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Solar distillation with single basin solar still using sensible heat storage materials

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HIGHLIGHTS

- Performance of single slope single basin passive solar still integrated with thermal storage was experimentally investigated.
- Its performance is compared with that of conventional still.
- The effect of varying water depth and storage material depth on productivity was studied.
- Thermal storage improved still performance in summer.

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ABSTRACT

In this experimental study, performance of a single slope single basin solar still have been analyzed with sand and servotherm medium oil (heat transfer oil) as passive storage material beneath the basin liner. The influence of varying depth of storage material for a given quantity of basin water is investigated and compared with the conventional solar still for same parameters. The experiments were conducted at Chandrapur city (19° 57′N, 79° 17′ E) of Maharashtra state, India, during summer months. For both, sand and Servotherm medium oil, lower storage depths were found to yield higher productivity compared to conventional still. Also, with passive storage, overnight productivity was found enhanced while daylight productivity lowered.

1. Introduction

Many countries face acute shortage of potable water in remote and arid regions. Saline water is unsuitable for drinking, domestic, agricultural and industrial applications. Existing desalination methods are energy intensive and hence solar distillation systems offer economic and green alternative. Solar stills have lower productivity and thus researchers have shown keen interest to improve it by various means such as providing internal and external condensers, reflectors, multiple basins, adding dyes in the basin, using absorbing materials, wick type, regenerative type etc. [1–5]. Amongst various design, single basin single slope solar stills are simple, easy to fabricate and can be operated even by unskilled workers [6]. Passive storage beneath the liner can be used to store heat during sunshine hours and discharge during the off-shine hours. Sensible and latent heat storage offers great opportunities with merits and demerits associated with their use [7].

Sensible heat storage materials have been investigated by various researchers. K Kalidasa Murugavel et al. [8] used quartzite rock, red brick pieces, cement concrete pieces, washed stones and iron scraps in the basin with minimum water depth. Quartzite rock with19 mm size was found to be best option. Glass balls, rubber and gravel as a thermal storage material have been tested by Nafey et al. [9]. Velmurugan et al. [10] experimented with sand, gravel, sponges, pebbles and black rubber in fin type single basin solar still.

Study revealed that with sand as storage material the output increases by 14% compared to the conventional still. Zeinab S. Abdel – Rehim et al. [11] used glass balls packed layer at the bottom of the basin and found 5% improvement in efficiency. Z.M. Omara et al. [12] conducted experiment using black and yellow sand beds inside the basin. Effect of variation of sand bed heights and water on the productivity was studied. Black sand bed with 0.01 m height resulted in 42% gain over conventional solar still, with water height of 0.01 m. Yellow Sand yielded 17% higher productivity than conventional still. A simulation study with thin sand layer beneath basin and a water flow yielded higher in a active solar still as reported by EL Sebaii et al. [13]. M Sakthivel et al. [14] used 6 mm black granite gravel inside the basin

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Table 1
Thermo physical properties of storage materials.

Property	Sand	Servotherm medium oil
Density kg/m^3	1640	840
Specific heat kJ/kg K	0.830	2.22
Conductivity W/m K	0.13	0.123

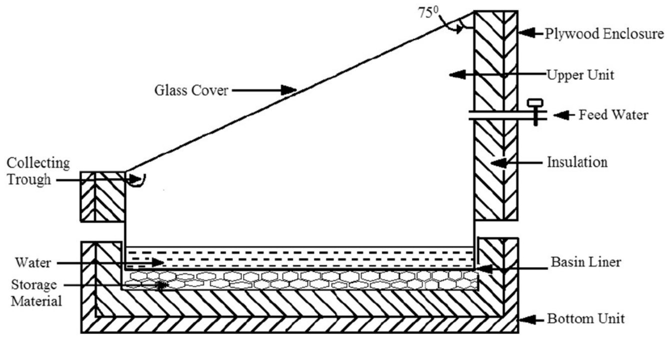

Fig. 1. Schematic of the still.

Table 2
Uncertainties involved in measurement of parameters.

	Temperature	Pyranometer	Measuring jar	Anemometer
Accuracy	±1.0 °C	±13.27 W/m^2	1% full scale	±0.1 m/s
Fluctuation	<±1.0 °C	<13.27 W/m^2	<1% full scale	<0.1 m/s
Uncertainty	±1.0 °C	±13.27 W/m^2	1%	±0.1 m/s
Minimum value measured	10 °C (temp difference)	167 W/m^2	One fourth of the jar	0.5 m/s
Uncertainty %	10%	6.7%	4.0%	5.0%

which improved the daily productivity by 20%. Farshad Farshchi Tabrizi et al. [15] used 12 cm sand bed below the basin liner. The integrated heat reservoir resulted in significant rise in overnight productivity and better performance on cloudy days. Overnight productivity was found to be around 12% of the daily productivity. Pinakeen Patel [17] experimented on a modified passive steel with thermic fluid and found 11.24% higher productivity over conventional solar still corresponding to 2 cm water depth. Also the effect of frontal height was experimentally investigated and best results were observed for the height in the range 50–70 mm. Alva G. et al. [18] have discussed in detail various thermal energy storage materials and their suitability to solar applications. The advantage of liquid thermal storage is highlighted owing to buoyancy effect leading to thermal gradient. Sharshir S W et al. [19] stated the use of cuprous oxide and aluminium oxide nano particles improving the productivity by 133% and 125% respectively.

