International Journal on Applications in Engineering and Technology
Volume 6 : Issue 1: April 2020, pp 1 – 7 www.aetsjournal.com ISSN (Online) : 2455 - 0523

Analysis of Enrichment in production of fresh water in Solar Still

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Abstract: Sufficient quality and ease availability of drinking water supply is essential one. Along with food and air,water isanecessityforhuman.Freshwaterisobtainedfromlakes,rivers and ponds but it becoming scarce because of industrial discharge, sewage and population explosion. Solar still is a distillation of brackishorsalinewater,whereveritisavailable,isagoodmethod 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 solarstills.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 alsoanalysedin thispaper.

Keywords: *Solar Still, PCM, Energy Storage Materials, Assimilation methods.*

I. 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 vaporto freshwater. Desalination in membrane process is converting waste or salt water into useful one, by pumping the inputwater which consumes 20% of electrical energy. Furthermore, retreatment of saline water is required in order to avoidfouling effect on the membranesurface.

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 enhancementpurpose, many used integratingmethodologiesofenergystoragematerialsandPCM (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].

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II. 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 inwhich 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 (center-line distance of 0.07 m). In each tube, inner cylinderisfilledwithwateranditsoutsidesurfaceisblackened 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 islower.

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

Theadvantageofthephasechangematerialasaheatstorage 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 factgives the PCM the advantage as an energy storage medium (charging) at low temperature level which is suitable to solar energy system.The storage energy system 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,thePCMplaysasaheatsource(discharging) for the basin water at low solar radiation periods (nighthours).

B. Experimental approaches to improving theefficiency

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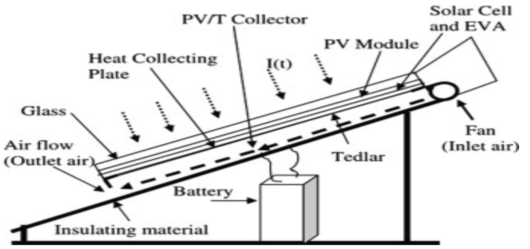


Fig. 1. Schematic diagram of a solar still assimilated with ETC, semitransparent PV module and PCM, b. Schematic diagram of thermo siphon process in single tube

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 of15˚so that the water dropletsformedonthesmoothsurfaceglidesdownandgetscollectedin 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 asmaterial for increasing the surface area of water. The dimension of each sponge is0.1 m, 0.075 m, 0.075 m and a total of 15 sponges were used in theexperiment.

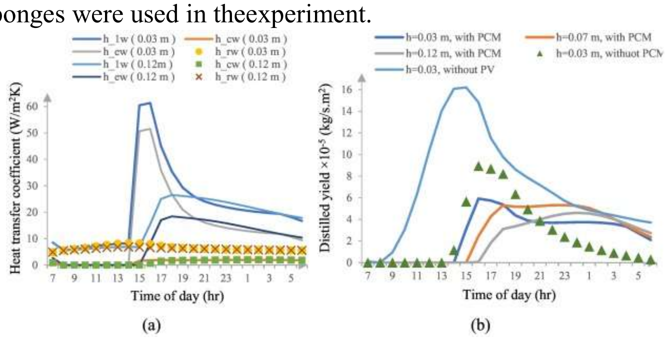


Fig. 2. Variation of the basin water temperature for 0.03 and 0.12m water depths, b. Variation of the basin water and PV temperatures for 0.03, 0.07 and 0.12m water depths.

Table 1
Thermo physical properties of some typical PCMs

PCM	Melting point Tm (°c)	Specific heat of solid/ liquid (KJ/Kg)	Density of solid/ liquid (kg/m³)	Thermal conductivity of solid/ liquid(W/m°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.Flowcontrolvalveisprovidedattheinletforthewater fedtobasin.Thewatermassiscontrolledbyfeedingwaterinto thebasinafterevaporationfromthesurfaceofwater.Drainpipe withcontrolvalveisprovidedatthebottomofthesolarstillfor theeasyremovalofexcesssalinewateranddduringthecleaning process. In our experiment two different methodsare 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 areusedtoincreasethesurfaceofwaterwithsolarintensityfor instant evaporation from the surface. The Fig. 1, shows the schematicdiagramofaconventionalsingleslopesolarstillwith spherical ball salt heat storage. The thermal conductivity and specificheatcapacityofsaltaremoreincomparabilitywithother 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 associated in spherical balls of diameter 62.3 mm made of plastic material (Fig. 3). Eachballisfilledwith127gofrocksaltandplacedatadistance of 200 mm in the longitudinal and transverse direction. Velmurugan et al. [12]-[15] investigated a similarconventional 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 orientationwhiletheglassisinclinedfacingthesouthdirection

