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Development of hierarchical structures for enhanced solar desalination

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ABSTRACT

Water scarcity is going to become one of the most serious challenges globally. Nearly 98% of the world's available water is sea or brackish water and desalination is an alternative source of clean water to recycling. Solar driven water desalination solutions could provide a viable low cost and large scale alternative with minimal environmental impacts. In this paper, experimental work carried out to improve the evaporation efficiency of potable water from the salty water by developing the micro and nano hierarchical structures with the help of 3D printing technology and anodization. The prepared micro and nano hierarchical structures tested along with Aluminum sheet and anodized Aluminum sheet with and without impregnating. These three types of materials tested with three different water quantities, like 50 ml, 100 ml, and 200 ml on sunny days. The maximum efficiency for all three materials observed for 50 ml of water. Among all three elements, micro and nano hierarchical structures with 50 ml got the highest efficiency of 60%.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Materials, Processing & Characterization.

1. Introduction

Water is a vital source for humans and other living things in the world. The purity of drinking water decreases day by day due to industrial sewage, fossil fuels, fertilizer, and pesticides. Due to this, diseases like cholera, typhoid, and hepatitis easily transmitted to humans as well as other living things on the planet, so there is a need for hygienic water for drinking. Different methods and techniques for converting the salty water into potable water are the thermal, membrane, and renewable energy sources, as described in Fig. 1 [1]. The thermal and membrane methods are as follows: Multi-Stage Flash (MSF), Electro Dialysis (ED), Mechanical Vapour Compression (MVC), Multiple Effect Distillation (MED), Reverse Osmosis (RO) and Thermal Vapour Compression (TVC). Out of this, renewable energy sources such as solar stills are the best and economical way of producing distilled water from the contaminated water because the materials required for developing those experimental setups are locally available and easily manufacturable [2]. These devices remove the salts from saline or brackish water and give fresh water for drinking. Several researchers [3] and [4] worked on the parameters affecting the SS's performance, which are controllable and non-controllable. The controllable parameters are depth of water, size, and shape of the SS, etc. And non-controllable parameters are wind velocity, solar intensity, and climatic conditions. After that, researchers worked on the different designs of solar stills like single slope solar stills [5], double slope solar stills [6], triangular solar stills [7], tubular solar stills [8], pyramidal solar stills [9], spherical solar stills [10], etc., with internal modifications like using the nanofluids, PCMs and stones, etc., [11] and external changes like using the photovoltaic panels, solar collectors and solar concentrators, etc., [12].

Here in this current work, the anodization process used to prepare the porous structures on the aluminium sheets. In general, the anodization process used to increase wear and corrosion resistance, gives better adhesion properties for paint primers. The anodization is a process for the generation of oxide films on metals by electrolysis [13]. The porous kind of structure depends upon the anodization process parameters [14] like electrolyte concentration [15], anodizing time, applied voltage, widening time, and temperature [16], etc. The electrolytes used for the generation of oxide formation on the aluminium sheets are sulphuric [17], oxalic [18], and phosphoric acids, etc., [19]. Several researchers worked on the anodization process to get the pore diameter [20], interpore

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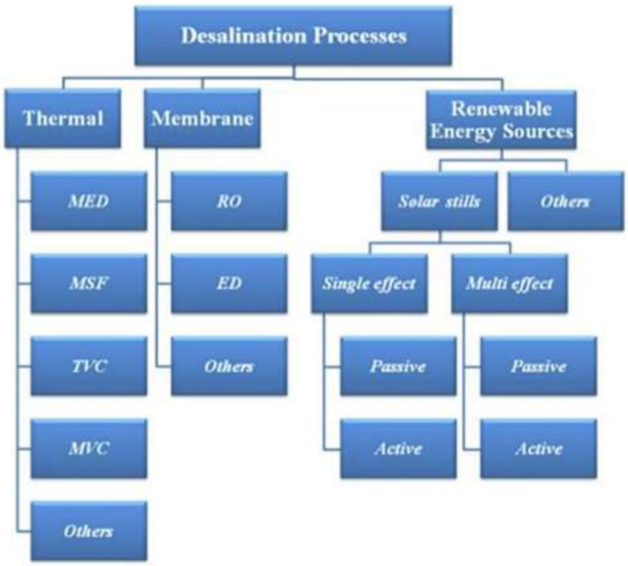

