A detailed review on design and analysis of wick to enhance performance of passive solar still

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***Abstract*— In this paper, the design and performance of different types of wick type passive solar steel have been reviewed. The black cotton material is more effective compare to the other wick materials. The wick solar still has become more effective compared to simple basin. The moving cloth wick solar still with copper oxide nanoparticles has thermal efficiency of 84% for off-time of belt equal to 30 minutes. The maximum value of daily output is recorded 10.025 l/m2day for the floating wick type basin with a tracking system in June month. The single basin double slope solar still is designed with a unique way with hanging wick material. The hanging light black cotton material is more effective compared to jute material in single basin double slope solar still. The wick type passive solar still is more effective compare to conventional passive solar still.**

***Index Terms*— Solar still, floating wick, rotating wick, Hanging wick, Tracking system, Hourly Output, Daily Output**

I.INTRODUCTION

Solar distillation is a technique to produce pure drinking water from saline water. As we know that around 97% of the water is in the ocean, approximately 2% is present as an ice and only 1% fresh water is available for the plants, animal, and human life. The 1% water is available in rivers, lakes, and underground reservoirs. The requirement of fresh water will be increased day by day with increasing population of the world. The pure water can be produced by solar distillation, which we can be used for domestic, industrial, and commercial purposes. Day by day people are inventing the innovative techniques to produce pure drinkable water from saline water by using renewable energy like solar.

The water vapor is produced from the saline water of the sea due to evaporation through solar radiation in the atmosphere. The water vapor is rising with the air and make up clouds. The water droplet is formatted due to condensation at low temperature of the atmosphere. The water droplet is falling down in the form of rain on the earth. The technique to produce pure water from saline water is alike rain process in a device, which is called a solar still. It is a simple closed device. Many researchers have been working with passive and active solar still to get more output. The jute or cotton black cloth as a wick material is used in a solar still to increasing the evaporation rate and to get more output. Researchers have designed and developed solar stills with wick material to make them more effective.

Following are the various designs of wick type solar stills which are reviewed in this paper.

- Basin wick type solar still
- Wick type solar still with reflector
- Wick basin type solar still
- Floating cum tilted wick type still
- Inclined wick still with absorber
- Clothes moving wick type solar still
- Single basin double slope wick solar still

II. WORKING OF A WICK TYPE SOLAR STILL

The solar radiation falling on the glass cover of a solar still transmits from the glass cover to the wick surface, where it is absorbed. The water is heated through the wick surface and evaporated as vapour. The saturated vapour is condensed and converted into water droplets, is which collected in the drainage channel.

Basin wick type solar still

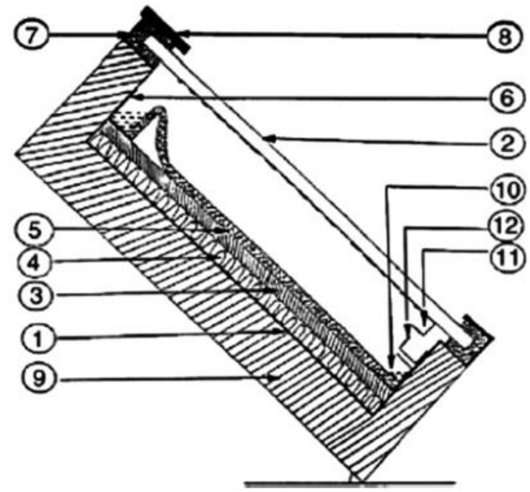
The researchers have developed wick type of solar still with different designs and different wick materials [1-3]. The floating jute material was used as a wick material [1,2]. The system consists of a simple solar still and it was covered with insulation. The jute material was floated on the basin water. The area of the wick was equal to the area of solar still basin. The jute material sucks water due to capillary action; the upper surface of the wick material is always wet. Water gets evaporated and converted into vapour which is condensed on inner glass surface and collected as a distilled water. The inclination of glass cover was kept as10° and observed output of solar still was recorded lower without insulation [1]. They also used 0.044 m thick insulation to reduce heat loss.

The experiments were tested with inclination of basin wick solar still at 10°, 20°, 30° and 40° by Sengar et al. [2]. The length of wick material was 0.632 m. They observed that output was recorded more with 10° inclination of basin during summer and with 40° inclination of basin during winter. The maximum yield recorded was 3.4 l/m2 at 10° inclination of basin wick solar still during summer.

