REVIEW ON ENHANCING THE PERFORMANCE OF SOLAR STILL USING THERMAL ENERGY STORAGE MATERIALS

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Abstract : As fresh water demand is growing day by day in the present times of rapid growth in terms of population and industrial development; the solar desalination is found to be quite economical process for distilling the saline water throughout the world. The present paper reviews the development in the field of solar still with the various thermal energy storage material to improve the performance of still. From the review on research carried out by the various researchers, it has been found that solar still is more efficient and economical in compare to conventional or without thermal energy storage material solar still. Thermal energy storage material improves the thermal performance of solar still and to make it more economic.

I. INTRODUCTION

The thermal energy storage system stores the energy when the collected amount is in excess of the requirement and discharges energy when the collected amount is inadequate. Thermal energy storage material is not only used to store the excess thermal energy, but also helps to increase distillate output and efficiency during off sunshine hours. There are two types of heat storage system used in solar still one is sensible heat storage system and other is latent heat storage system. Fig. 1 shows types of solar energy storage system.

In case of sensible heat storage system, energy is stored or extracted by heating or cooling a liquid or a solid which does not changes its phase during the process. Sensible energy storage materials include liquid like water, sodium, heat transfer oil (Caloria HT43, Therminol T66, Servotherm), certain inorganic molten salt (Hitec) and solids like rocks, pebbles, refractories (Magnesium oxide, Aluminium oxide, Silicon 7 oxide) and metal strips etc. Combination of liquid and solid heat storage media are also used. In such case, the solid is porous or granular with the liquid filling the hollow space.

In a latent heat storage system, heat is stored in a material when it melts and extracted from the material when it freezes. Various phase change materials (PCM) for such applications are Organic material (Paraffin wax, Capric acid), Inorganic materials (CaCl2.6H2O, Na2SO4.10H2O, Mg(NO3)2.6H2O) and other compounds (Ice, NaNO3, NaOH, LiCO3/K2CO3). A classification of PCMs is given in Fig. 2 (Sharma et al., 2009).

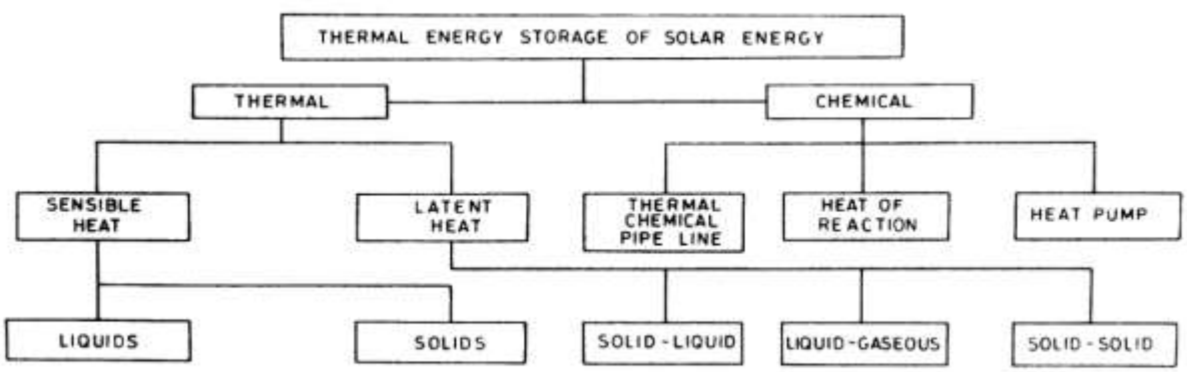

Fig.1: Types of solar energy storage system.

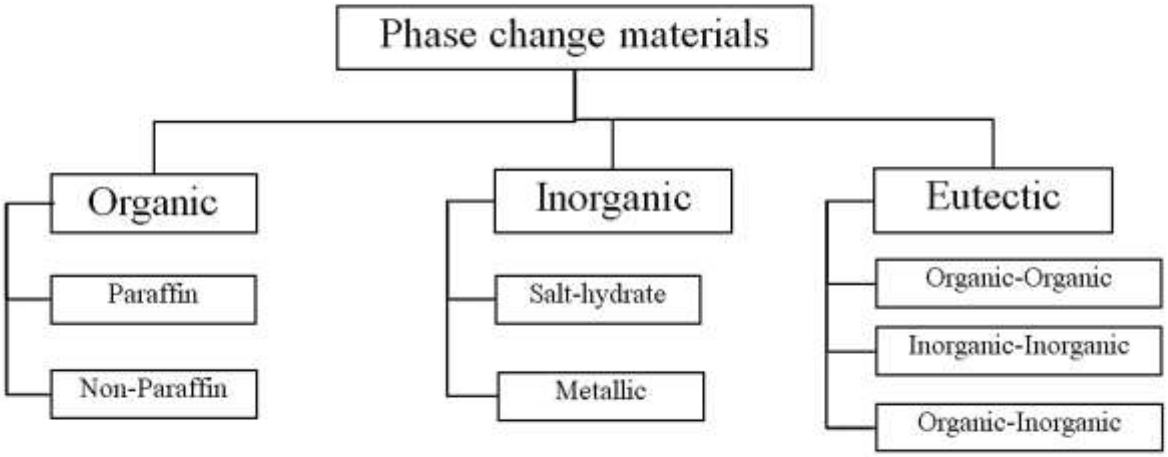

Fig.2: Classifications of PCMs [2]

II. LITERATURE REVIEW

LOVEDEEP SAHOTA et al. [3]

