

EXPERIMENTAL SETUPS AND MATERIALS

3.1 Introduction

After extensive literature reviews and analysis, this experiment started from scratch to design a solar still and use appropriate material to boost the performance of solar still. The design initiation and fabrication have been done at the rooftop of CERD lab, IIT (BHU), (25.2623° N, 82.9893° E) Varanasi, India. This has been started to find out a feasible solution to water scarcity in a sustainable manner. The prototype model of solar still was envisaged with different types of advanced material to support solar desalination.

3.2 Parametric Study of solar still

Several parameters include design characteristics such as angle of tilt, basin water depth, absorber material, orientation etc., and environmental parameters like ambient temperature, wind velocity, and solar flux. Among these tilt angles, absorber material and orientation were considered part of the investigation. The tilt angle of the solar still allows solar radiation to fall perpendicular to the condenser surface and to get trapped.

3.2.1 Study of tilt angle of solar still

Solar still was designed for domestic purposes to obtain fresh water from saline water. Three different types of solar still are made with different design specifications. The first one was Single Slope single basin Solar Still (SSSS) at a tilt angle of 25° from a horizontal surface. The second was Single Slope single basin Solar Still (SSSS) at a tilt angle of 30° from the horizontal surface, while the third one was a Double Slope single basin Solar Still (DSSS) at

a tilt angle of 15° from both sides. Computer-aided design software SolidWorks made the 3-D model of all three setups.

Three solar still models have been designed and fabricated. The solar basin absorber area was made from Fiber-reinforced polymer (FRP) that has an absorption coefficient of 0.68, and thermal conductivity of 0.57 W/mK. Glass cover was used as a condenser surface for evaporated water that has transmissivity in the range of 0.8-0.9. All three setups have the same basin area of 1m×1m coated with black paint from inside on the entire region, including side walls, to enhance the heat absorption capacity of the surface. The detailed summary of all design parameters of models is tabulated in Table 3.1.

Table 3. 1 Summary of design parameter of three models

S.N.	Parameters	Model-1	Model-2	Model-3
1.	Absorber surface area (m ²) (under basin water)	1.0	1.0	1.0
2.	Boundary walls area (m ²)	0.93	1.35	0.80
3.	Total Surface area (m ²)	1.93	2.35	1.80
4.	Minimum height (m)	0.1	0.1	0.2
5.	Tilt angle	25°	30°	15°
6.	Total condenser surface area (m ²)	1.10	1.15	1.03

All three setups have different glass cover tilt angles and have a thickness of 4 mm, as shown in Figure 3.1. In Model-1 and Model-2, the glass cover was tilted at 25° and 30° from

horizontally and facing southward with a glass cover area of 1.10 m² and 1.154 m², respectively. While Model-3 was a symmetrical double-sloped SS with a 15° cover tilt from the horizontal surface and having total glass cover area of 1.035 m² with a maximum among all, and model-1 has minimum space in-between the water surface and glass cover. Besides this, glass wool insulation of 5 cm thickness was used to prevent heat losses from the sidewalls and bottom surface, whose thermal conductivity varies from 0.023 to 0.040 W/m-K concerning the density and temperature of wool [116]. The silicon rubber adhesive was used to seal the leakages and prevent any loss of water vapor losses from the basin. These experimental investigations were performed in the metrological condition of Varanasi (25.3176° N, 82.9739° E), India, in the winter season of October and November. Three days of data, namely, Day-1 (Oct 28, 2019), Day-2 (Oct 29, 2019), and Day-3 (Nov 5, 2019), are presented. These days have the most negligible variation of solar intensity and irregularity, and experiments were performed from 10:30 to 17:30.

During this season, the northern hemisphere passes through the winter season (near winter solstice) and receives low-intensity radiation. The nocturnal yield was also recorded to study the competence of the heat-carrying capacity of different models from 17:30 to the next day at 10:30 hrs.

The raw (brackish) water was kept inside the basin and covered with a flat glass plate. The heat energy required to evaporate the water comes primarily from direct solar irradiation and partly from the absorber liner as an emitted heat. The water level kept at 2 cm inside the basin area corresponds to 20 L of raw water in all three models. Absorptivity of the silicon-based black dye was 0.95 and emittance was 0.90 [117] that absorb solar irradiance. Color

paints are generally pigment or dye. For safety purpose, pigment color are mostly used because it does not dissolve in the water [118].