The thermal capacity of jute wick is less, so the charcoal wick material was introduced in the tilted basin and analysed by Mahdi et al. [3]. The schematic of the design is shown in Figure 1. An option of changing angle of inclination of solar still basin was provided to absorb more solar radiation. They observed that the solar still efficiency is decreased from 38% to 20% with the salt concentration increased from 0.0% to 10%. Their observation shows that the wick type of solar still was more effective than convectional basin type solar still due to thermal capacity [1-3].

Wick type solar still with reflector

The corrugated wick type solar still with an inclined flat reflector was proposed by Matrawy et al. [4]. They developed simulation model for the proposed corrugated wick type solar still. They developed simulation model for the corrugated wick type solar still based on energy balance for the two main components. The simulated components included were the condensing surface (glass cover) and the evaporative one. The evaporative surface included was a part of the porous material above the water level beside the part of water surface exposed to the transmitted radiation (part of water surface was shaded by the corrugated surface). The 6 mm thick glass cover of solar still was kept with reflector. The dimensions of flat inclined stainless steel reflector were 0.5 m height and 0.8 m width. The slope of reflector can be changed to get maximum solar radiation as shown in Figure 2. The 2 mm thick black porous cloth material with corrugated shape was used as a wick material.



(1) galvanised steel tray, (2) glass cover, (3) support board, (4) polystyrene, (5) charcoal cloth, (6) aluminium channel, (7) rubber gasket, (8) steel strip, (9) styrofoam, (10) brine gutter, (11) distillate gutter, and (12) distillate outlet channel

Figure 1. Cross sectional view of the basin wick type solar still [3]

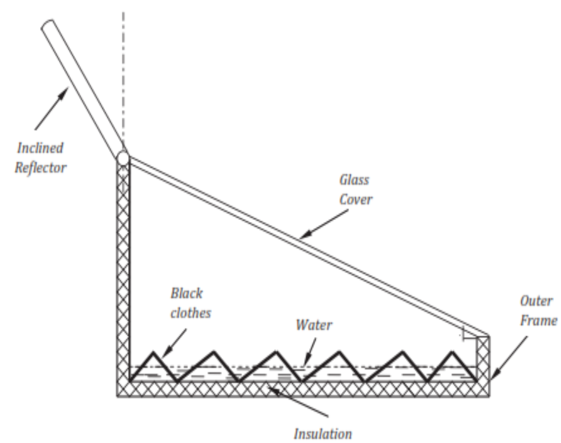


Figure 2. Proposed system of wick type solar still with reflector [4]

The observations were recorded for simple basin and wick basin simultaneously from 9.00 a.m. to 6.00 p.m. The observations were taken with 15-minute interval using programmed thermocouple data logger connected with PC. The maximum and minimum radiation were absorbed by reflector at 30° and 10° angle from vertical axis of reflector, respectively. The maximum value of temperature of porous material was recorded 87°C at 3 p.m. The calculated and measured value of temperature of glass cover were recorded

78°C and 74°C respectively. The value of productivity was recorded 0.93 kg/hr and 0.76 kg/hr for corrugated wick basin and simple basin respectively. The daily output was recorded 5.9 kg/m2 and 4.4 kg/m2 for corrugated wick basin and simple basin respectively.

Wick basin type solar still

The wick basin type solar still investigated by Minasian and Al-Karaghouli is shown in Figure 3 [5]. The still was made from 22-gauge galvanized iron sheet. The thickness of glass cover was 4 mm. The bottom and side were insulated. They connected two parts of convectional basin and wick basin to work together as a single one unit.

The area of convectional and wick type of solar still were 0.5 m2 and 1 m2 respectively. The angle of inclination was kept 15° and 25° for convectional and wick type solar still respectively. The black jute cloth was enclosed with a wooden frame in wick type solar still. The preheated water of the tilted wick type solar still was fed to convection basin type solar still through a pipe. They observed that the productivity of wick basin type solar still is 85% more than convectional basin type solar still and 43% more than wick type solar still.

