Enhanced Condensation on Porous Copper Surfaces

Project Course ME:299

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Introduction

Copper is a widely used material in condensation experiments because of its excellent thermal conductivity, electrical conductivity and durability. Its ability to transfer heat quickly makes it ideal for cooling and heat transfer applications. It is also used in electrical wiring, circuits, and heat transfer systems. The material also has high ductility and malleability, and can be stretched into very thin wires. The corrosion resistance ensures durability, even when exposed to moisture or chemicals, making it suitable for outdoor and industrial environments.

On the other hand, copper foam has a porous structure that significantly increases its surface area. This extra surface area helps improve heat transfer and makes condensation more efficient. The foam's pores allow water droplets to move through easily, helping to remove the condensate and keep good contact with the vapour.

The aim of our project was to enhance condensation by modifying the surface design. We took readings for four different types of surfaces by controlling various parameters.

Hydrophobic surfaces repel water, causing droplets to form and slide off easily. Superhydrophobic surfaces amplify this effect, with extreme water repellency creating nearly spherical droplets that roll off the surface quickly. This reduces thermal resistance and enhances condensation efficiency further. Superhydrophilic surfaces, on the other hand, attract water strongly, spreading it into thin, uniform films across the surface. Modifying these surfaces with hydrophobic, superhydrophobic, and superhydrophilic properties allows a detailed examination of their impact on condensation performance.

Apparatus:

- Copper plates
- Copper foam
- Beakers, Forceps, Spatula
- Sonicator
- Hot air oven
- Water based experimental cooling setup
- Analytical Balance
- Thermocouple
- Petri dishes

Chemicals:

- DI water
- Acetone
- Sodium Chlorite ($NaClO_2$)
- Sodium Hydroxide pellets
- Trisodium phosphate dodecahydrate ($Na_3PO_4 \cdot 12H_2O$)
- Toluene
- Hexyl Trimethoxysilane (HTMS)

Fabrication Details

1. **Cleaning:** The glassware was cleaned with acetone and deionized (DI) water, followed by drying with tissues after each cleaning step.

2. **Placing in the Sonicator:** The copper plate was cleaned using sandpaper. Both the copper plate and foam were dipped in acetone and placed in a heat sonicator for 10 minutes. The glass dish was then replaced with a fresh one containing DI water, and the items were placed back into the sonicator.

3. **Drying:** After cleaning, the samples were dried using a hair dryer.

4. **Oxide Layer Removal:** The samples were then dipped in hydrochloric acid and sonicated for 10 minutes to remove the oxide layer. Afterward, they were washed again with DI water.

5. **Solution Preparation:** A solution was prepared by adding 3.75 g of sodium chlorite ($NaClO_2$), 5 g of sodium hydroxide (NaOH), and 10 g of tri-sodium phosphate dodecahydrate ($Na_3PO_4 \cdot 12H_2O$) to 100 ml of DI water, which was maintained at 97°C using a hot plate. The solution was continuously stirred with a magnetic stirrer, and the temperature was kept constant at 97°C.

6. **CuO Nanostructure Formation:** The copper samples were immersed in the prepared solution for 10 minutes. CuO nanostructures formed on the test surfaces, which were visually identified by a color change from brown to black.

7. **Final Rinse and Drying:** The samples were carefully removed from the solution and dried in an air-free environment to avoid further oxidation.

Surface Treatment Procedures

1. **Uncoated Copper Plate and Foam:** For uncoated copper plate and foam, steps 1 to 4 were followed to prepare the samples.

2. **Superhydrophilic Copper Plate and Foam:** To make superhydrophilic copper plate and foam, steps 1 to 7 were followed.

3. **Superhydrophobic Copper Plate and Foam:** For superhydrophobic surfaces, steps 1 to 7 were performed as above, followed by an additional treatment. After cleaning and drying the samples, they were placed in a hot air oven with a mixture of 0.9 ml of toluene and 0.1 ml of Hexyl Trimethoxysilane (HTMS) solution in a small beaker. The beaker was placed in a glass dish, which was covered with aluminum foil. After treatment in the hot air oven, the samples were removed, yielding the superhydrophobic surface.

4. **Hydrophobic Copper Plate and Foam:** To make hydrophobic copper plate and foam, steps 1 to 4 were performed, followed by the same procedure as for superhydrophobic treatment, with the Toluene and HTMS solution in the hot air oven.