Nanofluids are the new generation of ultrafast heat transfer fluids due to their exceptional thermo-physical and optical properties and attracted attention of the researchers worldwide in recent times. Worldwide, research is underway to utilize the advances of nanotechnology for potable water production. In the present communication, the energy matrices, enviroeconomic analysis, and exergoeconomic analysis of passive double slope solar still (DSSS) fig. 3, has been carried out incorporating Al2O3, TiO2 and CuO-water based nanofluids. Significant enhancement in the annual productivity (Al2O3 19.10%; TiO2 10.38%; and CuO 5.25%), energy (Al2O3 26.76%; TiO2 19.36%; and CuO 12.96%), and exergy (Al2O3 37.77%; TiO2 25.55%; and CuO 11.99%) of passive DSSS system with nanofluids has been observed in comparison to the still with basefluid (water) only. On the basis of energy and exergy, the energy payback time (EPBT), energy production factor (EPF), life cycle conversion efficiency (LCCE), environmental cost and exergoeconomic parameter has been estimated for different interest rates (i = 4%, 8%, and 10%) and life span (maximum 50 years) of the passive DSSS loaded with proposed three different water based nanofluids

The values of optimized fluid (BF/NF) mass and concentration of NPs (Al2O3, TiO2, and CuO) for different months is given in Table 1. Both the basin fluid (BF/NF) mass and concentration of NPs have been found to be higher for the months of higher solar radiations (May and June). The optimal range of the basin fluid (BF/NF) mass has been found to be 20 kg $\leqslant$ Mw $\leqslant$ 40 kg. Whereas, the optimized values of the assisting NPs, Al2O3, TiO2, and CuO have been found to be in the range of 0.143% $\leqslant \varphi p \leqslant$ 0.272 %; 0.059 % $\leqslant \varphi p \leqslant$ 0.187%; and 0.044 % $\leqslant \varphi p \leqslant$ 0.153% respectively.

The monthly variation of maximum temperature difference $(\Delta T)_{max}$ between the base fluid and all three different water based nanofluids corresponding to the optimized parameters of that particular month is shown in Fig. 4. The value of $(\Delta T)_{max}$ has been found to be higher for Al2O3-water based nanofluid than the other studied water based nanofluids (TiO2-water, and CuO-water). The monthly productivity obtained from the base fluid and proposed nanofluids corresponding to the optimized parameter is presented in Fig. 5. The productivity of west side of the system has been found to be marginally higher than the east side of the system. Furthermore, the productivity is found to be higher for the month of May for Al2O3-water based nanofluid than the other studied nanofluids for both the east and west side of the system. Significant improvement in the annual productivity of the system has been observed by incorporating nanofluids (Al2O3 19.10%; TiO2 10.38%; and CuO 5.25%) in comparison to the still with basefluid only (Table 2).

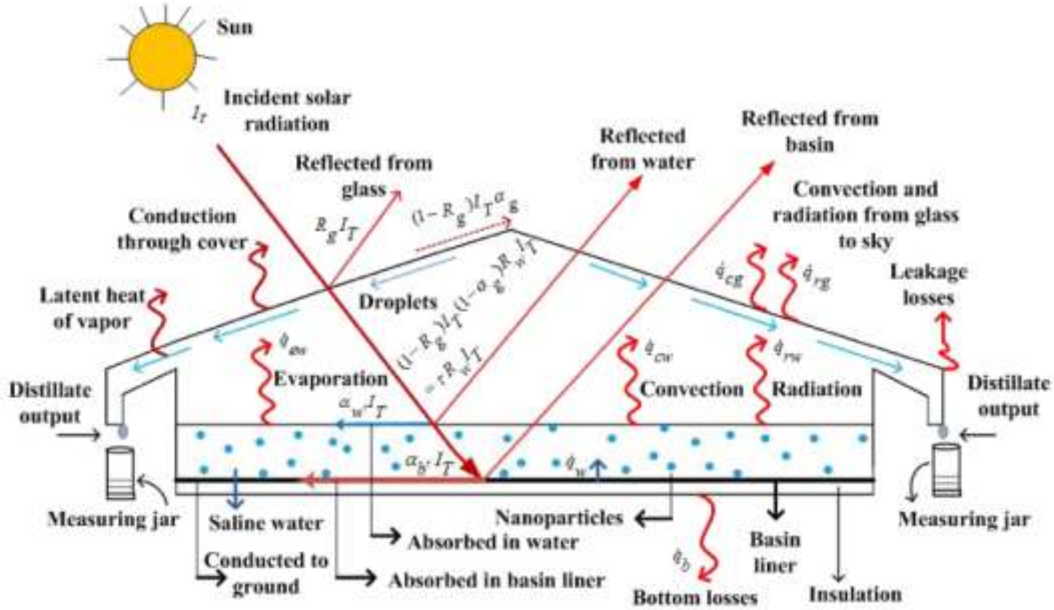

Fig. 3: Systematic view of passive double slope solar still loaded with metallic nanoparticles

Table 1

Optimized values of the basin fluid (BF/NF) mass and concentration of nanoparticles (Al2O3, TiO2, and CuO) for the passive DSSS corresponding to the each month.

