

Productivity Enhancement of Solar Still – A Review

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Abstract: Adequate quality and reliability of drinking water supply is fundamental needed one. Along with food and air, water is a necessity for human. Fresh water is obtained from lakes, rivers and ponds but it becoming scarce because of industrial effluent, sewage and population explosion. Solar still is a distillation of brackish or saline water, wherever it is available, is a good method to obtain fresh water by exposing thin layer of salt water to solar radiation and water vaporized from the brine, condensed on the underside of a sloped transparent cover in such a way that it can be collected in receiving troughs at the end of the still. Active and passive solar stills are the major type of solar stills. Methodologies used in the past years to improve the productivity of solar still build based on variations in geometry, materials; methods of construction and operation were reviewed in this paper. Techniques to improve the performance of the solar stills are also investigated in this paper.

Keywords: Solar Still, PCM, Energy Storage Materials, Integration methods.

1. Introduction

In earlier centuries, the possible method of getting safer portable water was by using a conventional boiler to heat the water to saturation limit and condensing the steam or vapour to freshwater. Desalination in membrane process is converting waste or salt water into useful one, by pumping the input water which consumes 20% of electrical energy. Furthermore, retreatment of saline water is required in order to avoid fouling effect on the membrane surface.

Solar desalination appears to be the easiest method of producing potable water. During the 19th century, basin type solar stills were designed and fabricated to get fresh water from saline water using solar energy. Many review papers have addressed only on the prospective design configuration. Basin type solar still is one of the breakthroughs of the 20th century, as many researchers carried out experiments to augment the freshwater yield. For augmentation purpose, many used integrating methodologies of energy storage materials and PCM (Phase Change Materials) techniques which are unaffordable from the economic aspect for people living in the rural areas. During the 21st century, change in geometry of solar still appeared to be important phenomenon on improving the yield [1]–[11].

2. Solar still with phase change material (PCM)

A phase change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid thus, PCMs are classified as latent heat storage (LHS) units. As it is seen, the system includes a single slope solar distillation system with phase change materials under the water basin liner and ETC in which water is connected to the basin water (Fig.1.a). The system is also considered with a semitransparent photovoltaic module replacing transparent glass in the conventional solar still. The basin liner is isolated in order to decrease the wasted heat from sides and the bottom. An evacuated tube collector installed at the angle of 45 degrees. The collector consists of concentric tubes with absorber (inner) and outer diameters of 44mm and 47mm respectively and length of 1.4 m. These tubes are installed over a diffuse reflector with equal distance from each other (centre-line distance of 0.07 m). In each tube, inner cylinder is filled with water and its outside surface is blackened in order to maximum solar radiation absorption. In addition, a vacuum gap is designed between the two concentric cylinders so as to reduce the wasted heat. ETC water temperature is higher in comparison to the basin water, so its density is lower.

A. Mechanism of heat transfer in PCM (charging and discharging)

The advantage of the phase change material as a heat storage system is the phase change zone (latent heat). The PCM temperature will be constant during the transformation from solid to liquid may be small while the storage energy is very large. This is due to the fixation of the melting temperature in the phase change zone. This phenomenon gives the PCM the advantage as an energy storage medium (charging) at low temperature level which is suitable to solar energy system. The storage energy mechanism within the PCM goes through three consequence steps. Sensible heating storage till the melting temperature, latent heating storage until the PCM is fully melted and finally sensible heating storage (degree of superheating). So, the PCM plays as a heat source (discharging) for the basin water at low solar radiation periods (night hours).