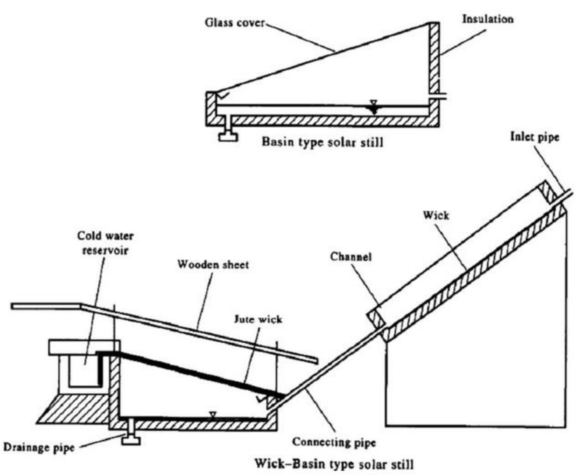


Figure 3 Schematic of wick basin type solar still [5].

Floating wick type solar still

A floating wick type solar still was proposed by Al-Karaghouli and Minasian [6] with blackened jute wick and aluminium black plate as a floating material was used inside the still by Safwat et al. [7]. The construction of solar still was simple and working was similar to the conventional type solar still. Al-Karaghouli and Minasian [6] tested three types of models (a) flat type basin (b) tilted wick type basin and (c) floating wick type basin as shown in Figure 4. The basin was metallic with 0.8 m × 0.6 m area. The 4 mm thick glass cover of solar still was kept with 12° inclination. The basin beneath was covered by 2 cm thick wooden frames. The bottom and side wall of solar still were covered by 5 cm thick polystyrene insulation. The flat type basin was painted with an ordinary black paint. The wicks used in the other two stills were with a special black dye. A blackened jute wick was floated with a 2 cm polystyrene sheet in floating wick type basin. They also used tracking system during testing to get more solar radiation. The maximum value of daily output recorded were 5.103, 3.595 and 6.019 l/m2day for flat type basin, tilted wick type basin and floating wick type basin respectively in June month. They observed 77% higher daily output for floating wick type basin in June month compared to January month. The maximum value of daily output were recorded as 7.1, 4.669 and 10.025 l/m2day for flat type basin, tilted wick type basin and floating wick type basin respectively in June month with using of tracking system. They observed 54% higher output while using the tracking system for floating wick type basin.

Safwat et al. [7] used the floating perforated black 0.5 mm thick aluminium plate. The energy balance equations were derived for glass cover, moist air, water liner, floating black plate, top layer of water block, water layer, bottom layer of the water block and basin liner. The experiments were done with 3 cm and 6 cm saline water depth in solar still. They observed higher productivity of solar still with increased depth of saline water.

Floating cum tilted wick type stills

A floating cum tilted wick type solar still was proposed by Janarthanan et al. [8,9] and Mani et al. [10]. The tilted wick and floating wick surfaces were absorbing heat from solar radiation, which was transmitted from glass cover of solar still. The corrugated floating wick was always coinciding with the upper level of the water in the reservoir. The tilted wick surface was always wet due to capillary action. The heat transfer was occurred from the tilted wick surface and floating wick surfaces to the glass cover of solar still by evaporation, convection, and radiation.

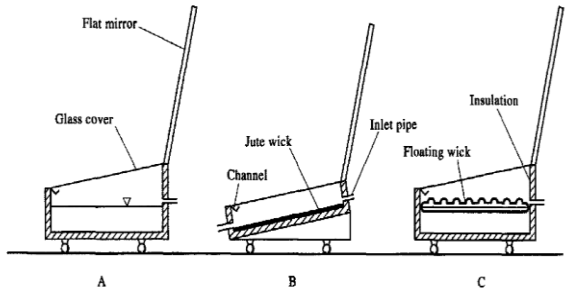


Figure 4. Experimental diagram of (a) flat type basin (b) tilted wick type basin and (c) floating wick type basin solar stills [6]

A theoretical model was proposed by Janarthanan et al. [8,9]. The sectional view and energy flow diagram for a closed cycle system of a floating cum tilted wick solar still is shown in Figure 5. The energy balance equations were written for the glass cover, floating wick water surface and tilted wick water surface [8] and the same energy balance equation were written for the effect of water flowing over the glass cover [9]. They proposed theoretical analysis for closed and open cycle systems [8], water flow over the glass cover of solar still [9] and the performance study was done during the winter season [10]. The schematic diagram and sectional view of the system proposed by Mani et al. [10] are shown in figures 6 and 7 respectively. The blackened jute wick was prepared in a corrugated shape which was spread along with 15° [8,9] and 13° [10] tilted portion. The floated wick in the water reservoir inside the solar still was with a thermocol sheet of thickness 2.5 cm [8,9] and 2 cm [10]. The water does not overflow on the tilted portion as the water level was maintained 0.25 cm below the top of the reservoir.

