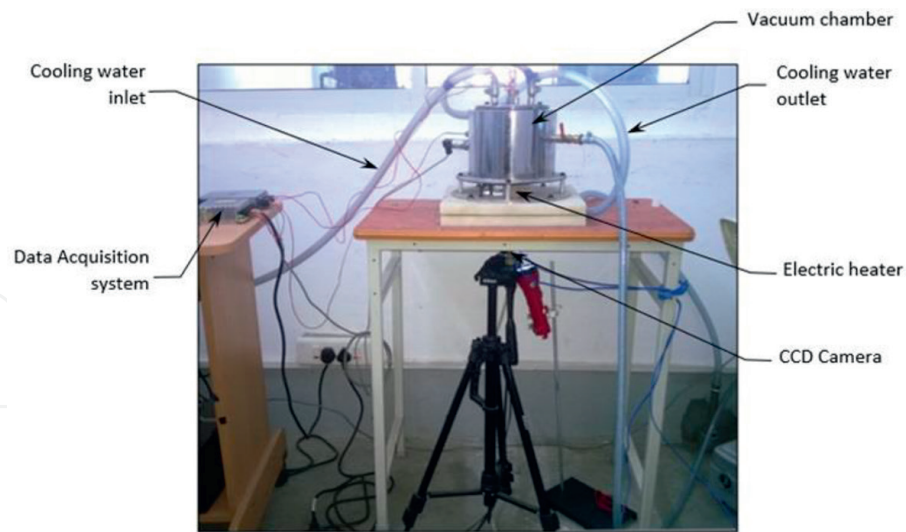


Figure 5.
Experimental setup.

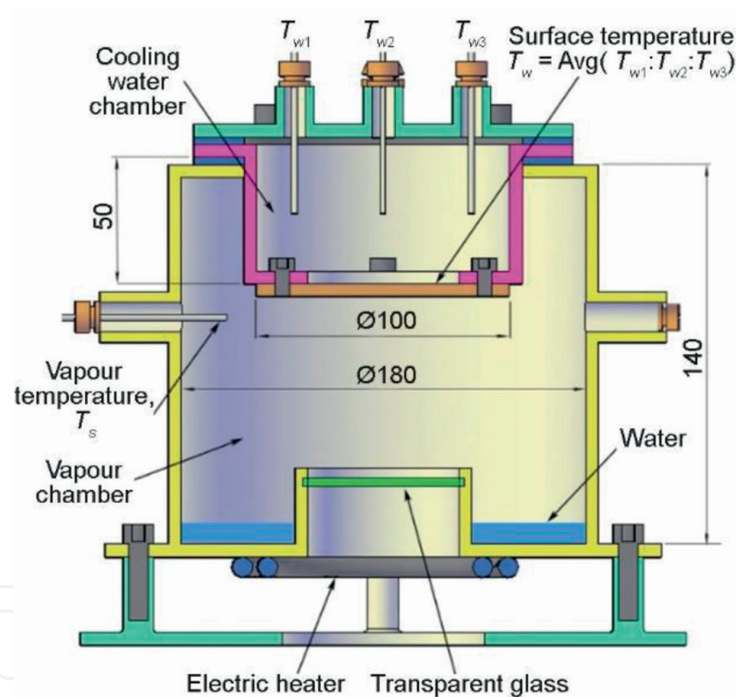


Figure 6.
Condensing chamber cut sectional view.

condensation chamber with a circular heater o.d = 70 mm, i.d = 40 mm was attached outside this annular space to give the necessary heat input. The upper end of the main vacuum chamber was closed with a circular flange with an inbuilt cavity wherein cold water was circulated to maintain constant temperature boundary conditions. Connections for evacuation, pressure transducer, and temperature sensors were provided on the main condensing chamber wall. The temperature of the condensing vapour was measured with one K-type thermocouple Omega, 0.5 mm diameter of the accuracy of 0.2°C after calibration. It was placed centrally in the chamber at a distance of 25 mm from its sidewall. Also, three different thermocouples are placed inside the cooling water cavity to measure the cooling water temperature. The average

of these three thermocouple values is treated as the substrate temperature on which the condensation is going to occur. The vacuum is obtained by connecting the vacuum chamber to a vacuum pump, and the vacuum is maintained to improve the condensation process. The data acquisition was carried out with National Instruments. The entire assembly could be tilted to any desired inclination at 0–90 deg. This setup is suitable for the inclined condition after the water is converted to steam by vertical position. After the generation of steam at a vertical position, the setup can be tilted to the required angle to analyse the behaviour of dropwise condensation on the required inclined superhydrophobic surfaces. A colour charge-coupled device CCD video camera Basler with 1024 × 1024 pixels at 100 fps was used to capture the images of the droplets forming on the underside of the superhydrophobic copper plate through StreamPix software. StreamPix software can be used for creating both image and video formats and further converted into required image formats. The LED light source placed under the set of the camera was directed on the substrate from the optical window on the bottom flange to maintain a near-parallel and symmetric beam on the droplets, ensuring a proper contrast level for subsequent edge detection. The volume flow rate of the cooling water and the steam temperature inside the vacuum chamber is modified with different conditions to analyse the dropwise condensation process underneath the prepared copper substrate.