Model-1 (25°)

Model-2 (30°)

Model-3 (15°)

Figure 3. 1 Three experimental models of conventional roof top solar stills with different tilt angle of glass cover in winter season

Various Instruments were used in this experiment to measure the parameters like K-type thermocouples for temperature measurement at different points, viz. basin water temperature, glass temperature (inside and outside), basin liner temperature, and absorber surface. The ambient temperature was measured by a digital thermometer that can also measure the humidity. A pyranometer (solar power meter) was used to measure the global horizontal radiation, including beam and diffuse radiation, and a measuring flask was used to measure the yield. Those many instruments are shown in Figures 3.2 and 3.3.

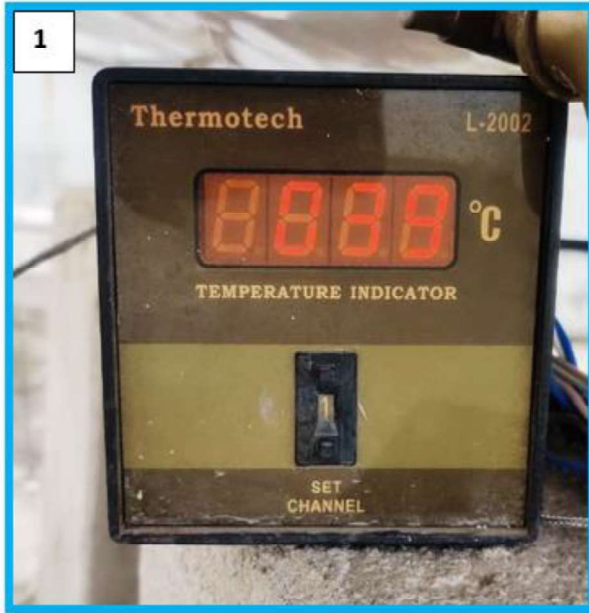


Figure 3. 2 Instruments used in the experiments (1). Temperature indicator (2). Measuring flask with container



Figure 3. 3 Weather measuring instruments (1). Solar power meter (ISO 9001:2008) (2). Digital thermometer

3.3 Study of QD concentration on SS

Two similar SSs were designed and fabricated with an equal absorber area of 1 m^2 having a glass cover (thickness, 4 mm) and tilt angle of 25° from the horizontal facing south direction at the rooftop of CERD lab, IIT (BHU), Varanasi (25.3176° N , 82.9739° E) India as shown in Figure 3.4. Fiber reinforcement material (FRP) was used to make the basin that has a thickness of 1.5 mm. To prevent heat loss from the basin side walls and absorber surface, glass wool coating ($k = 0.03 \text{ W/mK}$) of thickness 7 cm was done. The investigations were conducted on several days to ensure and compress the uncertainty of the observations. It was performed from 9:30 am to 5:30 pm in a daylight condition to utilize solar radiation. Solar desalination is the process of de-salting the saline water by evaporation and condensation processes. The temperature difference between (ΔT) basin water and condenser surface (glass surface) are desalination's driving force. Although the temperature difference between the basin water and condenser surface at the beginning of the experiment was relatively low, evaporation started due to the partial pressure difference between the basin water surface and the glass surface. To increase the ΔT , basin water temperature must increase. To achieve this, quantum dot materials are being used that have good absorbance and emissivity relative to black-coated FRP material only. Four cases are investigated to find the concentration effect of QD materials viz. 0g, 5g, 10g, and 15 QD in black dye of 500 mL. Only two SS were fabricated to reduce the overall cost of the experiment. In this work, two sets of experiments are reported. In the first set of experiments, observations were taken on two models, namely,

- 1) SS without Pyrex glass (0 g QD) coating
- 2) SS with Pyrex glass (5 g QD) coating

In the second series of experiments, observations were taken on the same SSs with modification on coating.