B. Experimental approaches to improving the efficiency

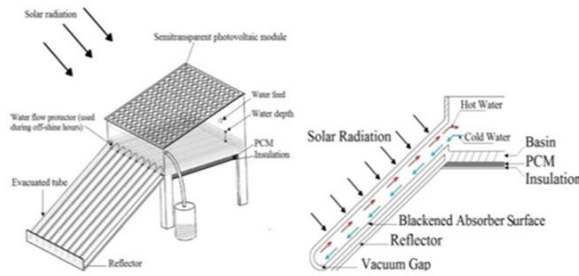


Fig. 1. Schematic diagram of a solar still integrated with ETC, semitransparent PV module and PCM, b. Schematic diagram of thermo siphon process in single tube

The experimental setup consists of a basin with an area of 1 m² and a glass area of 1.1 m². The glass is placed at the top of the solar still with an inclination of 13° so that the water droplets formed on the smooth surface glides down and gets collected in the distilled water collector placed at the end of the glass

and is inclined at an angle of 13° with the horizon in our experiment. Fig. 3 shows the solar still with sponge as material for increasing the surface area of water. The dimension of each sponge is 0.1 m, 0.075 m, 0.075 m and a total of 15 sponges were used in the experiment.

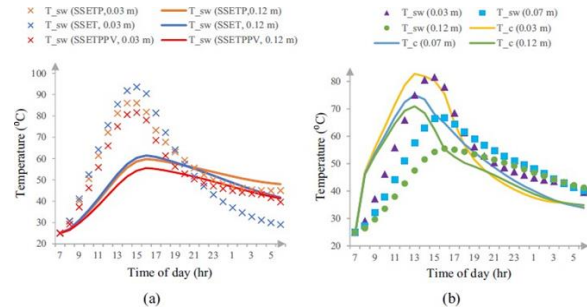


Fig. 2. Variation of the basin water temperature for 0.03 and 0.12m water depths, b. Variation of the basin water and PV temperatures for 0.03, 0.07 and 0.12m water depths.

Table 1
 Thermo physical properties of some typical PCMs

PCM	Melting point T _m (°c)	Specific heat of solid/ liquid (KJ/Kg)	Density of solid/ liquid (kg/m ³)	Thermal conductivity of solid/ liquid (W/m ² C)	Heat of fusion (KJ/Kg)
Paraffin wax	56	2.95/2.51	818/760	0.24/0.24	226
Gallium	29.78	0.372/0.397	6094.7/5903.7	33.68/33.49	80.16
Paraffin RT44HC	41-45	2.0	780/760	0.2	225

surface. Flow control valve is provided at the inlet for the water fed to basin. The water mass is controlled by feeding water into the basin after evaporation from the surface of water. Drain pipe with control valve is provided at the bottom of the solar still for the easy removal of excess saline water and during the cleaning process. In our experiment two different approaches are employed for improving the yield of solar still namely, (i) use of sensible heat energy storage with low cost and (ii) use of sponge inside the basin for capillary effect. Both the methods are used to increase the surface of water with solar intensity for instant evaporation from the surface. The Fig. 1, shows the schematic diagram of a conventional single slope solar still with spherical ball salt heat storage. The thermal conductivity and specific heat capacity of salt are more in comparison with other sensible or latent heat storage materials. Some latent heat storage mediums such as paraffin wax [49], [50], lauric acid, gubular's salt are very expensive. As salt appears to be an excellent sensible heat storage, it is encapsulated in spherical balls of diameter 62.3 mm made of plastic material (Fig. 3). Each ball is filled with 127 g of rock salt and placed at a distance of 200 mm in the longitudinal and transverse direction. Velmurugan et al. [12]-[15] investigated a similar conventional solar still with fins and fitted with sponges to increase the surface area of water. The replacement of corroded fins and spoiled sponges are frequently carried out to maintain the quality of water condensed in the glass. Sponge loses its porosity due to the trapping of salt in the pores, and the bad odour from the sponges will affect the quality of condensed water. The experiments are carried out in the North– South orientation while the glass is inclined facing the south direction

3. Solar still with thermal energy storage materials

A. Basic principle of use of thermal energy storage materials inside solar still

As we all know that, solar radiation is at the highest position between 12:00 and 01:00pm. Solar still efficiency is dependent on the solar energy. Hence, the distillate output of solar still should be higher between the 12:00 and 01:00pm. But, during such time period, water temperature inside the solar still remains higher due to higher amount of solar rays incident on the water, and also water vapour formation is also higher. Water vapour possesses a lower density, hence it moves upwards. Between the glass cover and water is always remains present, hence temperature of the air þ vapour mixture increased and which .Solar still distillate output depends on the temperature difference between water and inner glass cover temperature, hence due to higher water and inner glass covert temperature, enhancement in distillate output is not increased. Hence, touse excess energy, thermal energy storage materials is employed, which keeps the excess thermal energy and release during off-sunshine hours for increment in distillate output and efficiency.