Month	Basin fluid (BF/NF) mass	Concentration (φ_p) of metallic nanoparticles (%)		
	M_w (kg)	Al_2O_3	TiO_2	CuO
January	20	0.158	0.072	0.052
February	25	0.185	0.095	0.079
March	35	0.254	0.169	0.119
April	35	0.258	0.173	0.127
May	40	0.272	0.187	0.153
June	40	0.263	0.166	0.131
July	35	0.221	0.136	0.115
August	35	0.212	0.123	0.106
September	35	0.236	0.147	0.122
October	35	0.247	0.153	0.128
November	30	0.175	0.084	0.069
December	20	0.143	0.059	0.044

Table-2

Annual yield, energy, and exergy obtained from basefluid (water) and three different nanofluids.

Outputs	Water	Al_2O_3-water	TiO_2-water	CuO-water
Annual yield (East) (kg)	602.66	722.79	671.40	644.46
Annual yield (West) (kg)	639.23	755.86	699.46	662.75
Total annual yield (kg)	1241.89	1483.65	1370.86	1307.21
Total thermal energy (kWh)	1101.64	1396.51	1314.93	1244.43
Total thermal exergy (kWh)	82.29	113.25	103.32	92.164

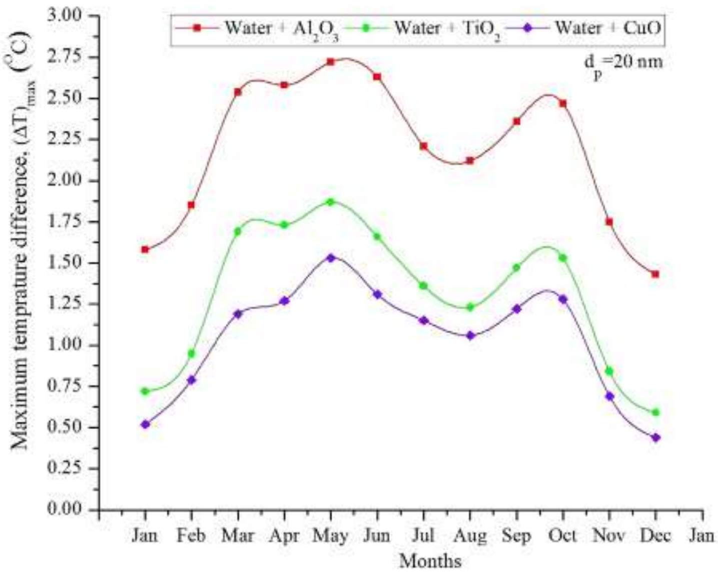

Fig. 4.Monthly variation of maximum temperature difference (typical day of each month) among the basefluid and water based all three different nanofluids.

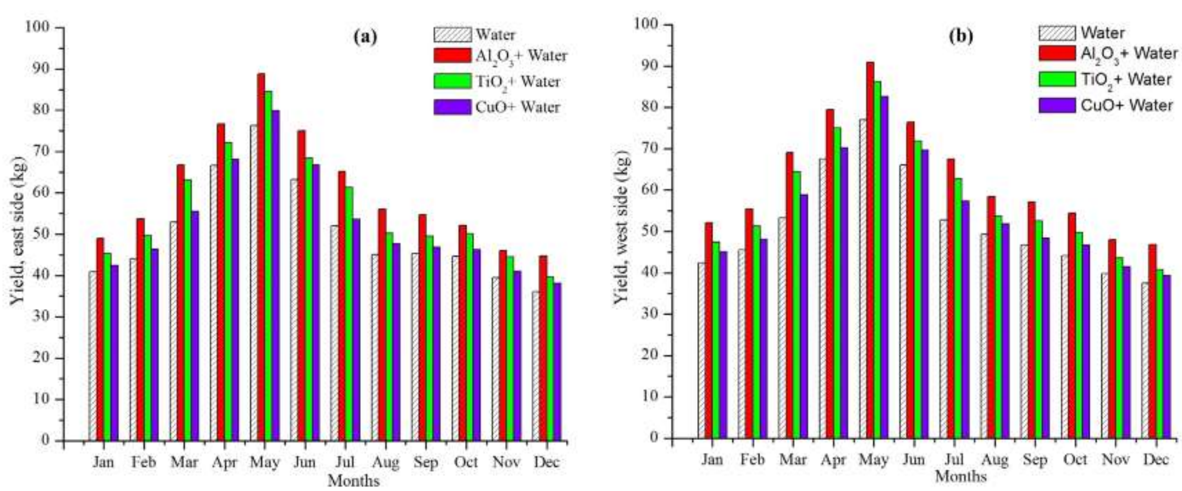

Fig. 5. Monthly variation of productivity (yield) obtained from the basefluid (water) and nanofluid of the (a) east and (b) west side of passive DSSS.

A.E. KABEEL et al. [4]

A modified pyramid solar still with both v-corrugated absorbers plate and PCM, and the conventional pyramid solar still was designed, constructed and fabricated under the same ambient conditions of Tanta city, Egypt. The performance of the modified pyramid still with both v-corrugated absorbers plate and PCM (modified pyramid still with PCM) are compared to the conventional pyramid still, to describe the improvement in the performance of the modified pyramid still with PCM. The experimental results showed that the accumulated distillate yield for modified pyramid still with PCM is higher than that of conventional pyramid still. The accumulated distillate yield reached approximately 6.6 L m^{-2} d^{-1} for modified pyramid still with PCM while its value was 3.5 L m^{-2} d^{-1} for conventional pyramid still. The use of v-corrugated absorbers plate and PCM under basin improved the accumulated distillate yield of a modified pyramid still with PCM by 87.4 % compared to the conventional pyramid still. Moreover, the modified pyramid still with PCM is superior in daily efficiency (86.41% – 88% improvement) compared to the conventional pyramid still in the period from September to October 2016 under the Egyptian conditions. Fig. 6 shows a schematic diagram of conventional pyramid still and modified pyramid still with PCM. Fig. 7 Photograph of conventional pyramid still and modified pyramid still with PCM.
The present work aims to improve the accumulated distillate yield of the pyramid still, by using v-corrugated absorbers plate and Phase Change Material (PCM) as a thermal storage medium under basin.