- 1) SS with Pyrex glass (10 g QD) coating
- 2) SS with Pyrex glass (15g QD) coating

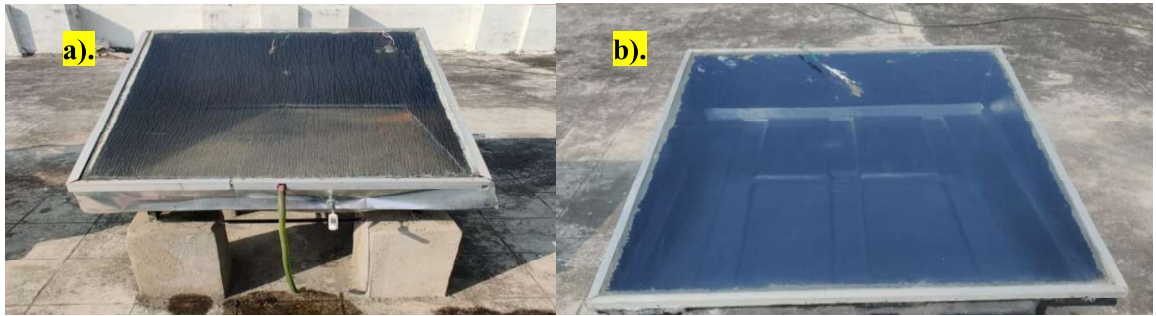


Figure 3. 4 Solar still (a). without QD's (b). with QD's coated on absorber surface

During the experiment, various parameters like inner glass surface temperature (T_{ig}) and basin water temperature (T_w), absorber surface (T_{ab}) and outer glass surface temperature (T_{og}), wind velocity (v_w), solar intensity (I_s), ambient temperature (T_a) and yield (m_{ew}) of SS were measured and recorded at every hour from 9:30 AM to 5:30 PM. To increase the absorption range of solar radiation, the inner surface of the basin was painted with Pyrex glass QD with black dye. The solar absorptance test reveals that basin liner solar absorptivity was 0.60 to 0.68 and 0.90 to 0.95 with and without QD, respectively. QD was purchased from the Centre for Materials and Electronics Technology(C-MET), Pune, India. The thermal conductivity (K) of the basin liner coated with black paint-QD mixture was estimated at around 0.82 W/mK by Hot Disk TPS 500. QD was mixed into black dye by magnetic stirrer at above room temperature. The tilt angle of the solar still is generally set according to the

latitudinal position of the experimental site to receive a perpendicular incident ray on the glass cover. The comparative performance of SSSS and solar still with QD at different concentrations was analyzed at the water depth of 2 cm, validating the analytical model of solar still with decent agreement.

QD-black paint mixture was prepared by thorough mixing of weighted QD in black paint. Magnetic Stirrer was used to mix the nanocrystal into paint at elevated temperature as shown in Figure 3.5.



Figure 3. 5 Preparation of coating material a). weighted BPQD b). QD with black dye c).
Mixing by Magnetic stirrer

3.4 Study of Prismatic SS

In the present experimental investigation, the performance of conventional solar still (CSS) and prism-shaped solar still (PSS) are compared with and without QD's and PCM in the metrological condition of IIT (BHU), Varanasi, India (25.2677° N, 82.9913° E). The fabricating material used for both models was FRP of 1.5 mm thickness and supported by a ceramic base. The condensing surface has been made up of a glass of 4 mm thickness. The

absorber surface area and condensing surface area are the same for both the setups of 1m^2 and 1.1m^2 , respectively, as illustrated by the 3D CAD model in Figure 3.6. The CSS has been fabricated with a minimum height of 100 mm and a 25° tilt angle that gives the maximum height of 556 mm of the solar still.

Similarly, prism-shaped SS has a tilt angle of 25° from both sides and has the same slant height. The basin water level was kept at 2 mm. Being in the northern hemisphere, the south direction for solar irradiation would be the most suitable direction. Hence CSS is oriented toward the southward direction. Whereas the PSS that has a double slope was placed in the east-west direction to receive maximum solar flux. The idea to install PSS in a southward direction would not be beneficial due to its small solar entrance area.