It is observed that around 16% heat is lost through the bottom [16] so there is a fit case for introducing heat storage beneath basin liner. Sand and thermic oils have been considered in the present study as storage materials. Very little work is reported in the literature on thermic oil as heat storage material beneath the basin. Higher depth of storage results in lower temperature resulting in lower productivity. The lower depths of storage have not been reported in literature. The objective of the present investigation is to compare the performance of sensible heat storage materials such as sand (solid, conducting) and servotherm medium oil (liquid, convecting) over the conventional solar still. The thermo physical properties of storage materials are given in Table. 1.

As the still operates below 90 °C and flash temperature of oil is 208 °C thus there is no danger of fire. The storage quantity used being less, the cost is also less. Sand from rivers is available in abundance and has very low price. Experiments were conducted at Chandrapur city (19° 57′N, 79° 17′E), Maharashtra state in the month of May 2014. This place has hot and dry conditions in summer months and has around 13 sunshine hours per day.

The daily, daylight and overnight productivities of solar stills charged with different quantities of sand and servotherm medium oil (SM oil) are compared with the performance of the base unit i.e. solar still without storage element. Experiments were conducted for various depths of water in the basin.

2. Experimental set-up

Schematic of experimental set-up is shown in Fig.1. The still basin has a square shape and measures 71 cm × 71 cm i.e. 0.5 m^2 area. Mild steel sheet of 1.2 mm thickness is used to fabricate the upper unit containing basin and bottom unit containing storage tray. Basin bottom is painted black to improve its absorption characteristics. All other surfaces are painted white for better reflections. To reduce heat loss from the still, 50 mm thick mineral wool ($k = 0.036$ W/m K) is used on bottom and lateral surfaces. It is encased in a 12 mm thick marine plywood to add rigidity to the unit. The gap between upper unit and bottom unit is filled with asbestos ropes and cotton strips to minimize heat losses. A 4 mm thick plain window glass is used as a glazing cover and makes an angle of 15° with the horizontal plane. It is fitted with silicone sealant on the collar of the still to avoid potential vapor leaks. Silicone after curing is observed to be flexible and provides a perfect vapor seal during daytime temperature variations and seasonal changes. It has better adhesive properties for both mildsteel and glass. Vapors condensing on the glass cover are collected in a metallic semi circular trough provided at the lower end of glass cover. Back high side wall is provided with tap feed water arrangement and also temperature sensors being inserted through an opening to measure still temperatures at various locations. Distillate collected in the trough is taken through a flexible hose to bottles with over 1000 ml capacity. The distillate was measured with different capacity calibrated jars having the least count equal to 1% of its full size capacity. The collection time was measured with a digital watch. Different capacity jars helped in maintaining uncertainty limit within ±4.0%.

It was thus mandatory to build multiple units to store different storage masses so that results can be directly compared on day to day or hour to hour basis. Fig. 2 shows the actual photographs of the unit fabricated under present investigation. Upper unit housing basin (a), bottom unit (b) containing storage tray and assembled still (c) can be

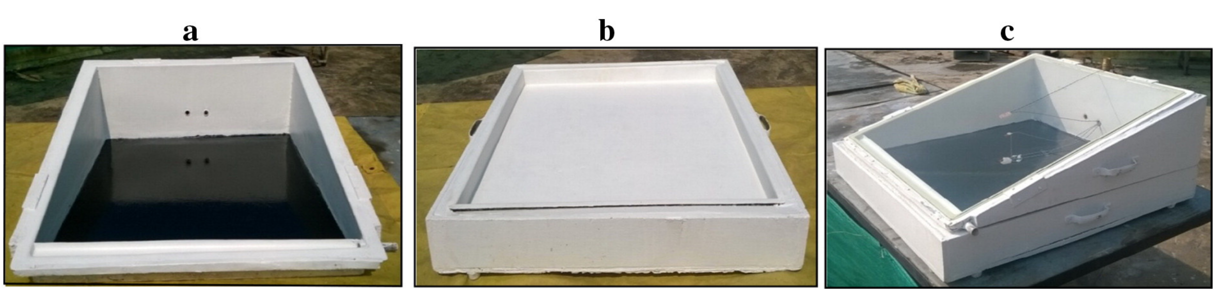

Fig. 2. Photographs of upper unit (a), bottom unit (b),assembled still (c).