Fig. 1. Classification of desalination processes [1].

distance [21], and pore density [22], etc. Yan et al. [23] studied the effect of additives on the anodization electrolyte for anodic oxide film of high silicon aluminium alloy. They found that the optimal concentrations of electrolyte additives as oxalic acid of 5 g.L^{-1}, citric acid of 15 g.L^{-1}, and tartaric acid of 5 g.L^{-1}, respectively. The author stated that citric acid was more useful to build up the corrosion resistance of the silicon aluminium alloy. Zhang et al. [24] studied the growth of highly ordered nanopores on the anodized aluminium sheets. They concluded that the domains of ordered pores grew linearly with time and improved with the increasing temperature, and remarkable heating occurs during the growth of nanopores. Sachiko et al. [25] evaluated the pore diameters of anodic oxide films formed on the aluminium for the different electrolytes, which are 1.5 M sulphuric, 0.3 M oxalic, and 0.4 M phosphoric acids respectively. The author communicated that minimum pores formed at the voltage of 5 V, and the pores formed are more substantial in the order as sulfuric acid < oxalic acid < chromic acid < phosphoric acid. The significant porosity occurred at the voltage less than 10 V. In this paper; experimental work carried out to improve the evaporation efficiency of potable water from the salty water by developing the micro and nano hierarchical structures with the help of 3D printing technology and anodization process. The prepared micro and nano hierarchical structures tested along with Aluminium sheet and anodized Aluminium sheet with and without impregnating.

2. Experimental procedure

Our main objective is to develop micro and nano hierarchical structures for the saline water's evaporation in this experiment. The aluminum sheet of 0.3 mm thickness was taken and divided into small aluminum plates with a square shape of 5 cm × 5 cm. The roughness of these sheets tested with the Mitutoyo surface roughness tester (SURFTEST SJ-310), and it found to be 2.2 μm.