III. Solar Still with Thermal Energy StorageMaterials

A. Basic principle of use of thermal energy storage materials inside solarstill

As we all know that, solar radiation is at the highestposition between 12:00 and 01:00pm. Solar still efficiency isdependent 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 thewater,andalsowatervapourformationisalsohigher.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, tousle excess energy, thermal energy storage materials is employed, which keeps the excess thermal energy and release during off-sunshinehoursforincrementindistillateoutputandefficiency.

B. Various thermal energy storage materials in the solarstill

Energy storage materials store excess heat during the sunshine Hours and release heat during off-sunshine hours; Hence,thedistillateoutputofasolarstillisincreasedbytheuse of various energy absorbingmaterials.

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 blackdye

Thecapacityofdifferentstoragematerialsusedinasolarstill to enhance the productivity of distilled water. Black rubber matt, black ink and black dyes were used in theexperiment.

3) Different sizes of black rubber and darkgravel

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 improvedtheproductivityby19%atbrinevolumecondition20 l/m2. Also, black gravel absorbs and releases incident solar energy faster than blackrubber.

4) Charcoalparticles

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 materialmixture

Energy storage material mixtures. The material was a mixof 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) Spongecubes

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 blackrocks

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 ironscraps).

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) Jutecloth

Jute cloth as an energy storage medium. The experiments wereconductedonaconventionalsingleslopesolarstill(fig.6) and on a regenerative solar still with jute cloth. In the regenerative solar still, jute cloth was kept vertically in the middleofbasinsalinewaterandtiedtotherearwardwallofthe still.

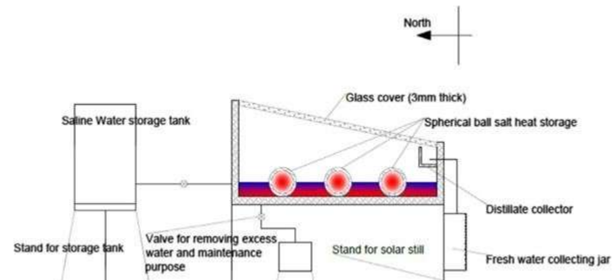
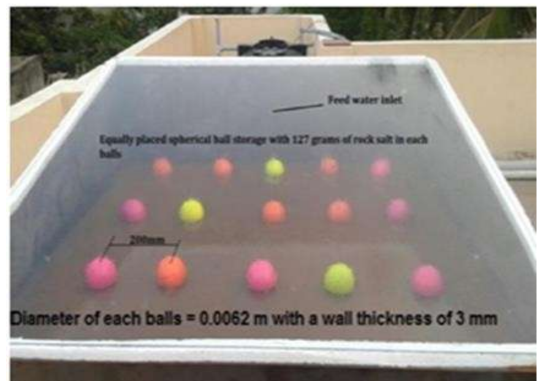
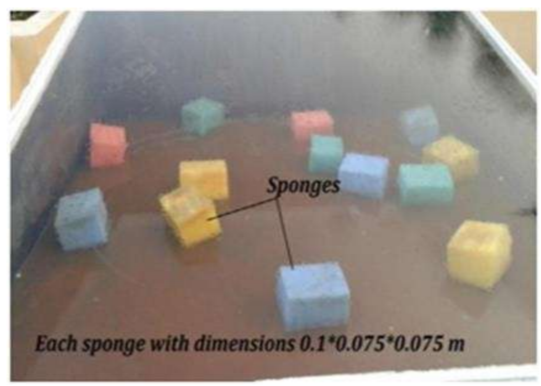


Fig. 3. Schematic diagram of a conventional solar still with sphericalball (Encapsulated) salt heatstorage



(a) Experimental photograph of a solar still with sphericalball (Encapsulated) salt heatstorage



(b) Experimental photograph of a conventional solar still withsponges Fig. 4. Experimentalsetup

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 thesponges will affect the quality of condensed water. The experimentsare carriedoutintheNorth–Southorientationwhiletheglassis inclinedfacingthesouthdirectionandisinclinedatanangleof 15° with the horizon in ourexperiment