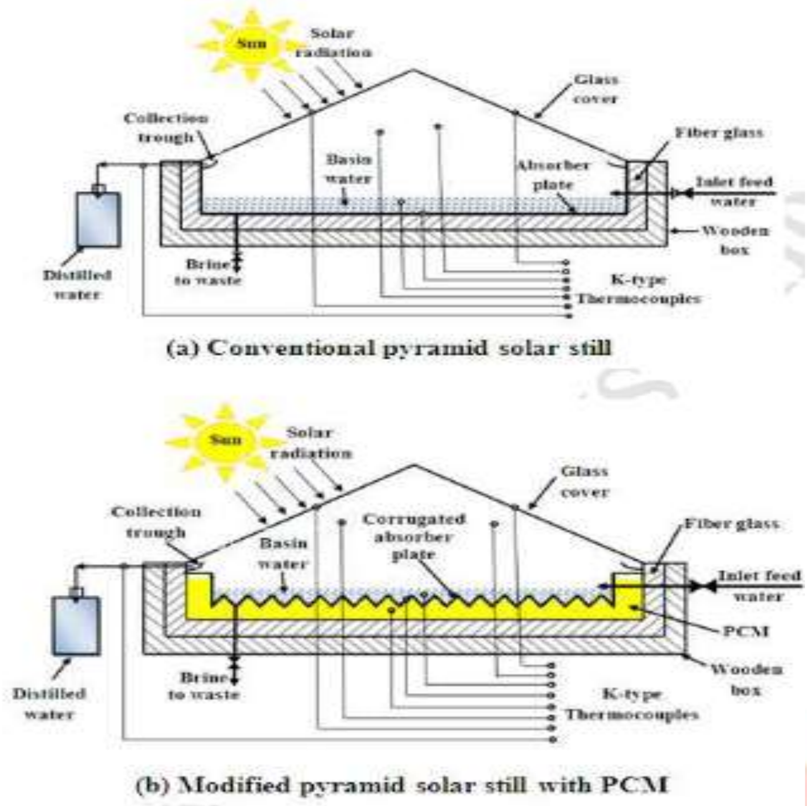

Fig. 6. Schematic diagram of conventional pyramid still and modified pyramid still with PCM.

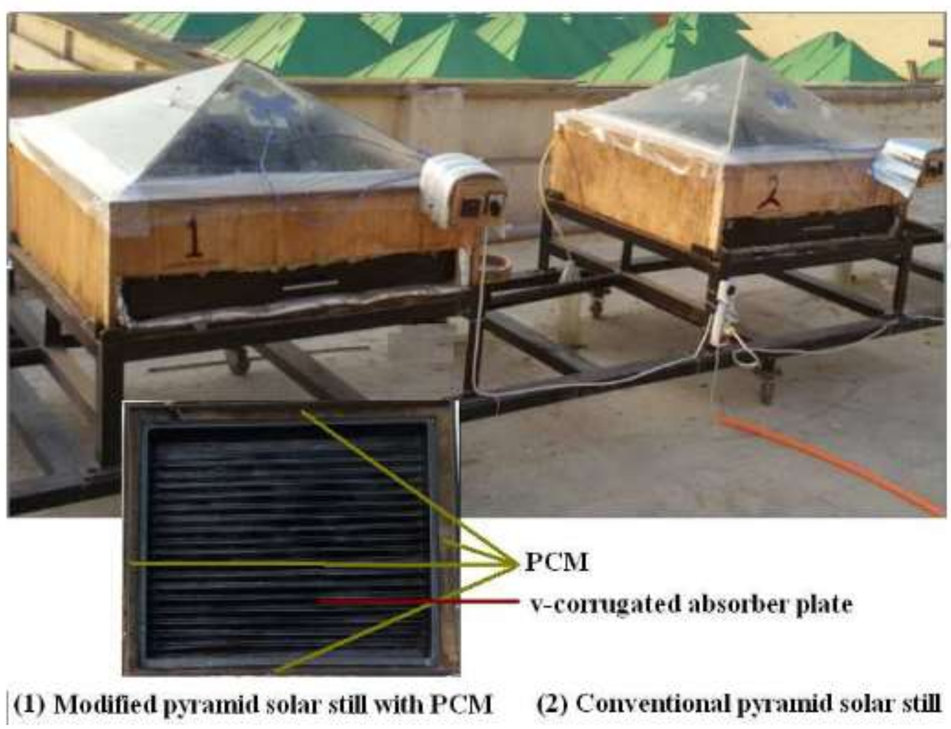

Fig. 7. Photograph of conventional pyramid still and modified pyramid still with PCM.

Table 3 shows the accumulated distillate yield, percentage rise in accumulated distillate yield, daily efficiency, and percentage increase in daily efficiency for both modified pyramid still with PCM and conventional pyramid still. As shown in Table 3 the accumulated distillate yield for modified pyramid still with PCM is higher than that of the conventional pyramid still.

Table 3 Accumulated distillate yield and daily efficiency.