4. Experiment and results

The experiment is conducted on both bare and superhydrophobic surfaces for varying the properties such as vapour temperature (T_s), surface temperature (T_w), power input (I), and cooling water flow rate (lph). The maximum input power that can be set by the setup is 100 W by regulating with the least of 1 W. The cooling water flow can be adjusted up to 500 lph. In this work, three different water flow rates are used for conducting the experiments on both the bare surface and the superhydrophobic surface. The temperatures of the vapour and surface are acquired from the data acquisition system connected with the setup to the computer through LabVIEW software. The surface temperature and the vapour temperature are obtained from the initial state to the steady state by varying the flow rate to 100 lph, 200 lph, and 300 lph, respectively. The images obtained are stored and videos are captured by the camera connected to another computer through StreamPix software with a 100-fps rate. The images shown in **Figure 7** are the bottom view and the droplets are falling downward underneath the bare and the prepared superhydrophobic surface, respectively.

Figure 7(a) shows the condensation of water vapour on the bare copper plate with irregular water particles underneath the horizontal copper plate. The wetting nature of the bare copper surface results in water film formation on the bare substrate, which reduces the contact surface area between the vapour and the substrate. This film increases the resistance to heat flow between the vapour and the copper surface. Also, the fall-off diameter of the droplet is high in bare copper surface condensation. This causes further resistance to heat transfer, a low-heat-transfer coefficient, and a low-condensation rate of water on the bare surface. **Figure 7(b)** shows the dropwise condensation on the prepared superhydrophobic surface with regular complete spheres-like droplets that increase the contact surface area between the vapour and the plate surface. The contact angle of the water droplet on the prepared surface is more than 150°, which offers dropwise condensation on the prepared

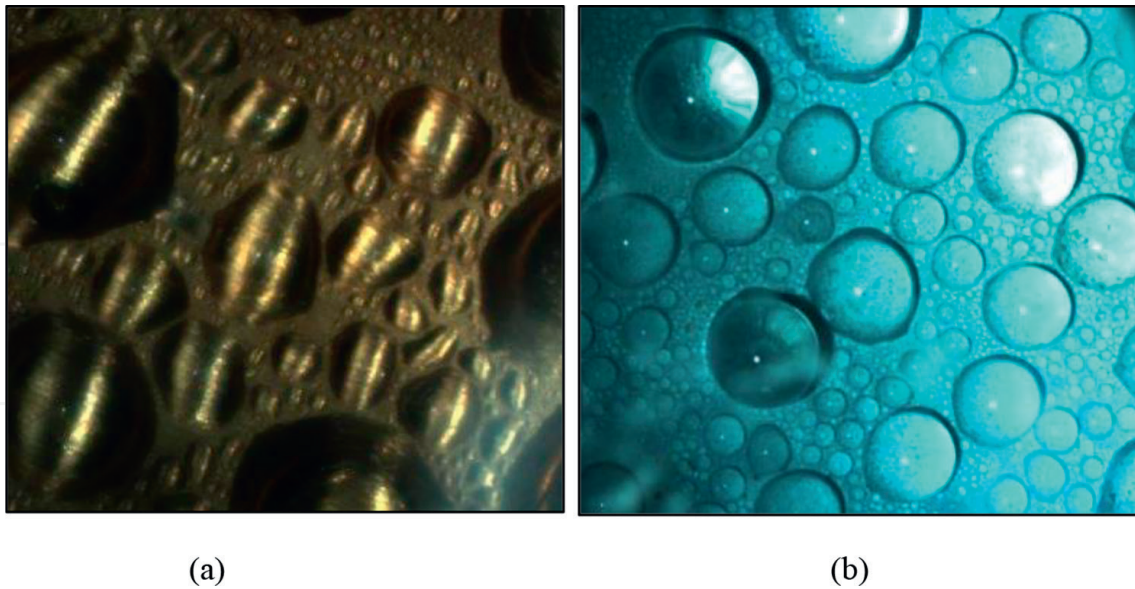


Figure 7.
 (a) Condensation on the bare copper plate and (b) condensation on the superhydrophobic surface.

superhydrophobic surface. The water droplets are formed, which results in a decrease in resistance to the flow of heat and the fall-off diameter of the droplet from the superhydrophobic surface. A higher contact angle produces a lower diameter of the falling water droplet, which increases the fall-off frequency of the water droplets. This causes an increase in heat-transfer coefficient and rate of condensation.