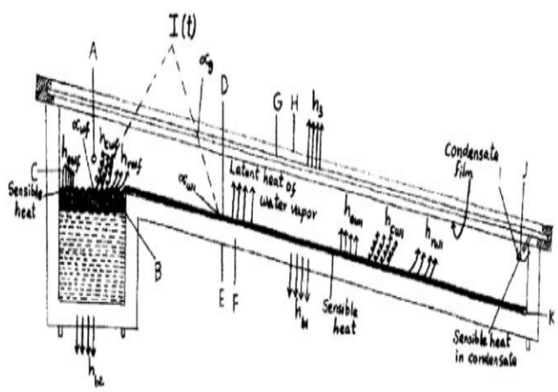


Figure 5. Energy flow diagram for a closed cycle system of a floating tilted wick solar still [8]

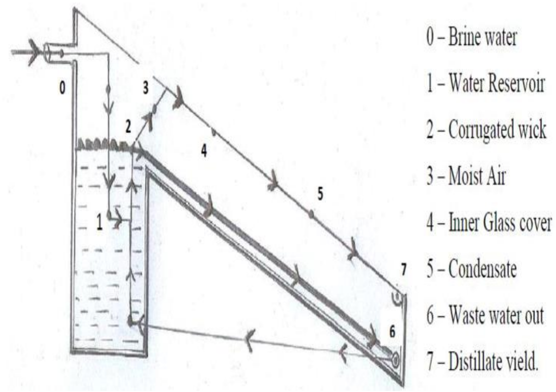


Figure 6. Schematic diagram of a floating cum tilted wick type solar still [10]

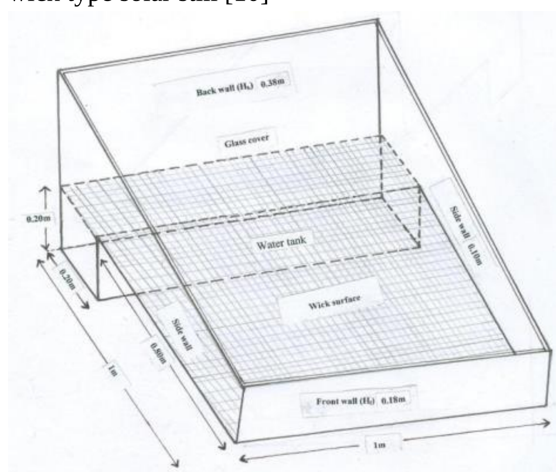


Figure 7. Proposed cross sectional view of floating cum tilted wick type solar still system [10]

Overall efficiency for the closed cycle system was higher compared to the open cycle system [8]. The optimum water flow rate over the glass cover was 1.5 m/s to get effective output [9]. The evaporation and condensation rate was increased due to water flowing over the glass cover during the working hours of the system. The theoretical hourly output, hourly efficiency and overall efficiency were recorded as 400 ml/hr, 45% and 26.19% respectively [10]. The maximum hourly output was recorded as 348 ml/hr and hourly efficiency was found as 39.98% at 13.00 hr. The daily output was recorded 3.33 litre and the maximum efficiency obtained was 25.76% for this system.

Inclined wick still with absorber

Inclined basin solar still was fabricated and tested at 30° inclination by Hansen et al. [11]. The dimensions of the still basin were 1 m × 0.75 m × 0.157 m made from mild steel. The glass cover thickness was kept 4 mm. The saline water was distributed by a pipe with 20 holes drilled on it at equal intervals. The water falls through those holes on the absorber or wick material and create a layer of water on it. The water was evaporated by solar radiation. The schematic of system is shown in Figure 8.