Date	Average ambient temperature along test day °C	Accumulated distillate yield (L m⁻² d⁻¹)		Percentage rise in accumulated distillate yield (%)
		Conventional pyramid still	Modified pyramid still with PCM	
5-9-2016	32.2	3.58	6.73	88
6-9-2016	31.9	3.47	6.5	87.3
7-9-2016	32.1	3.53	6.615	87.4
20-9-2016	31.9	3.46	6.5	87.8
5-10-2016	31.7	3.42	6.45	88.6
13-10-2016	31.6	3.4	6.36	87.05
Date	Average solar radiation intensity along test day W/m^2	Daily efficiency (%)		Percentage increase in daily efficiency (%)
		Conventional pyramid still	Modified pyramid still with PCM	
5-9-2016	574.8	37.35	70	87.42
6-9-2016	573	36.21	67.6	86.69
7-9-2016	573.5	36.83	68.79	86.78
20-9-2016	573	36.11	67.6	87.21
5-10-2016	571	35.68	67.08	88
13-10-2016	570	35.48	66.14	86.41

The solar radiation, temperatures of ambient and the basin water for the modified pyramid still with PCM and conventional pyramid still are shown in Fig. 8. As shown in this figure the solar radiation and ambient temperature increase to the maximum value at midday and decrease after that. The maximum temperature of basin water for modified pyramid still with PCM and conventional pyramid still are 77 ºC and 71 ºC respectively in 1:00 pm. This result shows that the temperature of basin water for modified pyramid still with PCM is higher than that of conventional pyramid still due to the higher solar radiation intensity absorbed in the v-corrugated absorber plate, as well as, the high heat transfer from absorber plate to basin water for the modified pyramid still with PCM.

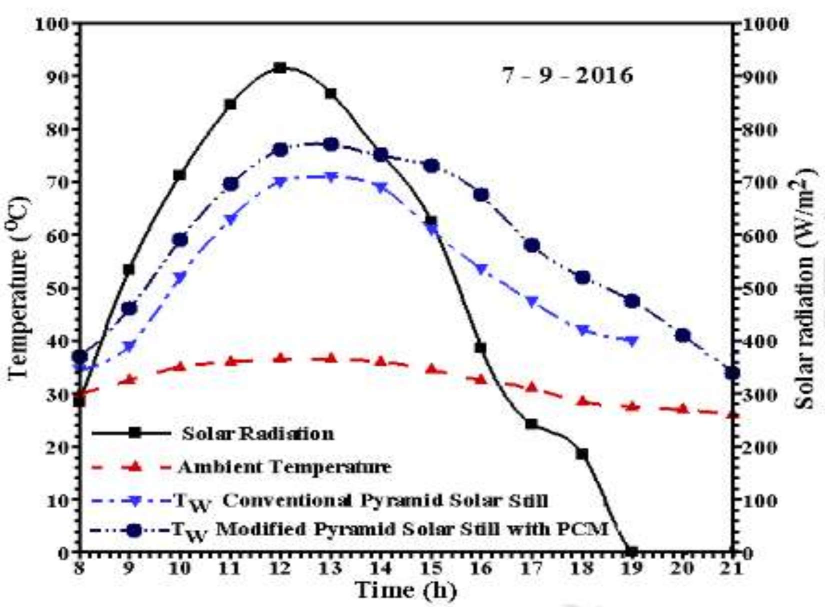

Fig. 8. Variation the solar radiation, temperatures of ambient and basin water along the test day.

Fig. 9 shows the accumulated distillate yield for the modified pyramid still with PCM and conventional pyramid still. As shown in figure the maximum accumulated distillate yield reached to 6.6 L m-2 d-1 for modified pyramid still with PCM and 3.5 L m-2 d-1 conventional pyramid still. The results show that, the accumulated distillate yield for a modified pyramid still with PCM is higher than that of the conventional pyramid still.

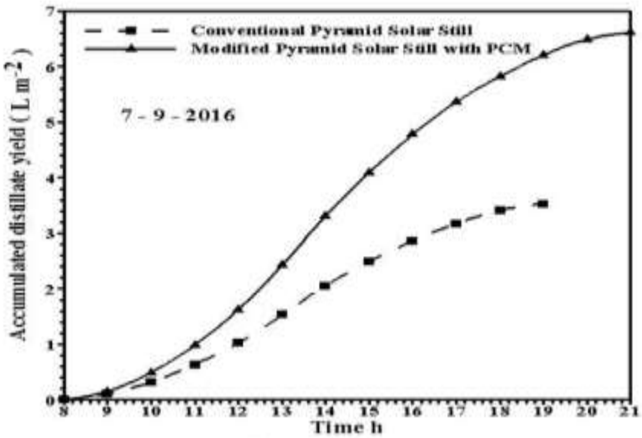

Fig. 9. Accumulated distillate yield for modified pyramid still with PCM and conventional pyramid still.

Fig.10. shows the hourly distillate yield for the modified pyramid still with PCM and conventional pyramid still. As shown in figure the maximum hourly distillate yield reached to 0.85 L m^{-2} h^{-1} for modified pyramid still with PCM and 0.51 L m^{-2} h^{-1} for conventional pyramid still. The results show that the hourly distillate yield for modified pyramid still with PCM is higher than that of conventional pyramid still. The improvement in productivity with PCM about 87.4 % compared to the conventional pyramid still.