4.1 Contact angle

The water contact angle is the angle between the liquid-solid contact surface and the tangential line obtained from the liquid-vapour interface. Wenzel model and Cassie Baxter model are the familiar contact angle model in which Cassie Baxter contact angle model is used in this work for dropwise condensation. In this model, the air

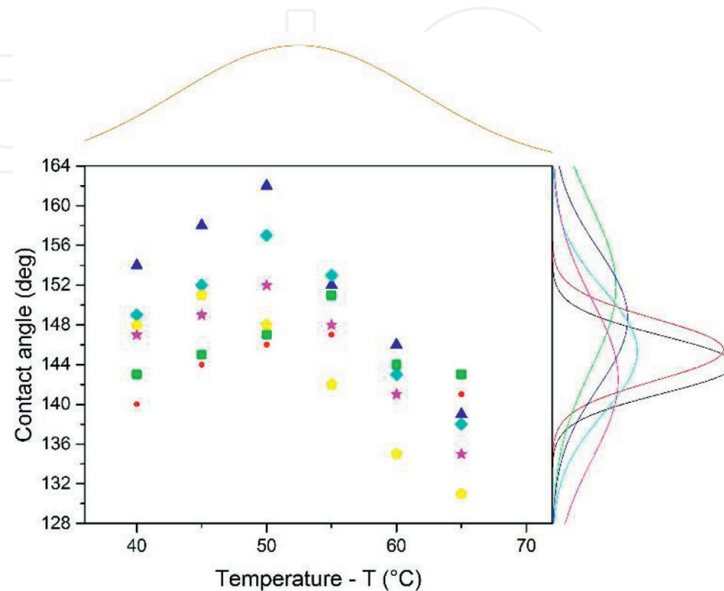


Figure 8.
 Contact angle vs. temperature.

is trapped in between the liquid and the solid surface, which offers superhydrophobic nature of the prepared surface with a contact angle of $120\text{--}162^\circ$. The contact angles obtained for the different temperatures vary from 40° to 65° and times are plotted in the distribution graph shown in **Figure 8**, which reveals that the maximum contact angle of 162° against the temperature of around 50°C for 3 h. The large number of contact angles obtained is in the region $140\text{--}152$ for the time durations of 2–3 h. The higher contact angles are also obtained in the region of $45\text{--}55^\circ$. The average contact angle on the prepared surface is obtained as 160° , which is greater than 150° and offers superhydrophobic nature on the prepared surface.

4.2 Vapour and surface temperature comparison

First, the experiment is conducted on a bare copper plate. The vacuum pump is used to obtain vacuum inside the vacuum chamber and the vacuum pump connection is closed after 15 min. Water is poured inside the vacuum chamber and the bare surface is located underneath the cooling water chamber. The power is given to the heater inside the vacuum chamber and regulated with different inputs from 30 to 100 W with a difference of 5 W. The cooling water flow is controlled for three conditions, 100 lph, 200 lph, and 300 lph, respectively. The temperatures are observed for different power inputs for each flow rate. The values of surface temperature T_w and vapour temperature T_s are obtained through the data acquisition system through LabVIEW software. The frequency of water droplet falling is obtained for finding the condensation rate. The experiment is repeated for superhydrophobic copper substrate with the same conditions and obtained the values of surface temperature, vapour temperature, and condensation rate. The heat-transfer coefficient is calculated by Newton's law of cooling and also compared all the parameters for the bare plate with a superhydrophobic surface.

Figure 9 shows the comparison of vapour temperature T_s with the corresponding power input I for the bare and superhydrophobic surfaces for different water flow rates. In both, cases 100 lph conditions give the highest vapour temperature due to the low mass flow rate. Increasing the water flow rate causes decreases in the vapour temperature due to higher heat transfer from the water vapour to the cooling water. **Figure 10** shows the comparison of surface temperature T_w with the corresponding