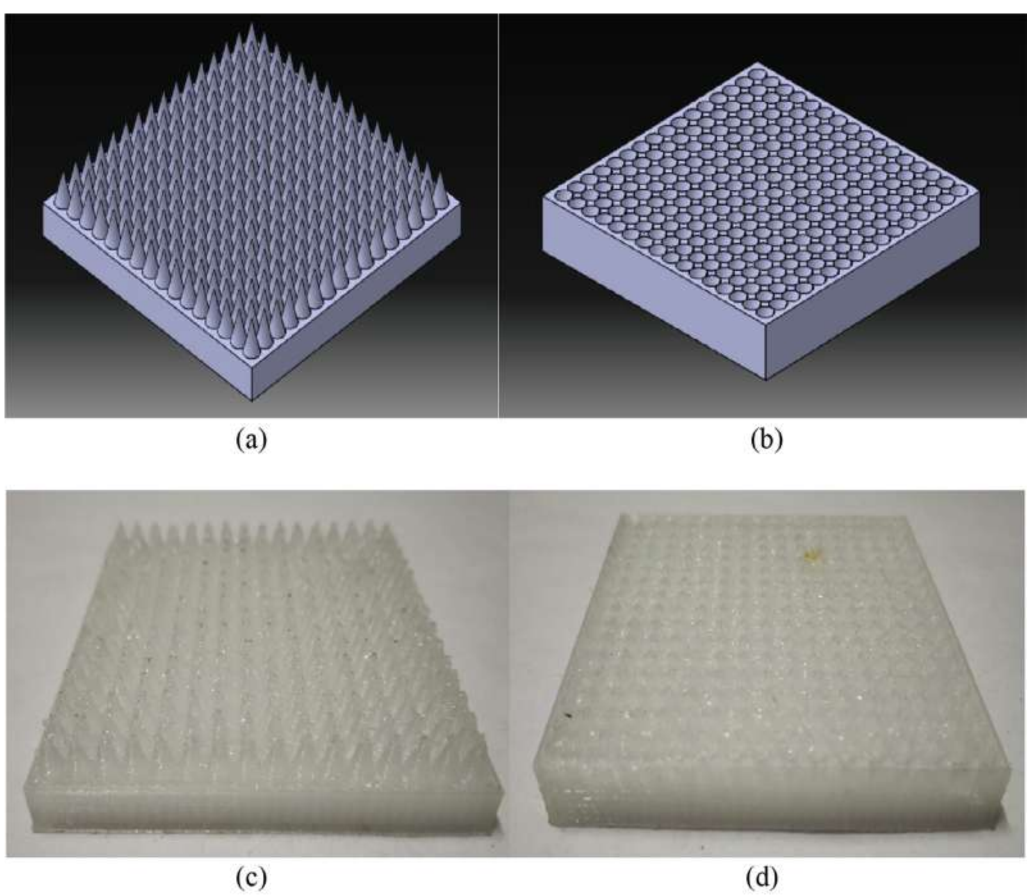

Fig. 2. a) CAD model of top mold. b) CAD model of the bottom mold. c) 3D printed part of top mold. d) 3D printed part of the bottom mold.

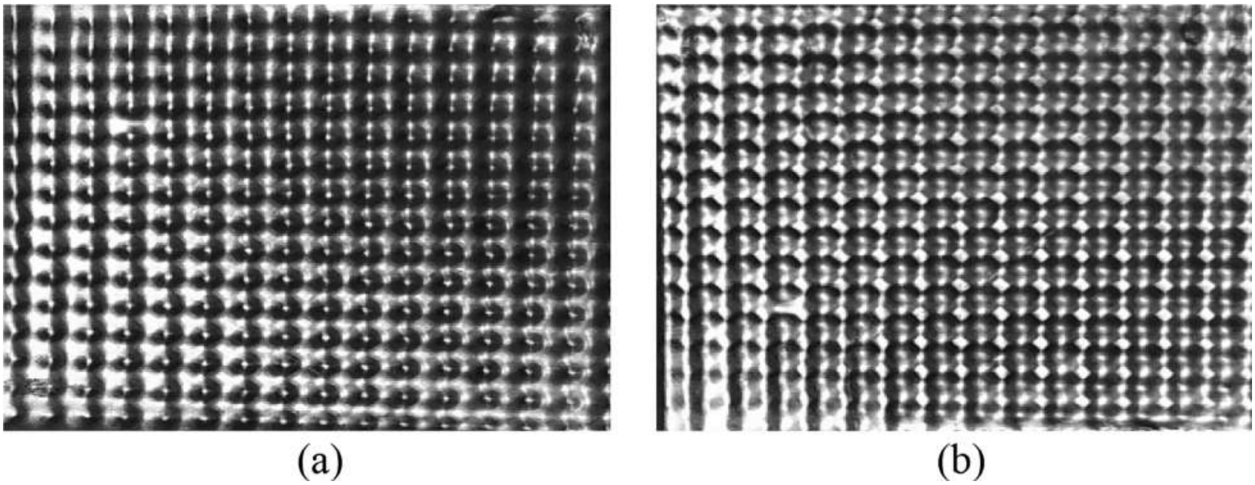

Fig. 3. a) Top and b) Bottom views of the Aluminum plates imprignated with the 3D printed mold.

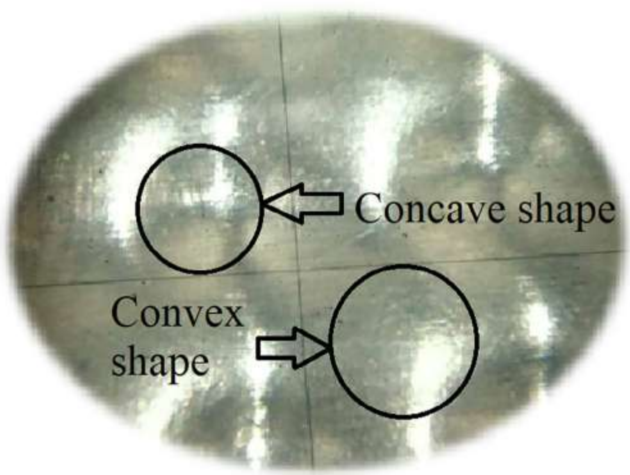

Fig. 4. Concave and convex shapes formed on the aluminum plate measured using the Tool Maker Microscope.

Now, these aluminum plates placed on the mold for impregnating the structure of the shape. The pattern prepared with the help of using 3D printing technology. First, the CAD models of the mold were modeled in CATIA software, checked for the STL file errors if there are any. Those models were printed in the FDM process with process parameters of 0.2 mm layer thickness and 100% infill to get the mold's required properties for impregnating the structure of the pattern on the aluminum plate. The material of the 3D printed pattern is PETG (Polyethylene Terephthalate Glycol), which has an equivalent strength of ABS (Acrylonitrile Butadiene Styrene) material. The CAD models and 3D printed parts of the mold described in Fig. 2.