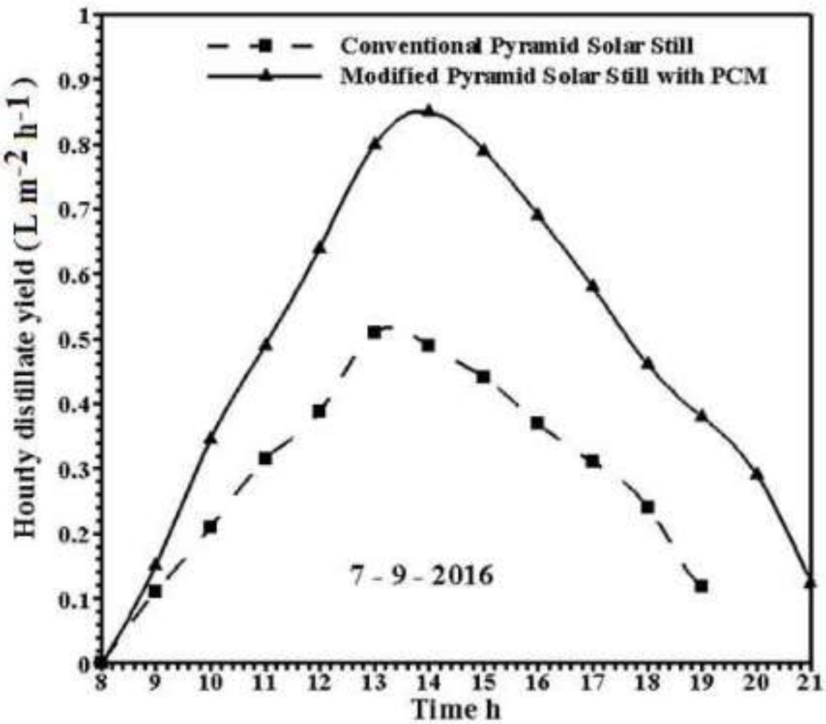

Fig. 10. Hourly distillate yield for modified pyramid still with PCM and conventional pyramid Still.

S. SHANMUGAN et al.[5]

An experimental investigation of the organization by Fig.11 has been equipped with the inner and outer enclosure of plywood with a face of 1.25 m × 1.25 m and 1.3 m× 1.3 m. In among the chitchat the plywood's are occupied with the benefit of glass wool having the wideness of 0.05 m. The back wall elevation is 0.03 m and front wall stature is 0.10 m. The viscosity of the glass cover is 4 mm and the slope of the glass cover is stationary as 11° which is equivalent to the latitude of the position and with the benefit of the metal putty charity of the arrangement no vapour escape. Accumulate of the concentration harvest are charity the j-shaped drainage channel is stable proximate the front wall. The yield trickled water down to the measuring jar. The basin area is made a copper sheet in a black paint mixed Al2O3 Nano particles coating by surface area with absorbing wick materials to absorb more solar radiation. The solar radiation communicated through the glass cover and fascinated by a wick & fin wick materials seeming – Al_2O_3 to comportment by the copper coil and then shadows the phase change materials – $C_{18}H_{36}O_2$. The solar radiation has been engrossed by Al_2O_3 Nano particles ascends esoteric the basin area escalation extra heat transfer style within near to visible and IR spectrum. The saline water through a special preparation has been completed to pour saline water drop by drop over the wick material kept in the basin. The drip heat transfer pipes full coating Nano particles mixed back paint to the lengthwise dripping arrangement is made of drip button fixed at regular intervals of 0.10 m and heat pipe stationary in amid the gap is 0.10 m horizontally in the basin. Fig. 12, Photograph of the different fin type absorbing materials during on 04/04/2016 is to accumulation of the water to glass at numerous for (A) 7.00 am (B) 7.30 am (C) 8.00 am (D) 11.59 am (E) 13.00 pm (F) 15.00 pm (G) 17.00 pm.

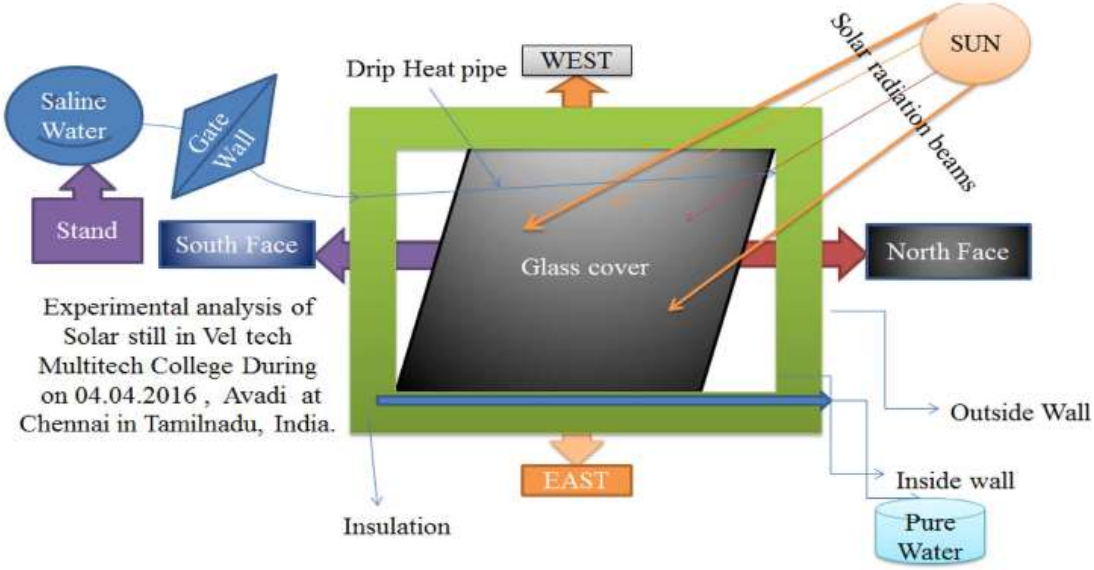

Fig. 11. Photograph of the experimental analysis of single basin still with different fin wick absorbing materials data collection on 04.04.2016.