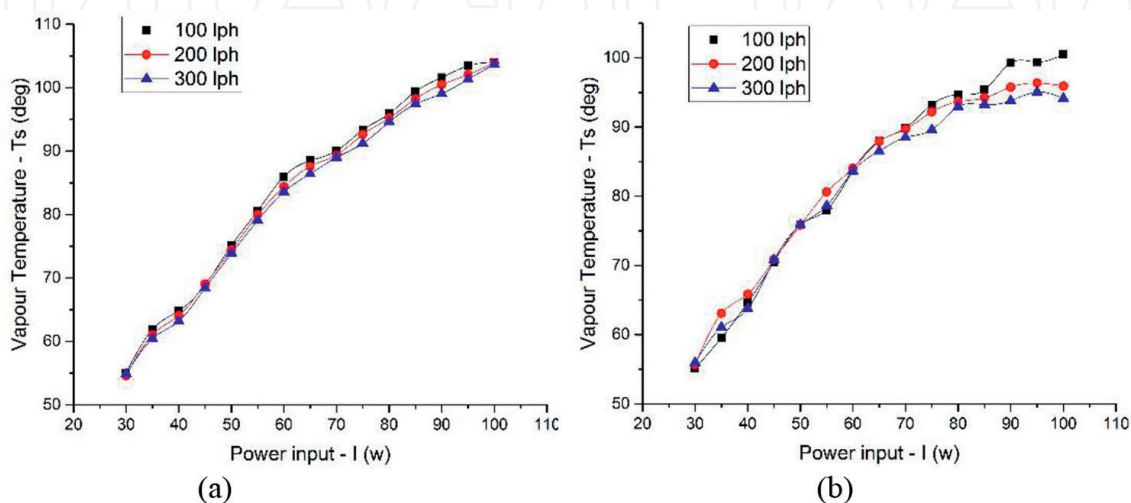


Figure 9.
(a) Vapour temperature variation with bare surface and (b) with the superhydrophobic surface.

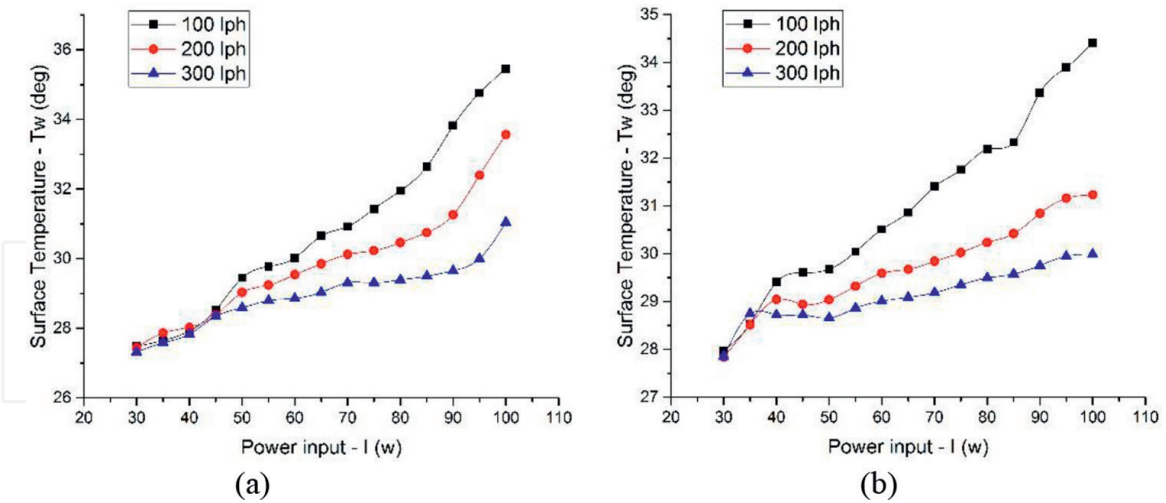


Figure 10.
 (a) Surface temperature variation with bare surface and (b) with the superhydrophobic surface.

power input I for the bare and superhydrophobic surface for different water flow rates in which the surface temperature is low with 300 lph of water flow and it is high with 100 lph of water flow rate. Similar to that of vapour temperature, the surface temperature also decreases when the cooling water flow rate is increased. The lower surface is obtained for 300 lph of flow rate for both the bare and the prepared superhydrophobic surfaces.

The difference in temperature $\Delta T = T_w - T_s$ is higher on the bare plate than on the superhydrophobic surface, which increases the heat-transfer coefficient and condensation rate. The temperature difference directly affects the condensation of water particles from the water vapour onto the condensed droplets. The resistance offered by the extra coating layer of the superhydrophobic surface is increased and heat flow from the vapour to the plate is decreased. Due to this, the temperature of the plate is always higher on the superhydrophobic surface than on the bare plate.