Once the mold preparation is over, then the aluminium plates with 5 cm × 5 cm × 0.3 mm size were placed between the top and bottom mold, compressed with a compressive testing machine with approximately 18 kN to get the structure of the mold pattern on the aluminium plate which shown in Fig. 3.

The Impregnated aluminum plates tested with the help of a toolmaker microscope to know whether convex and concave shapes formed on the aluminum plates or not. The tip of the concave and convex found to be approximately 90 μm. Fig. 4 describes the concave and convex shapes of aluminum plates.

Now the aluminum plates were at the micro-level and further anodized to get the micro and nano hierarchical structures. The

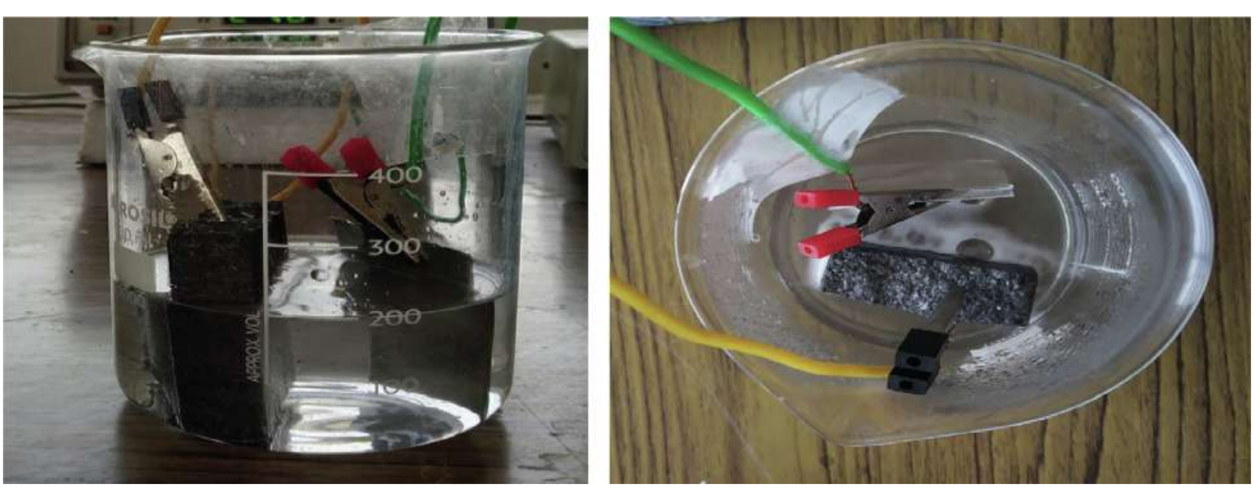

Fig. 5. a) Front and b) top views of the anodization processing of the aluminum plates.