To minimize the thermal losses from the basin 7 cm thick glass wool insulation has been applied around the boundary walls. At first stage, both solar still's basins are coated with only black paint to observe their performances with respect to the yield and efficiency. This surface coating has been applied on absorber and boundary wall area. At second stage, lauric acid (PCM) material was used beneath the basin absorber surface area in a well-insulated compartment. And in third stage, BPQD was applied along with PCM. The CSS and PSS are compared on different design parameters listed in Table 3.3.

Table 3. 2 Design value of different parameters of CSS and PSS

S.N.	Parameters	CSS	PSS
1.	Total black coated surface area (m^2)	2.132	1.4
2.	Absorber surface area	1	1

3.	Boundary walls area (m ²)	1.32	0.4
4.	Minimum height (m)	0.1	0.1
5.	Slope of condenser surface	25°	25° (both side)
6.	Total condenser surface area (m ²)	1.1	1.1
7.	Maximum slant height (m)	1.1	0.551
8.	Solar entrance area (m ²)	1.1	1.37

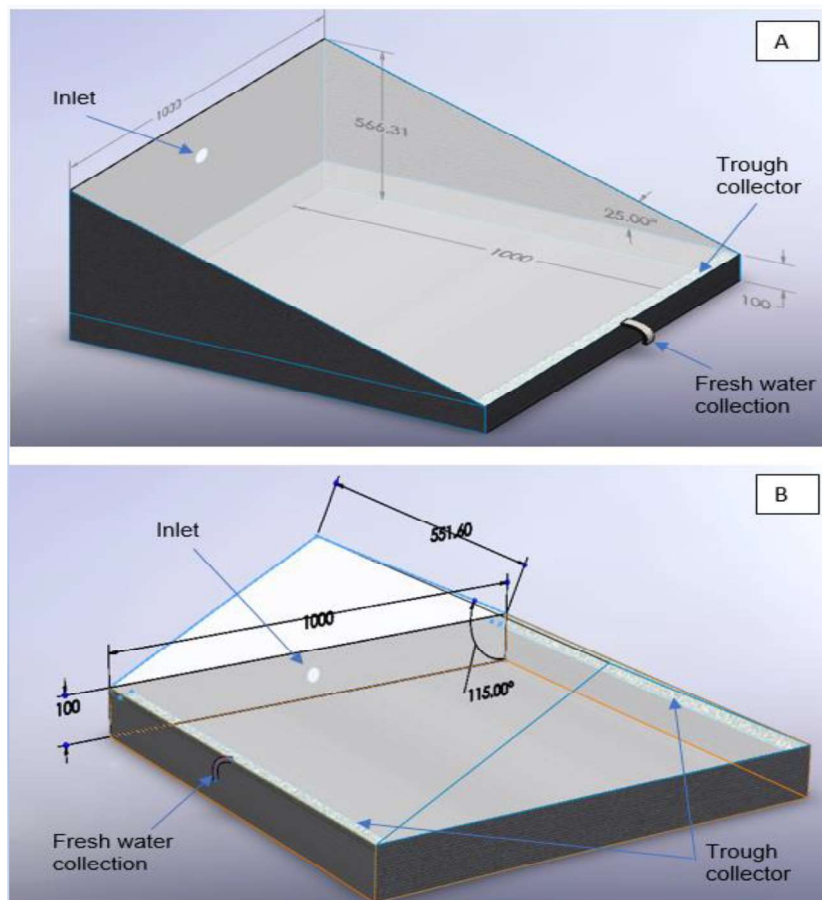


Figure 3. 6 Schematic diagram of (A) SSSS and (B) Prism-shaped SS with dimensions

3.5 Preparation of material

3.5.1 QD coating.

Generally, the inside surface is only coated with black dye or pigment in solar stills. Pigments were found to be more stable than dyes under UV radiation with suitable scattering properties [119]. The black coating is supposed to increase solar absorption, which can further liberate more heat energy from the coated surface to solar still. QD's materials may further increase this solar absorptance. This investigation uses two-dimensional black phosphorus quantum dots (BPQD) doped Pyrex glass to enhance the absorptance property. It is the most thermodynamically stable allotrope of phosphorus in atmospheric conditions, non-toxic and inflammable. Q-dot-based black paint has been used for the coating in the basin liner. It was prepared by 25 g of BPQD in 500 mL of black paint mixed with a magnetic stirrer for 30 min, as shown in Figure 3.7. The SEM image of the BPQD doped Pyrex glass matrix has been shown in Figure 3.8 in 20.0 K resolution, showing that the Pyrex glass granules inside of its nanosized BPQD can be seen in 50.0 K resolution.