Figure 11 shows the comparison of heat-transfer coefficient h obtained through Newton's law of cooling with corresponding heat input I . For bare surface, the

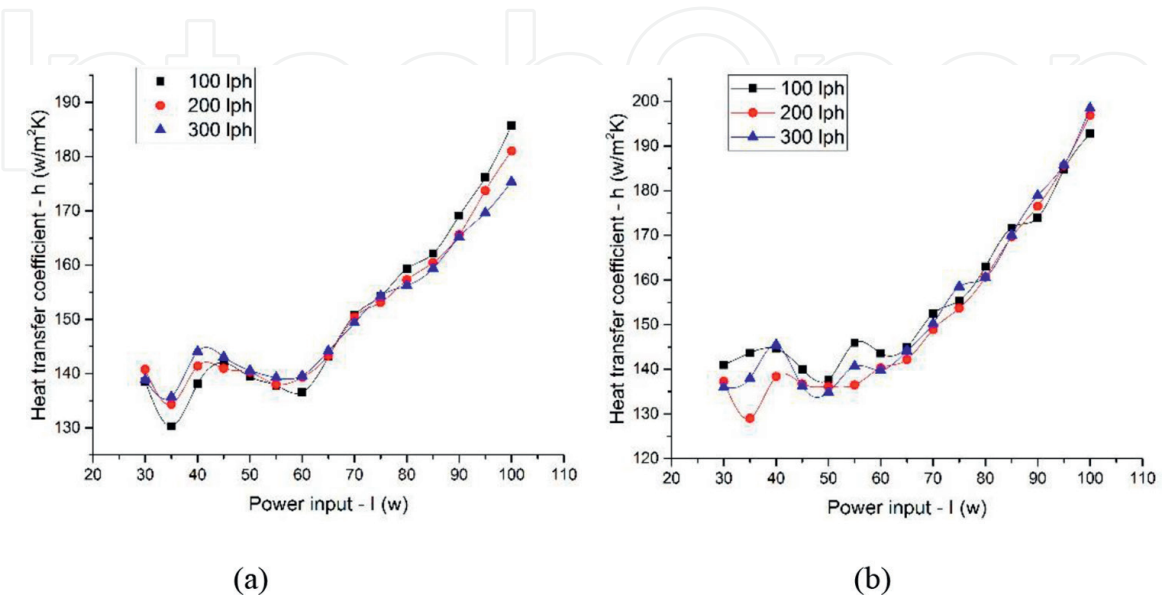


Figure 11.
 (a) Heat-transfer coefficient variation with bare surface and (b) with the superhydrophobic surface.

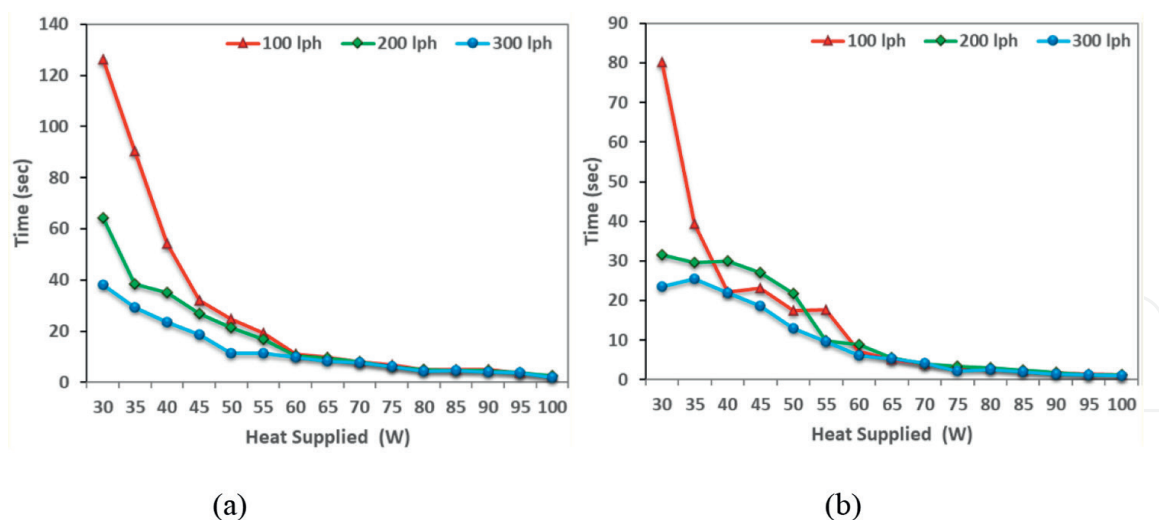


Figure 12.
 Condensed droplet falling time on (a) bare surface and (b) superhydrophobic surface.

higher amount of heat-transfer coefficient obtained as $186 \text{ W/m}^2 \text{ K}$ obtained for the cooling water flow rate of 100 lph at the maximum heat input of 100 W. Also, the increase in cooling water flow rate decreases the heat-transfer coefficient, as shown in **Figure 11(a)**. Whereas on a superhydrophobic surface, the maximum heat-transfer coefficient is obtained as $196 \text{ W/m}^2 \text{ K}$ with a cooling water flow rate of 300 lph. In this case, an increase in the cooling water flow rate increases the heat-transfer coefficient, as shown in **Figure 11(b)**. The condensation rate is also higher on the superhydrophobic surface.