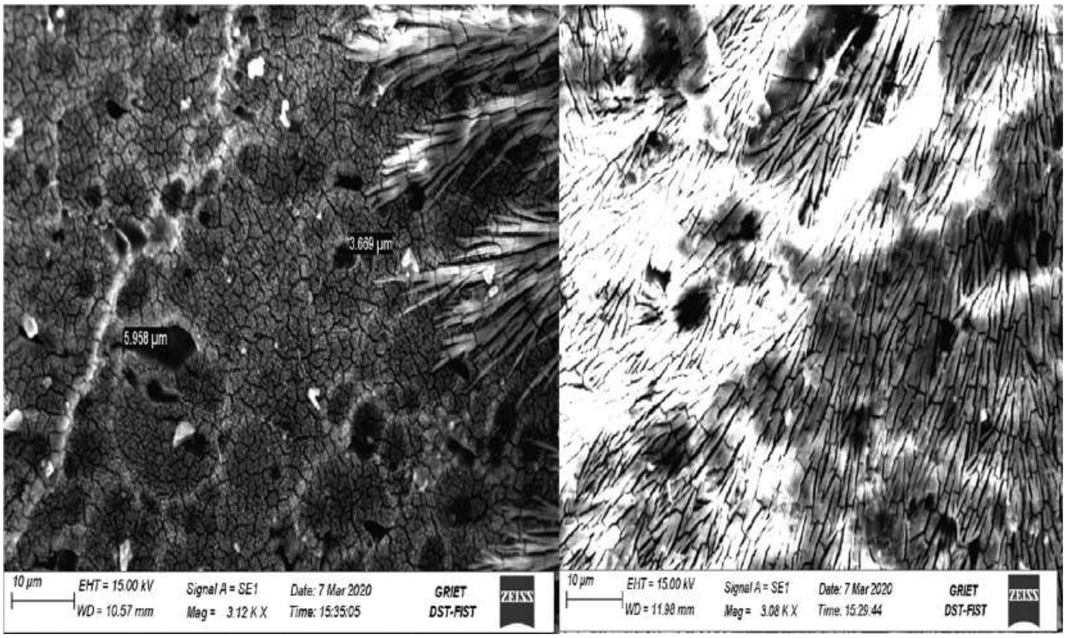

Fig. 6. SEM images of the a) Top and b) bottom views of anodized Al samples.

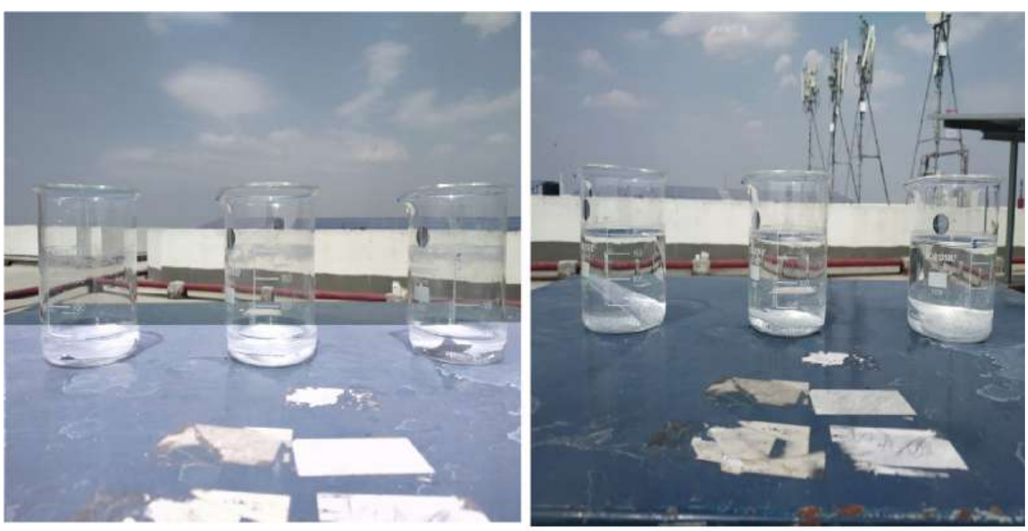

Fig. 7. Experimental setup of a) 50 ml and b) 200 ml quantity of saline water.

anodization process performed with 0.3 M sulphuric acid electrolyte solution with an applied voltage of 30 V and a duration of 30 min anodization time. Before conducting an anodization process, the aluminum plates were placed in an ultra-sonicator for 10 mins to remove the surface impurities preset on the aluminum plates. Fig. 5 describes the anodization of aluminum plates.

After anodization was over, then the prepared samples were further characterized by the SEM analysis to know the nanostructure of the anodized aluminum plates and are shown in Fig. 6. In the beginning of the anodization, there is thin oxide layer. Then there is continuous increase in the growth of the oxide layer. But continuous applied potential brought many cracks in the oxide layer as shown in Fig. 6(a). Further, lack of order etching, formation of aluminium nano structure of some kind of leaf as shown in Fig. 6 (b).

3. Results and discussion

An experimental investigation carried out to improve the evaporation efficiency of the salty water. In this experiment, three beakers with 50 ml of salty water taken. An unadorned aluminium plate (without anodization and without impregnating) dipped in one of the beakers, another aluminium plate with anodization (without impregnating), was placed in the second beaker. In the third beaker, an aluminium with anodization and impregnating