Figure 3. 7 BPQD-black paint mixture coated on solar still

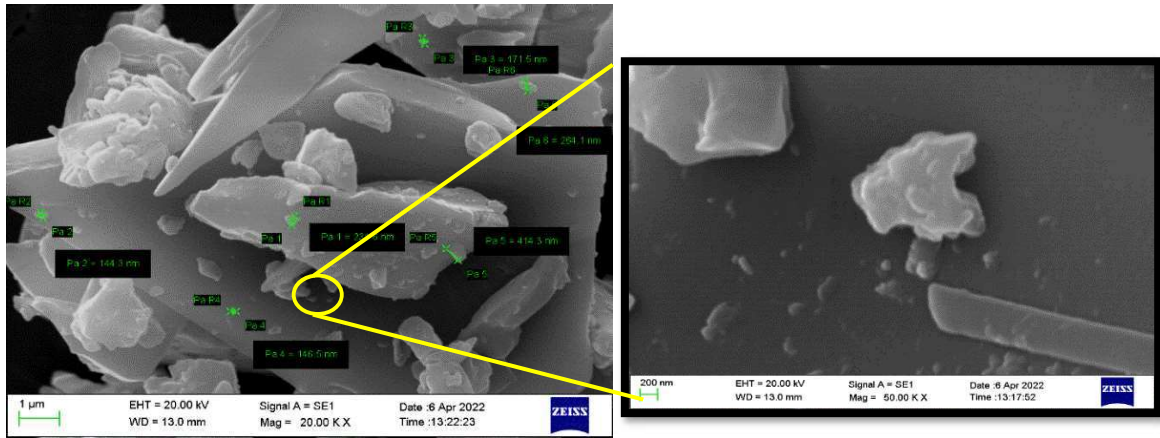


Figure 3. 8 SEM images of Quantum dot material at 20 K and 50 K resolution

3.5.2 Phase change material

In total, 20 kg of Lauric acid (a PCM) has been used to store the excess solar energy in heat during the sunshine period Figure 3.9 underneath the basin's absorber surface. This PCM is selected based on its non-toxic nature, easy accessibility, and economic viability. Additionally, it offers congruent melting, thermal, and chemical stability with good reliability. The thermophysical property, viz. latent heat of fusion, melting point, thermal conductivity, specific heat, and density, are listed in Table 3.5. The DSC results [120] of lauric acid showed the single endothermic pick during melting at an onset of 43.9 °C that reveals the melting point of the material and area under the curve represent the latent heat of fusion as shown in Figure 3.10.