Fig. 12. Photograph of the different fin wick absorbing materials on 04/04/2016 solar still, Accumulation in mass of the water to glass at various for (A) 7.00 am (B) 7.30 am (C) 8.00 am (D) 11.59 am (E) 13.00 pm (F) 15.00 pm (G) 17.00 pm.

- Al_2O_3 and $C_{18}H_{36}O_2$ used in the basin of techniques by a drip button to pour saline water drop by drop on absorbing materials in the basin.
- The usual efficiency of the still through 59.14% (summer) and 27.13% (winter) and henceforth it is established that Fin with Cotton Wick (FWCW) is the superlative material to be charity in the basin of the still.

H.S. DESHMUKH et al. [6]

Schematic of experimental set-up is shown in Fig.13. The still basin has a square shape and measures 71 cm × 71 cm i.e. 0.5 m2 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, 50mmthickmineralwool (k=0.036W/m K) is used on bottom and lateral surfaces. It is encased in 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 vapour leaks. Silicone after curing is observed to be flexible and provides a perfect vapour seal during daytime temperature variations and seasonal changes. It has better adhesive properties for both mild steel and glass. Vapours 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%.

In this experimental study, performances 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. Table-4 shows thermo physical properties of storage materials.

Fig. 14 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). Four such units identical in shape were mounted on the test bench for the simultaneous operation. Three units were charged with storage material such as sand or SM oil and the fourth unit without any storage served as the base unit for comparing the performance.

Fig. 15 displays variation of daylight overnight and daily productivities for different depths of sand (Fig. 15a) and SM oil (Fig. 15b) corresponding to water depth of 0.6 cm. Similar trends were observed for higher depths of water. Following observations can be made;

• All the units give daylight and overnight productivity

• Overnight productivity is quite less as compared to daylight productivity as it is dependent on the solar energy stored in the basin water and the storage material during the day time.

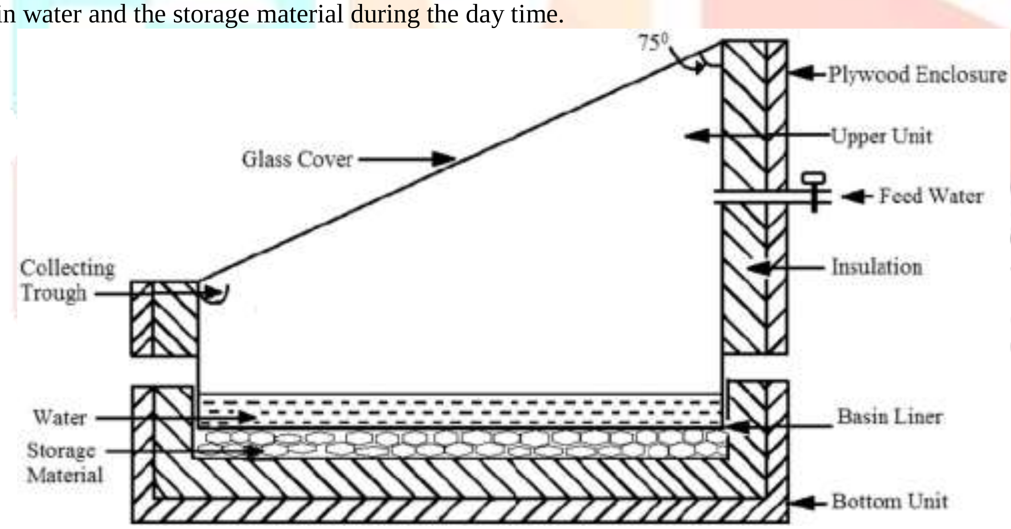

Fig. 13. Schematic of the solar still.

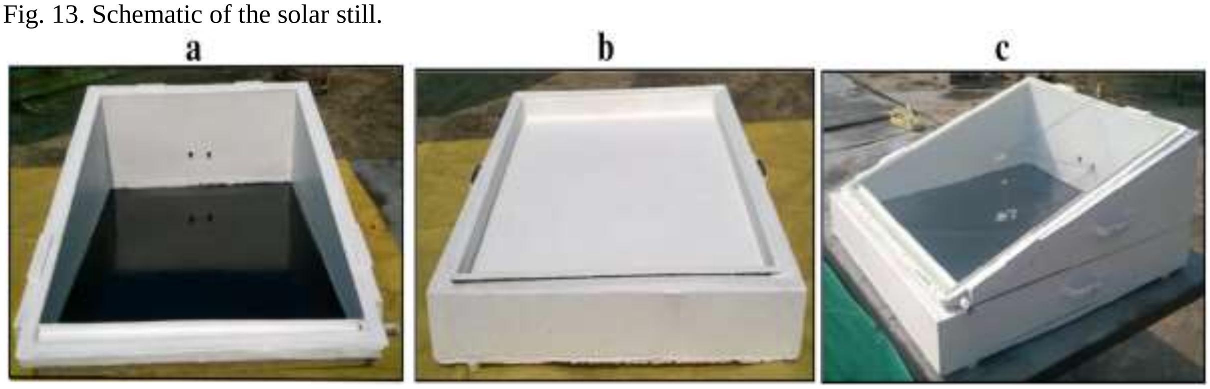

Fig. 14. Photographs of upper unit (a), bottom unit (b), assembled still (c).