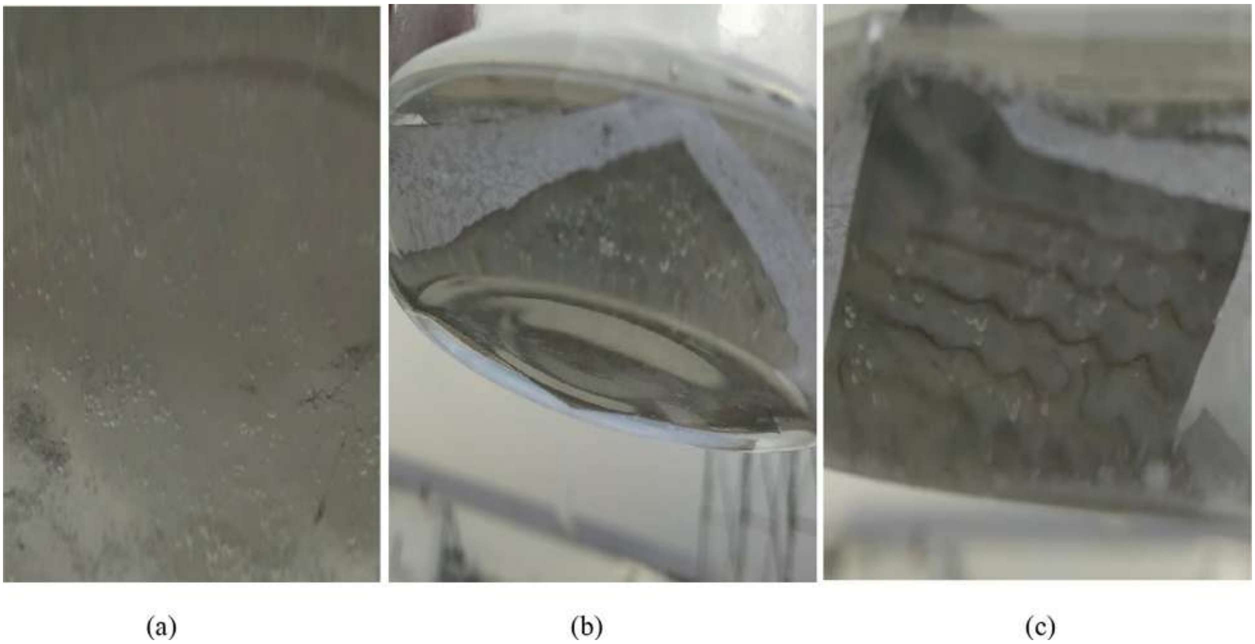

Fig. 8. Air bubbles formation in a) Plain aluminium sheet b) Anodized Al sheet and c) Anodized Al sheet with impregnating.

was dipped, checked for evaporation of the brackish efficiency from 9.00 AM to 5.00 PM. The same procedure repeated with 100 ml and 200 ml quantity of saline water and experimental setup described in Fig. 7 respectively.

The evaporation efficiencies of the brackish water for the 1st, 2nd and 3rd beakers were 46%, 50% & 60% for 50 ml, 27%, 30% & 37% for 100 ml and 20%, 21% & 24% for 200 ml quantities respectively. Out of this, the 3rd beaker with 50 ml saline water containing the anodized plate with impregnating gives maximum evaporation efficiency of 60%. It is due to the air bubbles form around the anodized aluminium plate with concave and convex microstructure was more when compared to the anodized plate without concave and convex shapes and plain aluminium sheet, which described in Fig. 8. These air bubbles around those aluminium plates help to improve the evaporation efficiency of saline water in the beakers by shattering the hydrogen bonds. From the experiments, it observed that if the quantity of water in the beaker increases, then the evaporation efficiency of saline water decreases.

4. Conclusions

- By using the Anodization process and 3D printing technology, the micro and nano hierarchical structures prepared.
- The concave and convex shapes formed on the aluminum plate with approximately 90 μm.
- The evaporation efficiencies of the brackish water for the 1st, 2nd and 3rd beakers were 46%, 50% & 60% for 50 ml, 27%, 30% & 37% for 100 ml and 20%, 21% & 24% for 200 ml quantities respectively.
- The 3rd beaker with 50 ml saline water containing the micro and nano hierarchical structures obtained maximum evaporation efficiency of 60%.

CRediT authorship contribution statement

Ajay Kumar Kaviti: Conceptualization, Methodology, Validation, Writing - review & editing. **Akkala Siva Ram:** Investigation. **A. Aruna Kumari:** Resources, Writing - review & editing. **Shaik Hussain:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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