The Fig. 4 (b), shows the solar still with sponge as material for increasing the surface area of water. The dimension of

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each spongeis0.1m*0.075m*0.075mandatotalof15spongeswere usedintheexperiment.Thetemperaturesofvariouselementof solarstilllikewater,glass,andbasinismeasuredusingaPT-100 (RTD sensor) with an error of ±1%. Environmental parameters such as solar intensity and wind velocity are measured using TES1333R solar power meter with a range of 0–2000W/m2andAM4836Ccuptypewindanemometerwith arangeof0–40m/srespectively.Theerrorofsolarpowermeter and anemometer are ±5% and ±2.5% respectively. Digital weighing machine is used to measure the water collectedevery 1 h with an error of±2.5%.

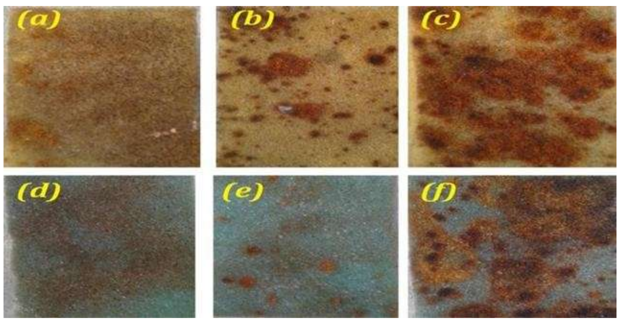

Fig. 5. Use of sponge on different testing days with yellow sponge (a) day 3,(b) day 7, (c) day 14 and green sponge, (d) day 3, (e) day 7 and (f) day 14

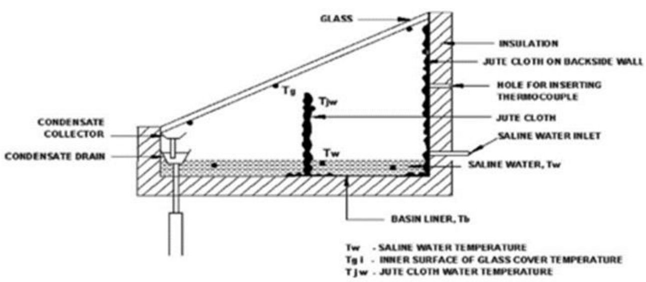

Fig. 6. Schematic diagram of a single slope solar still with vertical jute cloth

Fig. 7. Different energy storage materials

IV. ASSIMILATION 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 heaterwereusedtoimprovetheyieldandefficiencyofthesolar still.

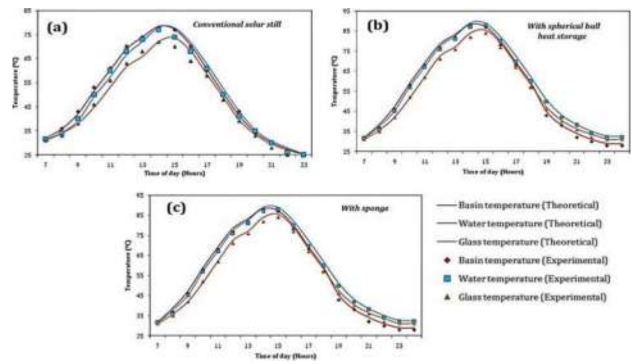

Fig. 8. Theoretical and experimental hourly variation of basin, water and glass temperature (a) conventional single slope solar still, (b) solar stillwith spherical ball heat storage and (c) withsponges

A. Flat platecollectors

On integrating flat plate collectors to the solar still, there isa 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 platecollector.AsperRaietal.[18]theincreaseintemperature 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 20kg. Further increase in the water mass has decreased the temperature and yield of water in the basin as it was notevenly 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 flatplate collector,anditwasobservedthattherewasan improvement in yield when the flow rate was increased from 1to 3 kg/min. It wasrecommendedtocoolglasscoverasitwasimprovedalong the condensationrate.