Different wick materials of wood pulp paper, water coral and polystyrene sponge were kept to keep the entire surface of the basin wet. Three different types of absorber viz. flat plate absorber made from 3 mm steel plate, rectangular stepped absorber plate made from 2 mm thick aluminium sheet, and wire absorber made from 1 mm thick aluminium wire were experimented.

The observations were recorded with nine different configurations with three wicks and three absorbers as shown in Figure 9. The minimum and maximum basin temperatures were recorded 48°C and 69°C for flat absorber with wood pulp paper wick and wire mesh absorber with water coral wick respectively at 2.30 p.m. The hourly yield was recorded as 320 ml, 345 ml and 360 ml for flat, stepped and wire mesh absorber with water coral wick material respectively. The daily yield was recorded as 2500 ml/day, 2875 ml/day and 3230 ml/day for flat, stepped and wire mesh absorber with wood pulp paper respectively. The daily yield was recorded 3140 ml/day, 3550 ml/day and 3950 ml/day for flat, stepped and wire mesh absorber with wood polystyrene sponge respectively.

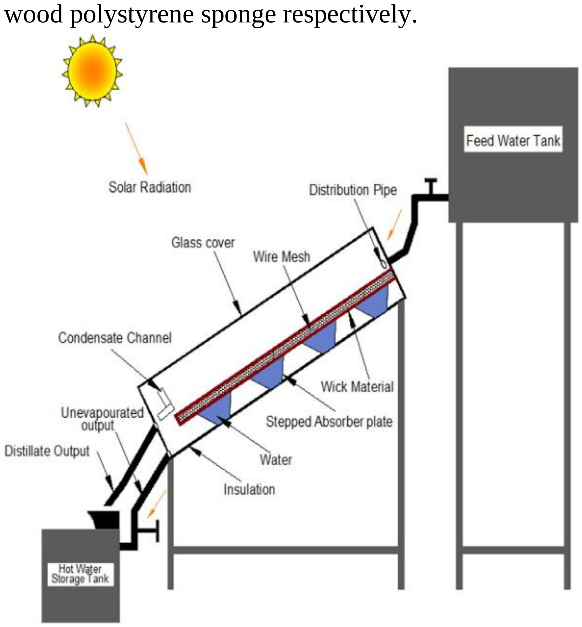


Figure 8. Schematic diagram of inclined wick solar still with absorber [11]

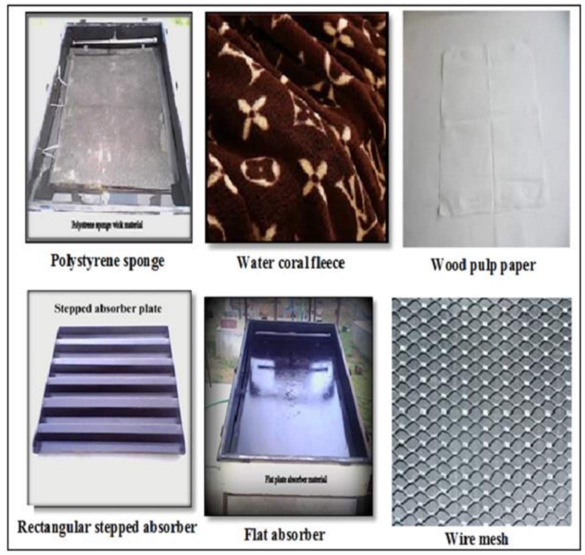


Figure 9. Photographic view of three wick materials and three absorber designs [11]

The daily yield recorded was 3635 ml/day, 3930 ml/day and 4280 ml/day for flat, stepped and wire mesh absorber with water coral respectively. The maximum productivity was recorded for wire mesh absorber with water coral wick material due to 69.67% of porosity, 25 seconds of absorbency, 10 mm/hr of capillarity rise and 34.21 W/m K heat transfer coefficient properties of coral wick material.

Clothes moving wick type solar still

A new model of solar still with moving clothes wick was proposed by Helmy et al. [12] The still basin was made from wooden box with 80 cm length, 60 cm width and 15 cm depth from inside. The 3 mm thick glass cover was kept with 30° angle facing south. The moving black cloth was connected with two roller copper tubes and belt with mirror at one side and without mirror in other side. The copper tubes were rotated by DC motor as shown in Figure 10 [12].