Figure 12(a) and **(b)** shows the condensed water droplet falling time on the superhydrophobic and bare surface for different water flow rates of 100 lph, 200 lph, and 300 lph, respectively. It shows that about 120 s is required for the first condensed fall-off water droplet from the bare surface, whereas it takes about 80 s in the case of the prepared superhydrophobic surface. The condensed water droplet fall-off time is about 1 s on the superhydrophobic surface and 2 s on the bare surface against the mass flow rate of 300 lph. It is noted that the condensing rate of falling water droplets is higher on a superhydrophobic surface than on a bare surface.

4.3 Ordinary surface and superhydrophobic surface comparison

In the previous chapter, the surface temperature, vapour temperature, heat-transfer coefficient, and condensation rate are discussed for three different cooling water flow rates, 100 lph, 200 lph, and 300 lph, respectively. The higher heat-transfer coefficient and good condensation rate are obtained on the superhydrophobic surface for the cooling water flow rate of 300 lph. To compare the surface temperature, vapour temperature, heat-transfer coefficient, and condensation rate directly between the ordinary surface and superhydrophobic surface, 400 lph of cooling water flow rate is used and discussed in this chapter. On comparing 300 lph results with 400 lph cooling water flow rate, there is a negligible amount of variation obtained for steam temperature and the surface temperature. Whereas for heat-transfer coefficient, a slight increase in variation is obtained, and for condensation rate, a notable variation is obtained between an ordinary surface and the superhydrophobic surface.

The water vapour temperature, surface temperature, heat-transfer coefficient, and condensation rate are measured for different heat supplies varying from 30 W to

100 W, and the comparisons between ordinary surface and superhydrophobic surface are shown in **Figures 13–16**, respectively. The temperature of the water vapour T_s inside the vacuum chamber is decreased on the superhydrophobic surface compared to that of the ordinary surface when the heat supplied is increased due to thermal resistance offered by the coating on the superhydrophobic surface, as shown in **Figure 13**. In both cases, the vapour temperature varies similarly when the heat supplied is between 40 and 75 W. Further increase in temperature decreases the vapour temperature on the superhydrophobic surface and increases the vapour temperature on the ordinary surface. **Figure 14** shows the comparison of surface temperature T_w with the corresponding power input I varying from 30 to 100 W for the ordinary and superhydrophobic surface for a water flow rate of 400 lph in which the surface temperature of the ordinary surface is always lesser than that of the superhydrophobic surface. This is because there is smooth heat flow across the ordinary surface with lower thermal resistance. Whereas for a superhydrophobic surface, the thin coating offers higher resistance to heat flow across the superhydrophobic coating, resulting in lower heat transfer through the substrate. Similar to that of vapour temperature, the surface temperature also decreases when the cooling water flow rate is increased. A very negligible amount of surface temperature is obtained for both 300 lph and 400 lph of flow rate for both the bare and the prepared superhydrophobic surfaces.

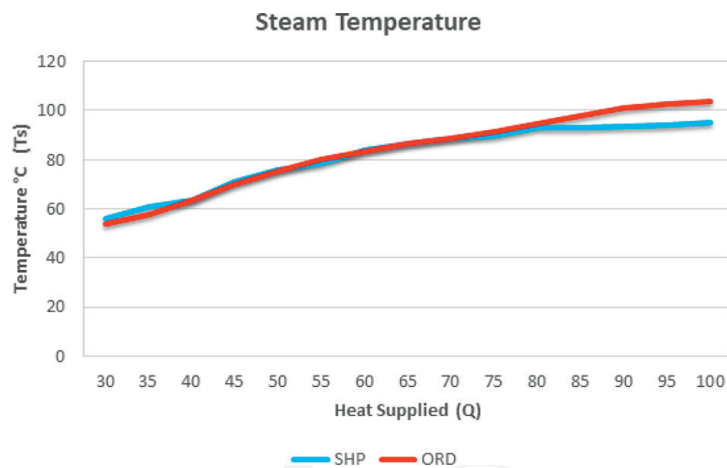


Figure 13. Steam temperature of ordinary vs. superhydrophobic surfaces.