B. Various thermal energy storage materials in the solar still

Energy storage materials store excess heat during the sunshine Hours and release heat during off-sunshine hours; Hence, the distillate output of a solar still is increased by the use of various energy absorbing materials.

1) Dyes

The analytical and experimental study on the effect of adding

dyes to a solar distillation unit. Different dyes such as black naphthylamine, red carmoisine and dark green dye are used.

2) *Black rubber matt, black ink and black dye*

The capacity of different storage materials used in a solar still to enhance the productivity of distilled water. Black rubber matt, black ink and black dyes were used in the experiment.

3) *Different sizes of black rubber and dark gravel*

For the investigation of the productivity of a solar still, used black rubber and black gravel of different thickness (2, 6 and 10 mm, and 7–12, 12– 20 and 20–30 mm, respectively) as energy storage materials. Black rubber with a size of 10 mm thickness improved the productivity by 20% at brine volume condition 60 l/m² and black gravel with a size of 20–30 mm improved the productivity by 19% at brine volume condition 20 l/m². Also, black gravel absorbs and releases incident solar energy faster than black rubber.

4) *Charcoal particles*

It is used a specially designed solar still. Different sizes of charcoal particles (coarse, medium and fine) were used in this experiment to investigate the still's productivity. Results were obtained at different flow rates of brine water.

5) *Energy storage material mixture*

Energy storage material mixtures. The material was a mix of paraffin wax, paraffin oil and water in which Aluminum turnings were added. The solar still parts were planned with different ingredients such as aluminum, galvanized iron and copper.

6) *Sponge cubes*

Sponge cubes of different sizes in a still basin to study the effect of sponge cubes on distillate production (yield). Yellow sponge, black sponge, black steel and black coals were used in the experiment.

7) *Black coated and uncoated metallic wiry sponges, and black rocks*

The different types of storage materials such as black coated and uncoated metallic wiry sponges, and black rocks to examine their effect on the productivity of solar stills.

8) *Small and large size of different materials (quartzite rock, red brick pieces, cement, concrete pieces, washed stones and iron scraps).*

Different sizes of small and large materials such as quartzite rock, red brick pieces, cement, concrete pieces, washed stone and iron scrap during an experiment to investigate the effect of energy storage materials is increases the productivity of single basin, double slope and minimum basin depth solar stills.

9) *Jute cloth*

Jute cloth as an energy storage medium. The experiments

were conducted on a conventional single slope solar still (fig.6) and on a regenerative solar still with jute cloth. In the regenerative solar still, jute cloth was kept vertically in the middle of basin saline water and tied to the rearward wall of the still.

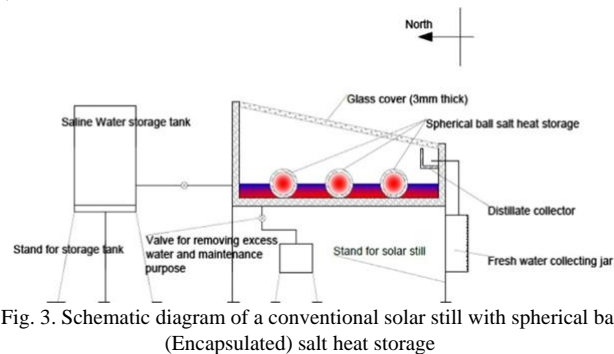
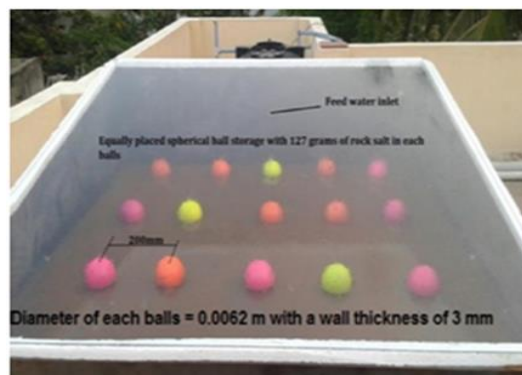
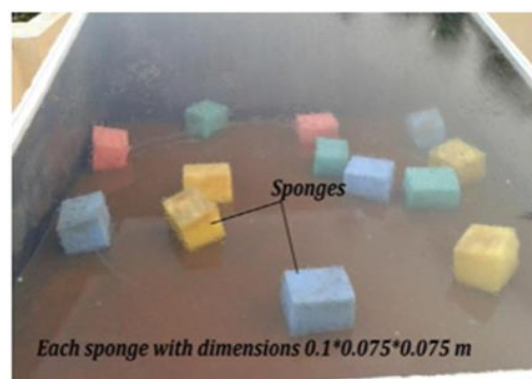