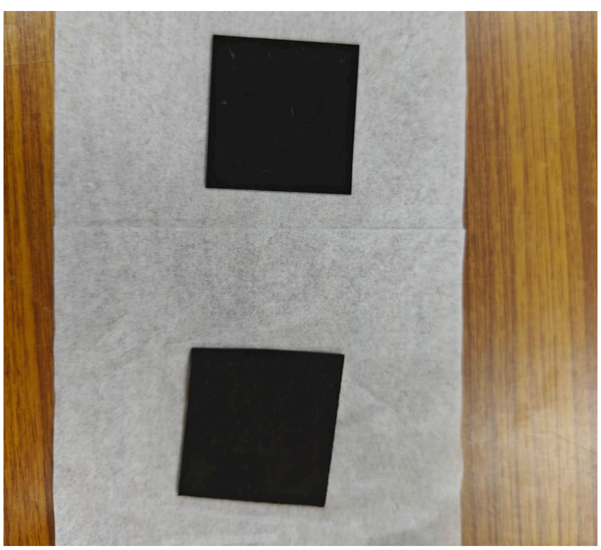


Figure I .Superhydrophobic copper plate and foam.

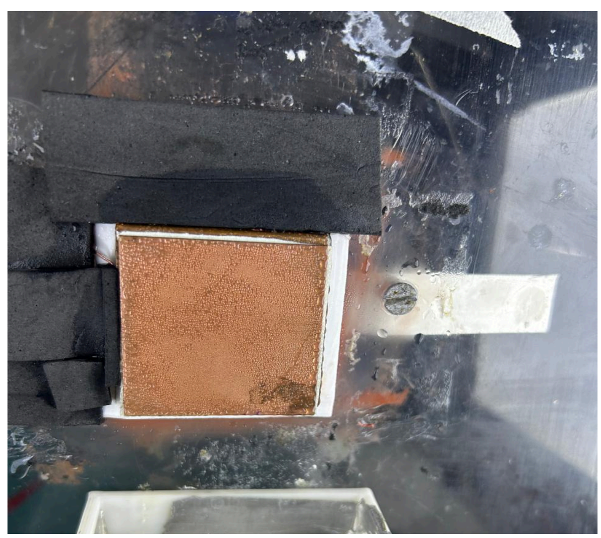
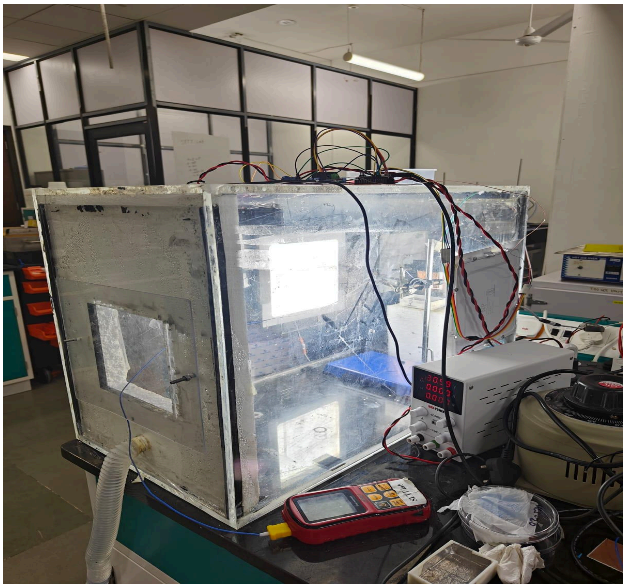


Figure II. Hydrophobic copper plate

Setup Details:



The set of experiments were performed in the above setup which is water cooled as displayed in the images above.

Procedure:

The samples were fixed in the controlled setup using a heat-conductive adhesive and left for at least 2 hours to allow for stabilization. A petri dish was placed beneath the sample in the setup to collect the condensed water.

The experimental conditions for the setup were as follows:

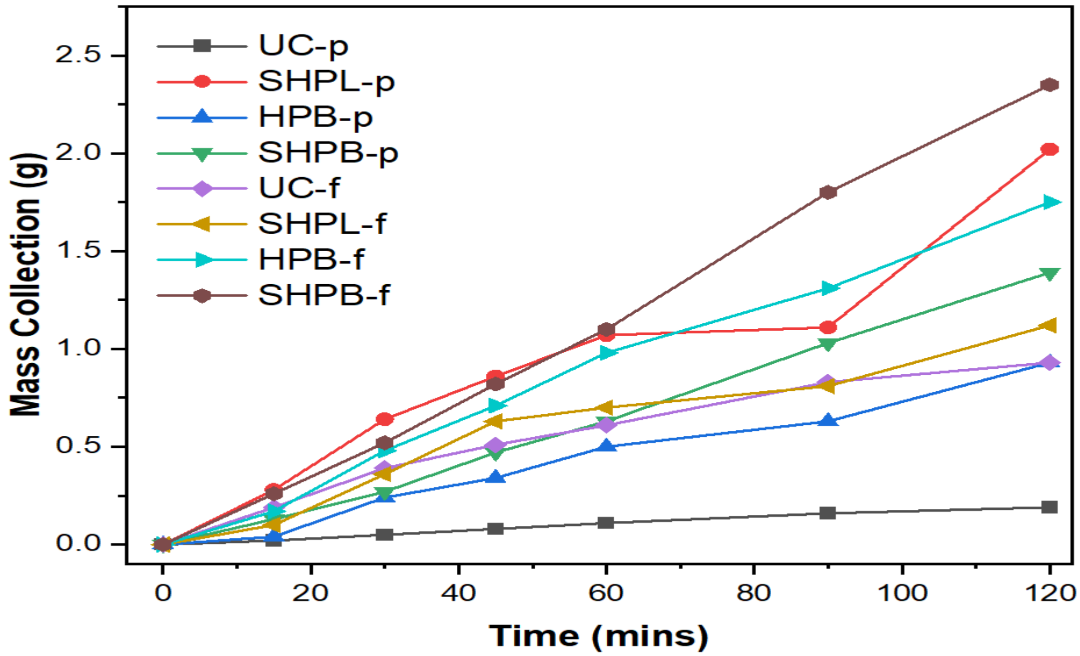
- Relative Humidity: 85%
- Chamber Temperature: 35°C
- Dew Point: 32.1°C
- Surface Temperature: Maintained at 12°C for all samples, resulting in a temperature difference (ΔT) of 20°C.

The water collected and the surface temperature were recorded at intervals of 0, 15, 30, 45, 60, 90, and 120 minutes.

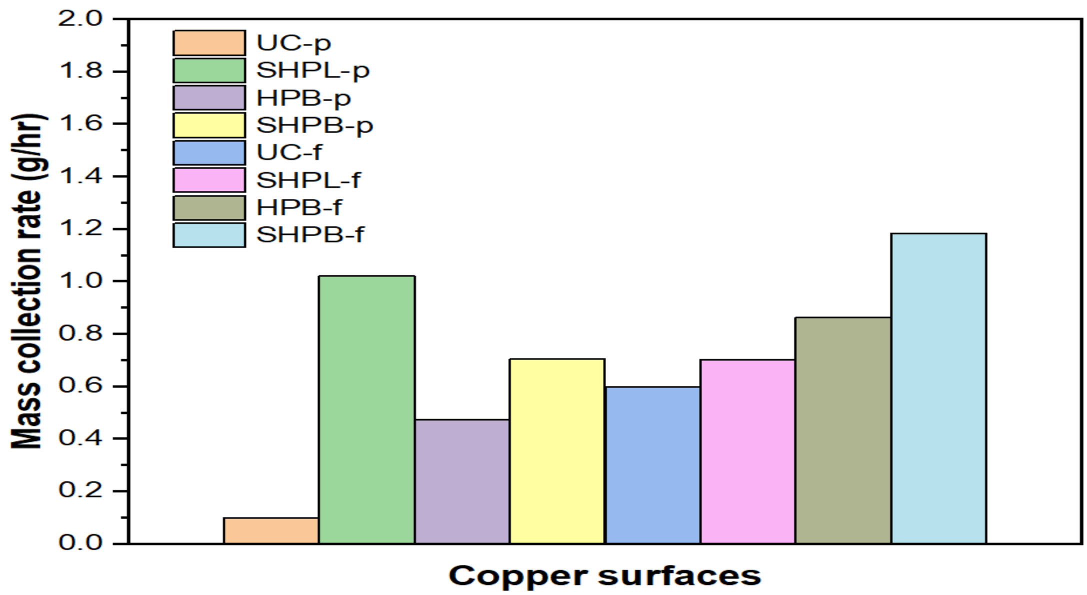
Excel sheet link to the readings taken: Link

Results:

Graphs plotted with the results obtained are as follows:



- Highest water collection was observed in superhydrophobic copper foam followed by superhydrophilic copper plate, hydrophobic copper foam. The lowest was observed in uncoated copper plate.



- Superhydrophobic copper foam also shows the highest mass collection rate i.e. in grams/hour.

Challenges Faced:

- Changes in parameters like temperature and humidity affected the rate of condensation.
- Ensuring the mass of water droplets collected was measured accurately.

Learning outcomes

- Learning fabrication techniques for various samples such as superhydrophobic and superhydrophilic.
- Understanding the changes in heat transfer efficiency due to surface treatment.
- Understanding its applications and future scope in real engineering systems.

Conclusion

This project demonstrates the changes in rate of condensation and heat transfer efficiency caused by altering the surfaces of copper plate and copper foam. The results clearly depict that superhydrophobic copper foam and superhydrophilic copper plate gave the best outcomes. Future work can be to use these surface treatments to enhance the rate of heat transfer in large scale engineering systems.

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