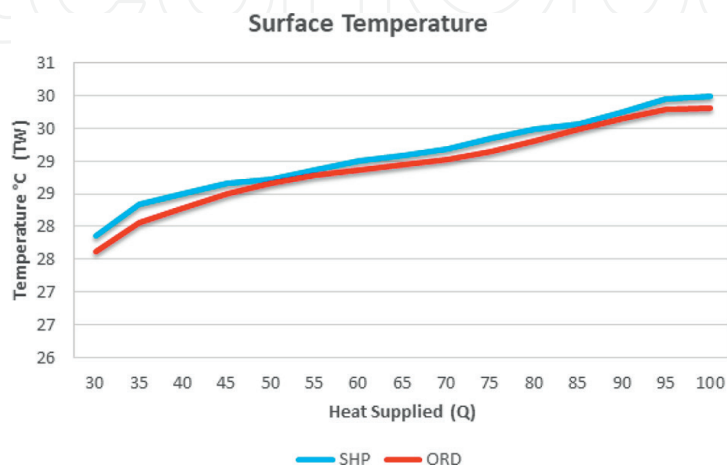


Figure 14. Surface temperature of ordinary vs. superhydrophobic surfaces.

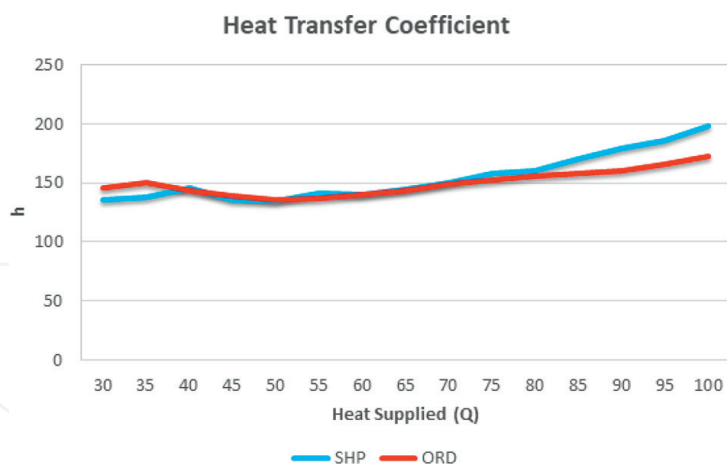


Figure 15.
 Heat-transfer coefficient of ordinary vs. superhydrophobic surfaces.

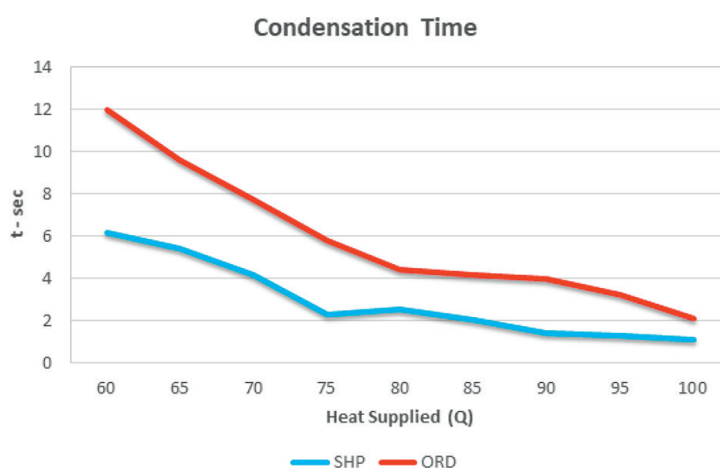


Figure 16.
 Condensation time for drop fall off on ordinary vs. superhydrophobic surfaces.

The heat-transfer coefficient is obtained from Newton's law of cooling for both ordinary and superhydrophobic surfaces. The superhydrophobic surface provides a higher heat-transfer coefficient than the ordinary surface when the heat supplied increases from 70 W. This is due to the higher contact angle of the water droplets on the superhydrophobic surfaces. Higher contact water angle increases the surface area contact between the vapour and the solid surface. Whereas in the ordinary surface, the film-wise condensation offers a decrease in direct surface contact between the vapour and the substrate and provides higher thermal resistance across the film, and decreases the heat-transfer coefficient. When the heat supplied is lesser than 40 W, the formation of condensed particles on the ordinary surface is lesser and offers an increase in heat-transfer coefficient. Whereas on a superhydrophobic surface, the nucleation and coalescence of tiny water particles offer more thermal resistance and decrease the heat-transfer coefficient across the substrate.