Fig. 3. Schematic diagram of a conventional solar still with spherical ball (Encapsulated) salt heat storage



(a) Experimental photograph of a solar still with spherical ball (Encapsulated) salt heat storage



(b) Experimental photograph of a conventional solar still with sponges
 Fig. 4. Experimental setup

The longitudinal and transverse direction. Velmurugan et al. [12-15] investigated a similar conventional solar still with fins and fitted with sponges to increase the surface area of water. The replacement of corroded fins and spoiled sponges are frequently carried out to maintain the quality of water condensed in the glass. Sponge loses its porosity due to the trapping of salt in the pores, and the bad odor from the sponges will affect the quality of condensed water. The experiments are carried out in the North– South orientation while the glass is

inclined facing the south direction and is inclined at an angle of 13° with the horizon in our experiment

The Fig. 4 (b), shows the solar still with sponge as material for increasing the surface area of water. The dimension of each sponge is $0.1\text{ m} \times 0.075\text{ m} \times 0.075\text{ m}$ and a total of 15 sponges were used in the experiment. The temperatures of various element of solar still like water, glass, and basin is measured using a PT-100 (RTD sensor) with an error of $\pm 1\%$. Environmental parameters such as solar intensity and wind velocity are measured using TES1333R solar power meter with a range of $0\text{--}2000\text{ W/m}^2$ and AM 4836C cup type wind anemometer with a range of $0\text{--}40\text{ m/s}$ respectively. The error of solar power meter and anemometer are $\pm 5\%$ and $\pm 2.5\%$ respectively. Digital weighing machine is used to measure the water collected every 1 h with an error of $\pm 2.5\%$.

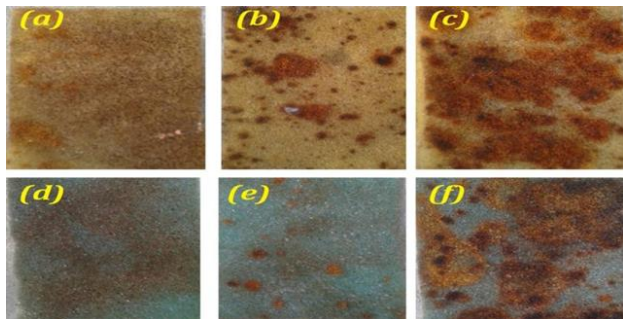


Fig. 5. Use of sponge on different testing days with yellow sponge (a) day 3, (b) day 7, (c) day 14 and green sponge, (d) day 3, (e) day 7 and (f) day 14

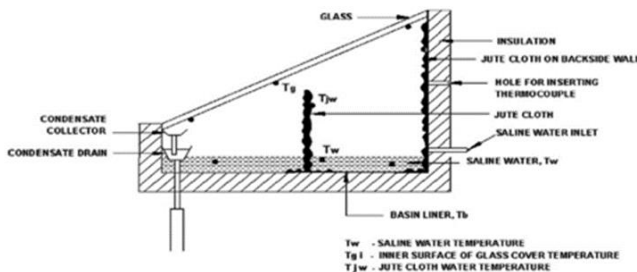


Fig. 6. Schematic diagram of a single slope solar still with vertical jute cloth



Fig. 7. Different energy storage materials

4. Integration methods

Various enhancement technologies are incorporated to improve the performance and yield of solar still. Enhancement techniques includes flat plate collectors, pulsating heat pipes,

concentrating collectors, evacuated tube collectors, thermoelectric effect, parabolic trough, PV/ T still, solar water heater were used to improve the yield and efficiency of the solar still.