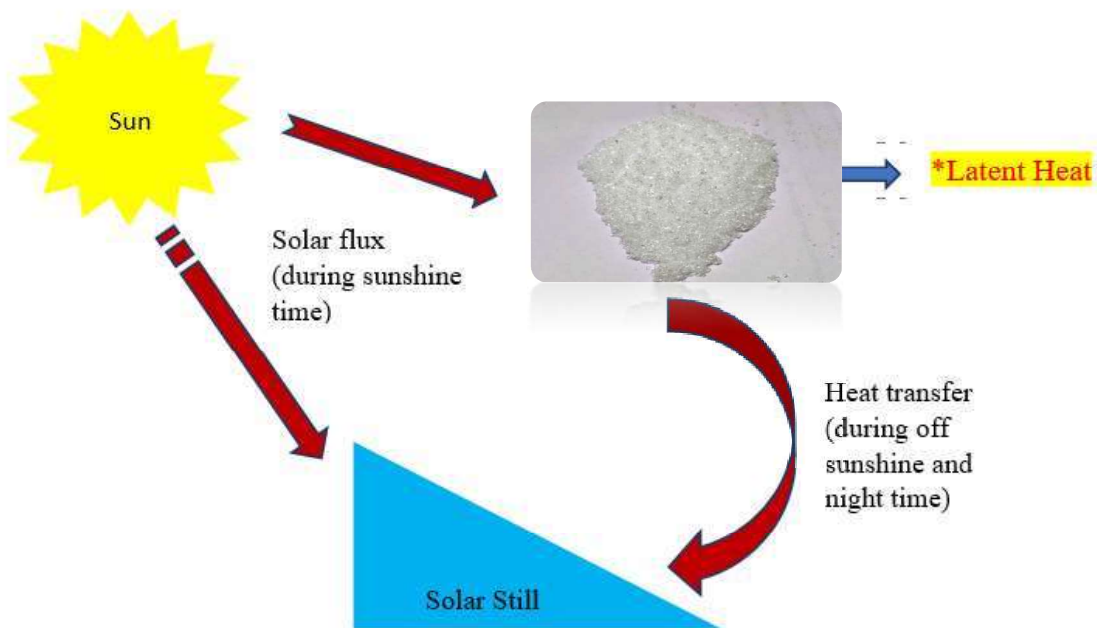


Figure 3. 9 Sample of Lauric acid used in the experiment with heat transfer in sunshine and off sunshine period.

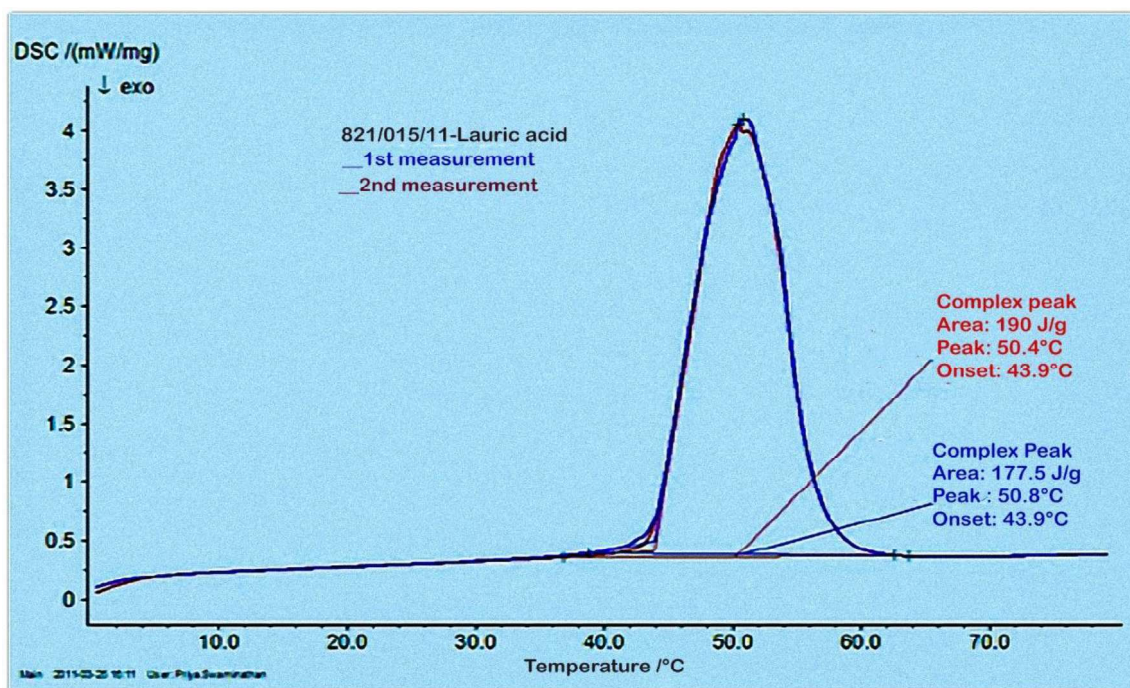


Figure 3. 10 DSC result of Lauric acid with melting point (onset) and latent heat (area)

Table 3. 3 List of thermophysical properties of Lauric acid

S.N.	Property		Value
1.	Latent heat of fusion		177.5-180 kJ/kg
2.	Melting point		43.9 °C
3.	Specific heat	Solid at 25°C	2.1 kJ/kg°C
		Liquid at 44°C	3 kJ/kg°C
4.	Thermal conductivity		0.16 W/m°C
5.	Density	Solid	1007 kg/m ³
		Liquid	863 kg/m ³