When the vapour is directly in contact with a solid surface with a temperature lower than that of vapour temperature, the condensation of vapour starts on the solid surface. This offers film-wise condensation on an ordinary surface and dropwise condensation on the superhydrophobic surface. Although the superhydrophobic coating offers higher thermal resistance than that of an ordinary surface, the condensation rate on the superhydrophobic surface increases due to a lower fall-off diameter

of the water droplets. **Figure 16** shows the condensation time, that is, water droplet fall-off time, for both ordinary surface and superhydrophobic surface with different heat supplied. When the heat supplied is less than 60 W, the formation of the water droplet on the superhydrophobic surface and condensation of film on the ordinary surface are not occurring at a faster rate. When the heat supplied is increased from 60 W, the condensation of vapour occurs on the ordinary surface as well as the superhydrophobic surface. The first fall-off water droplet takes 6 s on a superhydrophobic surface and 12 s on an ordinary surface. This time is lower than the ordinary surface due to the higher contact angle of the water droplet on the superhydrophobic surface. In both cases, the superhydrophobic surface offers a lower fall-off time and higher condensation rate than the ordinary surface, as shown in **Figure 16**.

5. Conclusion

The superhydrophobic copper surface is successfully prepared by thermo-solution immersion technique with a quick time of 2 h. The highest contact angle of 162° is obtained with the concentration of the ethanol and myristic acid of 0.005 M when the solution is heated at $45\text{--}50^\circ\text{C}$ for the time duration of 2–3 h.

The obtained surface is experimented with for dropwise condensation by varying the power input and water flow rate. The complete sphere-like water droplets are obtained on the condensing surface with an increase in contact area that increases the heat-transfer coefficient and condensation rate. The maximum value of temperature difference between the vapour and the surface is 74°C and 64°C for bare and superhydrophobic surfaces, respectively. The maximum heat-transfer coefficient obtained is $196\text{ W/m}^2\text{ K}$ for a superhydrophobic surface and the bare surface is $185\text{ W/m}^2\text{ K}$. The condensed water droplet fall-off time is about 1 s on the superhydrophobic surface and 2 s on the bare surface against the mass flow rate of 300 lph. It is noted that the heat-transfer coefficient and condensing rate of falling water droplets on a superhydrophobic surface are higher than that of a bare surface. The superhydrophobic surface always promotes dropwise condensation, and the heat-transfer coefficient is increased by increasing the contact angle of the water droplet.

The experimental analysis is made by conducting a condensation experiment on both ordinary and superhydrophobic copper surfaces. The following conclusions have arrived in the present work:

1. The number of droplets formed is higher on a superhydrophobic surface than on an ordinary surface, which tends to increase the condensation rate.
2. An increase in static contact angle and a decrease in wettability of the substrate reduce the droplet area coverage.
3. A decrease in wettability also results in earlier water droplet fall off.
4. At a higher saturation temperature, the rate of growth of the drop is higher. Heat-transfer coefficient increases with an increase in the degree of sub-cooling of the substrate.
5. The droplets are formed on a superhydrophobic surface and look like perfect circles that decrease the contact area and increase the heat-transfer rate.

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References

- [1] Rose JW. Dropwise condensation theory and experiments: A review. Proceedings of the Institution of Mechanical Engineers, Part A. 2002;**216**:115-128
- [2] Leipertz A, Fröba AP. Improvement of condensation heat transfer by surface modification. Proceedings of the Seventh ASME, Heat and Mass Transfer Conference, IIT Guwahati, India. 2006;**K7**:k85-k99
- [3] Carey VP. Liquid-Vapour Phase-Change Phenomena. New York: Hemisphere; 1992. pp. 342-351
- [4] Marto PJ, Looney DJ, Rose JW. Evaluation of organic coating for the promotion of dropwise condensation of steam. International Journal of Heat and Mass Transfer. 1986;**29**:1109-1117
- [5] Zhao Q, Zhang DC, Lin JF, Wang GM. Dropwise condensation on L-B film surface. Chemical Engineering and Processing. 1996;**35**:473-477
- [6] Vemuri S, Kim KJ, Wood BD, Govindaraju S, Bell TW. Long term testing for dropwise condensation using self-assembled monolayer coating of N-Octadecyl mercaptan. Applied Thermal Engineering. 2006;**26**:421-429
- [7] Rausch MH, Fröba AP, Leipertz A. Dropwise condensation heat transfer on ion implanted aluminum surfaces. International Journal of Heat and Mass Transfer. 2008;**51**:1061-1070
- [8] Ma X-H, Wang B-X. Life time test of dropwise condensation on polymer-coated surfaces. Heat Transfer - Asian Research. 1999;**28**(7):551-558
- [9] Majumdar A, Mezic I. Instability of ultra-thin water film and the mechanism of droplet formation on hydrophobic surfaces. Transactions of the ASME, Journal of Heat Transfer. 1999;**121**:964-970
- [10] Wang S, Feng L, Jiang L. One-step solution-immersion process for the fabrication of stable bionic superhydrophobic surfaces. Advanced Materials. 2006;**18**:767-770