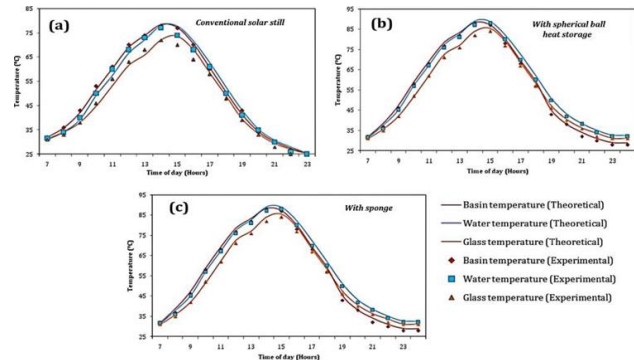


Fig. 8. Theoretical and experimental hourly variation of basin, water and glass temperature (a) conventional single slope solar still, (b) solar still with spherical ball heat storage and (c) with sponges

A. Flat plate collectors

On integrating flat plate collectors to the solar still, there is a significant increase in the temperature of the brine solution for the better improvement in the efficiency and yield. Fig. 9, shows the diagram of a single slope solar still coupled to a flat plate collector. As per Rai et al. [18] the increase in temperature of brine solution depends on parameters such as mass flow, solar intensity, absorber material. Experimental results showed that, two different materials (dyed jute cloth knitted with wool and Jute cloth) in a thermo syphon mode was improved the yield by 48.15% than the minimum water mass of 20 kg. Further increase in the water mass has decreased the temperature and yield of water in the basin as it was not evenly distributed. The average distillate increases with increase in water mass up to 6 kg and thereafter decreases. Also, it was reported that the yield depends on mass flow in flat plate collector, and it was observed that there was an improvement in yield when the flow rate was increased from 1 to 3 kg/min. It was recommended to cool glass cover as it was improved along the condensation rate.

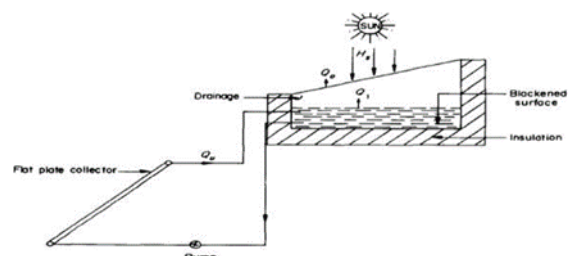


Fig. 9. Single slope solar still coupled to flat plate collector [18]

B. Tubular solar collector

The diagram of the single slope solar still integrated with tubular solar collector is shown in Fig.10 The tubular solar collector and solar still receives the solar radiation where the water is heated and evaporated respectively. The inlet feed

water is heated using tubular collector and the brine enters into the solar still for evaporation. The transient analytical expression for a single slope solar still with tubular collector was derived by Yadav and Yadav [19]. In the other words of the solar still explicit equations for water temperature, instantaneous distillate output.

C. Evacuated tubes

The Fig. 11(a) and 11(b) show the schematic diagram and Thermo syphon operation mode of an evacuated tube collector integrated to a solar still in natural circulation mode. In the evacuated tube collector water was used as a working medium, and it was partially filled inside the tubes. The energy received by each tube in the collector increases the temperature of water, and hence it can be said that the circulation of water flow inside each loop depends on collector area, solar intensity and configuration number of collectors (series, parallel). Reflectors were kept under the tubes to raise the temperature of working fluid. In natural circulation mode, the 1/2 of the energy was rejected by the working fluid (condenser zone) and in the other part energy was received by the working fluid (evaporator zone/evacuated tubes). This working was acted to be like a

thermosyphon process in evaporator and condenser.