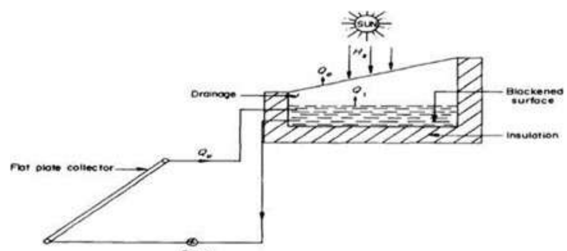

Fig. 9. Single slope solar still coupled to flat plate collector [18]

B. Tubular solarcollector

The diagram of the single slope solar still assimilated 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

C. Evacuatedtubes

The Fig. 11(a) and 11(b) show the schematic diagram and Thermo syphon operation mode of an evacuated tube collector assimilated 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 byeachtubeinthecollectorincreasesthetemperatureofwater, andhenceitcanbesaidthatthecirculationofwaterflowinside 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/evacuatedtubes).Thisworkingwasactedtobelikea thermosyphon process in evaporator and condenser.

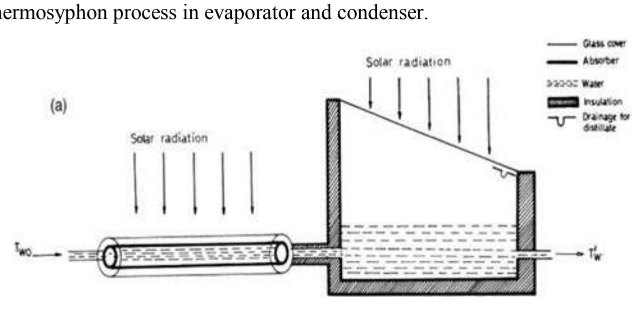

Fig. 10. Single slope solar still assimilated to tubular solar collector [19]

Singh et al. [19] theoretically analyzed the performance of a solar still assimilated 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 inthe case water depth (dept of

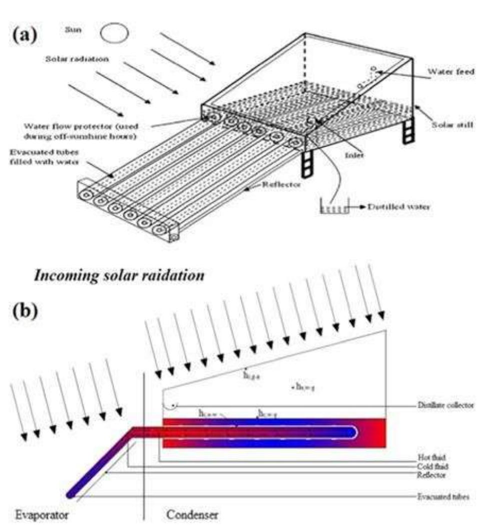

Fig. 11. Schematic diagram of (a) Evacuated tube collectors assimilated to conventional solar still [20] (b) Thermo syphon operation mode in evacuated tube collector in a natural mode with a conventional solar still

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 stillwashigherinthecaseofwaterdepth(dew=0.07m)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. Ifthe depth decreases, the productivityincreases. 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 stillis increased by 9.75% with PCM.
2	Sakthivel et al.	Jute cloth placed invertical position	Basin area=1m x 0.5m Still cover = 0.003m thick Daily yield=3.9 kg/m2	Productivity is 20% more than conventional still. Maximum efficiency of the still is 52%.
3	Kabeel et al	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/m2 and efficiency is 45%
4	M. Appadurai et al.	Conventional single slope solarstill and mini solar pond assimilate 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 assimilated 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 Assimilation method

S. No.	Type of solar still	Average yield (kg/m2 day)	Inference from the study
1	Flat plate collector	3	The optimized water mass inside the basin for active solar still was found as 20kg.Theyieldwithminimumwatermassof15kgwasfoundas2.5kg/day and maximum water mass of 2.34 kg/day. Obviously for increasing the basinareaof thesolarstilltheequivalentwatermasscanbemaintained 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 assimilated 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/m2daywithcovercooling.TheyieldisimprovedbyYieldoffreshwater improved by 70% with constant water mass of 20 kg inside thepyramidal solar still.

V. RESULTS AND DISCUSSION

A. Discussion

Byusingtheenergystoragematerialtheabovepercentageof increase is obtained as in observation (Table1)

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

As in the above Table 2, the assimilation 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.

VI. 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 traditionalmethod.
- By integrating the productivity is increased by the optimumfillingratioformaximumyieldwasfoundas 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 usingsolar

  air heater compared with the traditional method.
- There was gain of 33% recorded for still with condenser compared to conventional still. Simple pin fin absorber gains only 15% compared to conventionalstill.

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