The moving cloth wick solar still with modification was also proposed by Abdullah et al. [13]. The solar still was fabricated with black painted basin having area of 0.50 m2 made of 1.5 mm galvanized steel sheets. The 3 cm thick wooden box was used as a container for basin of solar still. The black jute cloth was connected with four aluminium rollers and wick belt of 3.4 m long and 0.46 m wide. The rollers and belt were rotated by DC motor connected with PV system. The top of the basin was covered with glass cover with aluminium frame inclined at 39° facing south as shown in Figure 11 [13].

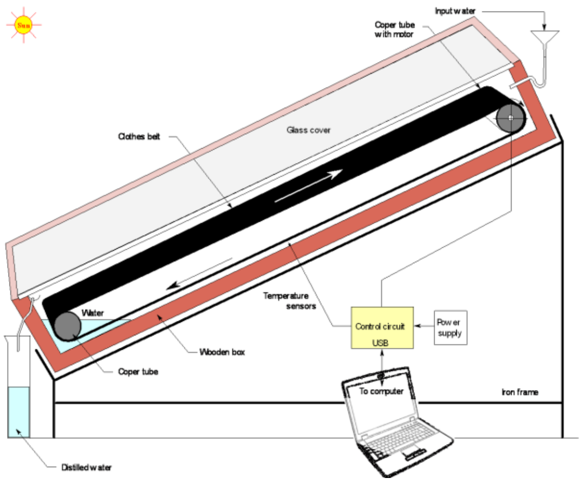
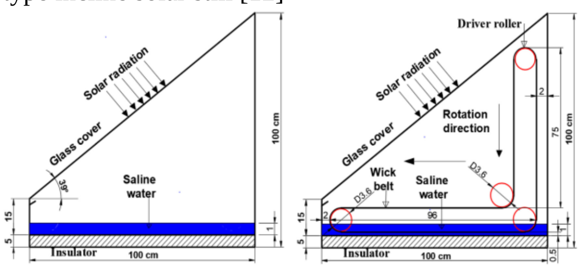


Figure 10. Schematic diagram of clothes moving wick type incline solar still [12]



a. The conventional solar still b. The rotating wick solar still

Figure 11. Schematic diagram of the conventional and the rotating wick type flat solar stills [13]

The observations were recorded for inner glass surface, basin and ambient temperatures. The solar radiation data and distilled water output was recorded at every 30 minutes interval [12].

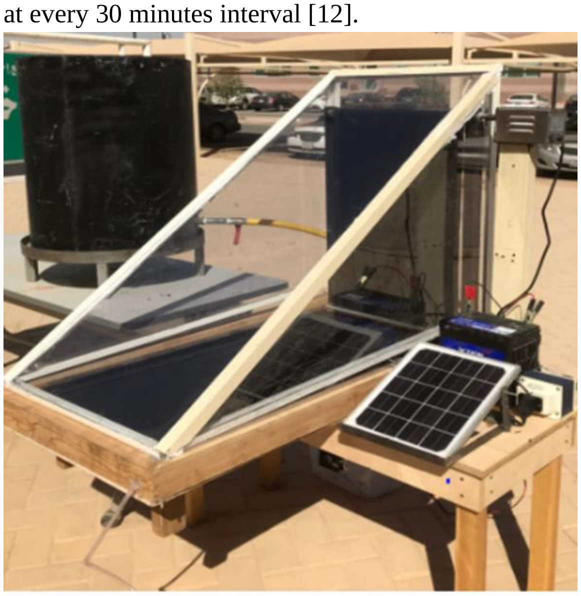


Figure 12. Experiment set up of the rotating wick type flat solar stills [13]

The value of parameters such as ambient speed, solar intensity and temperatures of glass, ambient and water were measured from 08:00 am to 06:00 pm.

The distilled water output was measured hourly. The saline water depth kept 1 cm for experiment. The experiments were performed in two groups (a) the effect of different rotating periods of the wick belt was tested and (b) the effect of used copper oxide nanoparticles in wick solar still was tested. The experiment set up is shown in Figure 12 [13].

The results were recorded for 5, 10, 15, 20, 30, 40, 50 and 60 minutes of the OFF time of DC motor [12,13] and ON time of DC motor was 30 seconds [12] and 5 minutes [13]. The results were also recorded for zero minute OFF time of DC motor, means the DC motor was continuously ON [12].