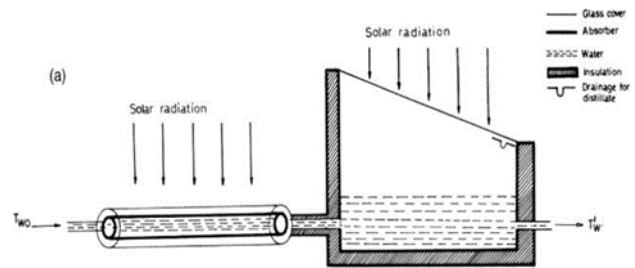


Fig. 10. Single slope solar still integrated to tubular solar collector [19]

Singh et al. [19] theoretically analyzed the performance of a solar still integrated to evacuated tube collectors. Parameters such as number of collectors, water depth were optimized for higher efficiency and yield from the solar still. The results showed that the energy and energy efficiency was higher in the case water depth (dept of water=0.03m) and number of collectors (Nc=10). And the energy and exergy efficiencies for dew=0.03 and Nc=10 were found to be 33% and 2.5% respectively. Further increase in depth of water and number of collectors decreased the above parameters. The yield of solar still was higher in the case of water depth (dew=0.07 m) and

Table 1
Energy storage material

S. No	Author	Modifications/ Apparatus used	Specifications	Effects / Observations
1	P.Sundaram And R.Senthil.	PCM(Paraffin Wax)	Paraffin wax = 27Kg melting temperature range =range of 55-60°C	1. An improvement of productivity is achieved at the depth of water in the basin as 10 mm (15 litres of water) when compared to the depth of water at 20 mm and 30 mm. If the depth decreases, the productivity increases. 2. The productivity is increased by 11.6% with addition of PCM at an optimal depth of 10 mm in the basin. The peak yield of the still is increased by 9.75% with PCM.
2	Sakthivel et al.	Jute cloth placed in vertical position	Basin area=1m x 0.5m Still cover = 0.003m thick Daily yield=3.9 kg/m ²	Productivity is 20% more than conventional still. Maximum efficiency of the still is 52%.
3	Kabeel	Blackwick is placed on concave absorber surface	Basin area=1.2m x 1.2m Basin material = galvanized steel Insulation = glass wool Glass cover=3 mm thick	Productivity is 4l/m ² and efficiency is 45%
4	M. Appadurai et al.	Conventional single slope solarstill and mini solar pond integrate with fin type.	Basin area=1 m x 1 m Basin material=galvanized steel Insulation=wooden box Glass cover=5 mm thick	Fin type single basin solar still have increased the water collection gain of around 47%,45.5%,50% at different water levels
5	Kamel Rabbi et al.	Comparative study carried out between the modified solar still with in fins absorber and conventional still.	Basin area=1 m x 1 m Basin material=galvanized steel Insulation=wooden box Glass angle=30°	A cumulative water level production is of gain 41.95%,23.39% and 11% implying an hourly gain of 12.9%,9.7% and 3.1% recorded for pin fin absorber coupled with condenser respectively the conventional still. The gain of 32.18% is recorded for still with condenser compared to conventional still. Simple pin fin absorber gains only 14.53% compared to conventional still.
6	T.Rajaseenivasan et al.,	Comparative study carried out between the solar still with circular and square fins integrated at basin	Basin area=1 m x 1 m Basin material=mild steel Insulation=wooden box Glass cover=4 mm thick	Daily productivity of the still increases by 26.3 and 36.7% for circular and square finned stills and it changes to 36 and 45.8% for fins covered with wick materials.

Table 2
 Integration method

S. No.	Type of solar still	Average yield (kg/m ² day)	Inference from the study
1	Flat plate collector	3	The optimized water mass inside the basin for active solar still was found as 20 kg. The yield with minimum water mass of 15 kg was found as 2.5 kg/day and maximum water mass of 2.34 kg/day. Obviously for increasing the basin area of the solar still the equivalent water mass can be maintained inside the basin.
2	Tubular solar collector	4.5	The daily efficiency and distillate (Yield) decrease with increase in water depth. From the transient analysis the energy absorbed by the tubular collector was higher as compared with the solar still.
3	Double basin active solar still with tube in tube arrangement	5.5	Fresh water yield depends on the flow direction, mass flow rate and depth of water.
4	Concentrating collector with cover cooling	4	The increase in flow rate of water over the cover surface increase the yield of fresh water with hemispherical absorber, PCM balls and concentrator.
5	Evacuated tubes	3.8	Optimum filling ratio for maximum yield was found as 40% (F_w/F_v) Energy and exergy efficiency was higher in the case water depth (dew= 0.03 m) and number of collectors ($N_c= 10$)
6	PV and Evacuated tube integrated solar still	4.78	There is a decrease in the yield of 23.31% compared to solar still with window pane glass than semitransparent PV panel.
7	PV/T solar still	10	The yield of fresh water increases with increase in the collector arrangement and number of collectors. The optimum number of collector was found as 4 and water mass as 50 kg inside the basin.
8	Solar water heater	7	The average thermal efficiency of active solar still was found as 20.2% for continuous flow operation throughout the day, whereas, the thermal efficiency of passive solar still was higher. Due to the heat removal factor from the collector during the off shine period the efficiency of active solar still is lower. With 8 h operation the efficiency of solar still increases by 0.8%.
9	Solar still with solar air heater	5.4	The maximum yield of fresh water during high intensity was found as 1 kg/m ² day with cover cooling. The yield is improved by Yield of fresh water improved by 70% with constant water mass of 20 kg inside the pyramidal solar still.

number of collectors ($N_c=30$). The yield was increased by 35.7% and the maximum temperature of water in the still was found to be $T_w=93^\circ\text{C}$ in both the cases. The increase in yield was due to fact the number of collectors as water was quickly evaporated which evaporates the water quickly. Also, the circulation of water inside the evacuated tubes was directly proportional to solar intensity.

5. Results and discussion

A. Discussion

By using the energy storage material the above percentage of increase is obtained as in observation (Table 1)

Solar still with solar air heater, flat plate collector, and tubular solar collectors are such factors that influence the enhancement of solar desalination.

As in the above Table 2, the integration part shows the percentage increase of solar desalination by using additional or external agents. Therefore preferring the above two methodology productivity of the solar desalination is obtained.

6. Conclusion

From the above observation and result we conclude the following point

- By using the PCM productivity is increased by 11.6% at an optimal depth of 10 mm in the basin. The peak yield of the still is increased by 9.75% compared to traditional method.
- By integrating the productivity is increased by the optimum filling ratio for maximum yield was found as 40% in evacuated chambers than the traditional method and The yield is improved by Yield of fresh water improved by 70% with constant water mass of 20 kg inside the pyramidal solar still while using solar

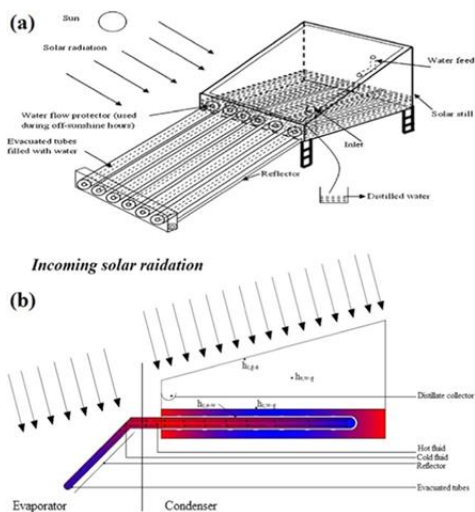


Fig. 11. Schematic diagram of (a) Evacuated tube collectors integrated to conventional solar still [20] (b) Thermo syphon operation mode in evacuated tube collector in a natural mode with a conventional solar still

air heater compared with the traditional method.

- There was gain of 32.18% recorded for still with condenser compared to conventional still. Simple pin fin absorber gains only 14.53% compared to conventional still.

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