The wick material was immersed in water, when the motor was ON and the wet clothes was subjected to solar radiation, when the motor was OFF. The maximum value of yield and thermal efficiency were recorded for 30 seconds of ON time and 25 minutes OFF time of DC motor [12].

The hourly yield and daily yield for rotating cloth wick solar still were recorded 1000 ml and 7080 ml/m2 respectively under zero OFF time of moving wick and for conventional solar still the same were recorded as 420 ml and 2080 ml/m2 respectively. The maximum value of hourly yield and daily yield were recorded as 1110 ml and 8780 ml/m2 respectively for rotating cloth wick solar still under 30 minutes OFF time and 5 minutes ON time and 360 ml and 2210 ml/m2 respectively for conventional solar still. The maximum value of hourly yield and daily yield with use of copper oxide nanoparticles were recorded 1200 ml and 8625 ml/m2 respectively for rotating cloth wick solar still under zero OFF time and 460 ml and 2300 ml/m2 respectively for conventional solar still. The thermal efficiency of rotating wick solar still was found 76.5%, 84% and 73.5% with copper oxide nanoparticles under OFF time of moving wick as zero, 30 and 60 minutes respectively. The same was and 74%, 82%, 72% without nanoparticles under OFF time of moving wick as zero, 30 and 60 minutes respectively. The best performance was recorded at OFF time of 30 minutes and ON time of 5 minutes for both conditions. The estimated cost of distilled water was found 0.05$ and 0.027$ for conventional and rotating cloth wick solar still [13].

Single basin double slope wick solar still

Murugavel et al. [14] proposed single basin double slope solar still with wick material. The solar still was fabricated from mild steel plate with 1.75 m2 area of basin. The 4 mm thick two glasses were kept at 30° from both sides. The schematic diagram is shown in Figure 13.

The experiments were performed with 3.4 kg of saline water in basin with wick materials like light cotton cloth, light jute cloth and sponge sheet of 2 mm thickness and porous materials like washed natural rock with size of 9.525 mm × 6.35 mm and quartzite rock with size of 9.525 mm. The observations were recorded for 24 hr at an interval of 15 minutes. The stills productivity is depended on parameters like solar radiation, wind velocity, atmospheric temperature, basin water depth, glass cover material, thickness, its inclination and the heat capacity of the still. The maximum production rate was recorded for light cotton cloth compared to the other materials.

The basin water temperature of solar still with black cotton material was recorded maximum at 1.00 p.m. compared to other wick materials.

Pal et al. [15] fabricated the solar still basin with 2 m2 area and North wall were made up from 5 mm thick Fibre Reinforced Plastic (FRP) as shown in Figure 14. Three walls of East, West and South were made up from a 3 mm thick transparent acrylic sheet. The 4 mm thick two glass cover were tilted at 15°.

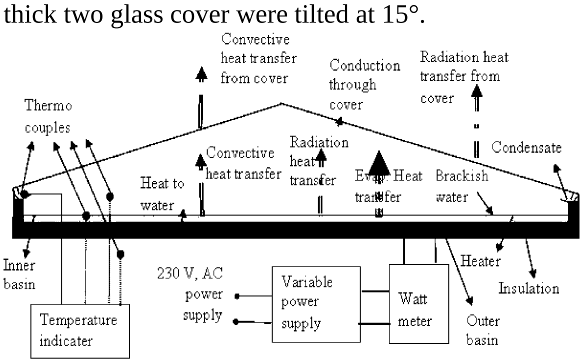
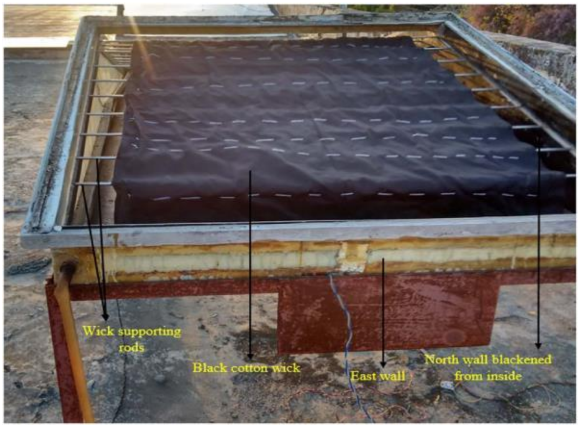


Figure 13. Sectional and energy flow diagram of double slope single basin wick solar still [14]

The modified basin type double slope multi wick solar still (MBDSMWSS) was fabricated with 19 hanging wicks with an increasing pattern of heights 10 cm to 37 cm towards the centre of solar still and then decreasing pattern of height 37 cm to 10 cm towards the wall of solar still. The maximum height of hanging wick was at centre and minimum height of hanging wick was at on E and W of side wall of still. The horizontal gap between the two consecutive wicks was 10 cm. In MBDSMWSS, 19 rods supported the layers of wick and maintained the gap between two wicks and also maintained continuous supply of water to the top surface of wick. The photographs of MBDSMWSS with jute and black cotton wick material are shown in Figure 15 (a) and (b) respectively. The observations were recorded for 24 hrs with 5 cm water depth. The maximum solar radiation measured was 1150 W/ m2 in May 2016 at 11.00 hrs and 720 W/ m2 in December 2015 at 13.00 hrs. In December 2015, the maximum value of daily yield obtained was 5017 ml/day (2.50 l/m2/day) and 4418 ml/day (2.21 l/m2/day) for 1 cm and 2 cm saline water depth respectively with jute wick. In March 2016, the maximum value of daily yield obtained was 7040 ml/day (3.52 l/m2/day) and 7740 ml/day (3.87 l/m2/day) with jute and black cotton wick respectively with 2 cm saline water depth. In May 2016, the maximum value of daily yield recorded was 9012 ml/day (4.5 l/m2/day) with black cotton wick with 2 cm saline water depth. The overall efficiency was found 20.94% and 28.27% for jute and black cotton wick respectively. The optimum annual cost of distilled water per kg and per kWh with black cotton wick were Rs. 1.51 (0.023 US$) and Rs. 2.41 (0.037 US$) respectively with 12% of interest rate for 15 years life of the system.

Figure 14 Photograph of the modified basin type double slope multi wick solar (MBDSMWSS) [15].

(a)



(b)

Figure 15 Photograph of MBDSMWSS (a) with jute wick (b) with black cotton wick [15].

III. DISCUSSION AND CONCLUSION

Based on the studies of various designs of wick type solar still, following conclusions are drawn.

1. For a basin wick type solar still, the maximum yield recorded was 3.4 l/m2 at 10° inclination for jute material during summer.
2. The charcoal wick is more effective than jute wick due to thermal capacity.
3. The maximum temperature of black cloth porous wick was recorded as 87°C at 3 p.m. in a wick solar still with reflector. The daily output recorded was 5.9 kg/m2.
4. The productivity of wick basin type solar still was 85% higher than convectional basin type solar still and was 43% more than wick type solar still.
5. The maximum value of daily output recorded was 6.019 l/m2 and 10.025 l/m2 for floating wick type basin without tracking system and with tacking system respectively in June month. These values were 77% and 54% higher compared to January month.
6. The productivity of solar still was increased by 15% and 40% when the depth of the saline water was kept 3 cm and 6 cm respectively with aluminium plate as floating wick.
7. For floating cum tilted wick type solar still system, the maximum value of hourly output and hourly efficiency were recorded as 0.348 l/hr and 39.98% at 13.00 hr. The daily output was 3.33 litre and the maximum efficiency obtained was 25.76%.
8. The maximum basin temperature was recorded 69°C for wire mesh absorber with water coal wick material at 2.30 p.m. The hourly and daily yields were recorded as 360 ml and 4280 ml/day respectively.
9. The hourly yield was recorded as 1 litre and 1.2 litre for rotating wick solar still without and with copper oxide nanoparticles under zero OFF time. The thermal efficiency under 30 min OFF time was found 82% and 84% for rotating cloth wick solar still without and with copper oxide nanoparticles respectively. The estimated cost of distilled water was found 0.027$ for rotating cloth wick solar still.
10. The maximum production rate was recorded for light cotton cloth compared to any other materials in hanging wick double slope single basin solar still. The maximum value of daily yield was 9.012 l/day (4.5 l/m2/day) with black cotton wick with 2 cm saline water depth in May 2016. The overall efficiency for jute and black cotton wick was found 20.94% and 28.27% respectively.

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