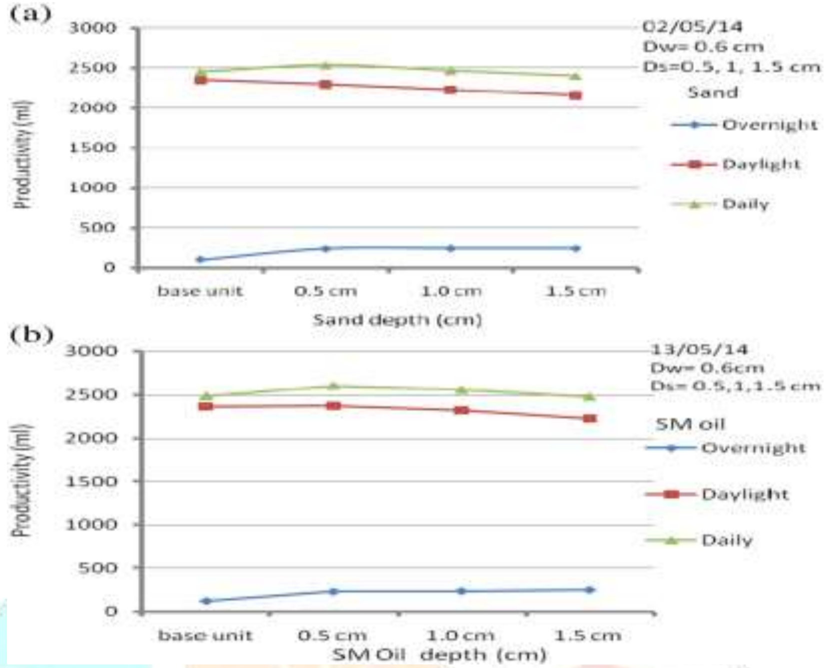

Fig. 15. Variation of productivity with storage depth sand (a) and SM oil (b).

Table – 4.

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

Experiments were conducted with sand and servotherm medium oil as sensible passive storage in a single slope single basin solar still. Their performance is compared with the base unit i.e. without storage. The following conclusions are drawn.

• All the units with passive storage such as sand and SM oil give higher overnight productivity.
• Overnight productivity increases with increase in storage and water mass.
• Daylight productivity, in general, decreases with the increase in storage and water mass.
• There exists optimum storage mass for maximum daily productivity.
• The optimum storage mass is found to be corresponding to mCp value of 8 ± 15% kJ/m2 K.
• Productivity is more if relative humidity is low.

GUIZHI XU et al.[7]

The work reported in paper concerns the use of diatomite to form-stabilise sodium nitrate, a phase change material (PCM) for medium temperature thermal energy storage applications. The composite was found to be able to retain up to 70% of the nitrate salt. X-ray diffraction (XRD) analyses suggested an excellent chemical compatibility between diatomite and the salt. Scanning electron microscope (SEM) analyses demonstrated an even distribution of the salt within the diatomite structure. Differential scanning calorimetry (DSC) measurements showed that melting temperature of the material was approximately 307.8 _C with a latent heat of 115.79 kJ/kg. Mechanical characterization of the composite material showed a compressive strength of the composite materials as high as 22.17 MPa. The composite materials were found to have a fairly low thermal conductivity of _0.5 W/m K and an addition of graphite could give a substantial thermal conductivity enhancement (_6-fold with an additional of 10 wt % graphite).
Fig. 16 shows the DSC data for Sample A5 containing 70% of NaNO3. For comparison, the result for pure NaNO3 is also included in the figure. One can see a principal sharp peak and a second weak peak for both the composite material and the pure sodium nitrate. The weak peaks of the pure sodium nitrate and the composite material occur at almost the same temperature range of ≈250-280 ^{0}C, representing a solid-solid transformation, whereas the principal peaks of the two materials represent solid-liquid phase change also at almost the same temperature range of _285–330 ^{0}C. The peak temperatures of the two peaks of the two materials are ≈275 ^{0}C and ≈ 309 ^{0}C, respectively. The height of the principal peak of the composite material with 70% sodium nitrate is lower than that of the pure

salt, and the solid-liquid phase change latent heat of the composite material is approximately 70% that of the pure salt. Fig. 17 shows the results. Little change is seen in the solid-liquid phase-transition temperature of the composite during the thermal cycling tests, whereas a small change (≈3.45%) is observed in the latent heat (from 115.8 J/g to 111.8 J/g after 300 cycles). The exact reason for the small decrease in the latent heat is unclear. It may be associated with salt leakage during the thermal cycling and this appears to be supported by the weight loss during the thermal cycling process (≈2.74% weight loss over the 300 cycles); see Fig. 6. In addition, the thermal cycling may facilitate leaking of the salt close to the surface of the composite.

Fig. 18 shows the special heat, Cp, for the diatomite (Fig. 18a) and the samples containing different percentages of sodium nitrate measured with the DSC. One can see that the specific heats of both the diatomite and the composite materials increase with increasing temperature.

This work is concerned about sodium nitrate based composite phase change materials (PCM) for medium temperature thermal energy storage applications. The main conclusion of this work is Diatomite and sodium nitrate have an excellent chemical compatibility and are suitable for formulating composite phase change materials. Graphite is highly chemically compatible with both diatomite and sodium nitrate, making it an excellent thermal conductivity enhancer for the composite materials.

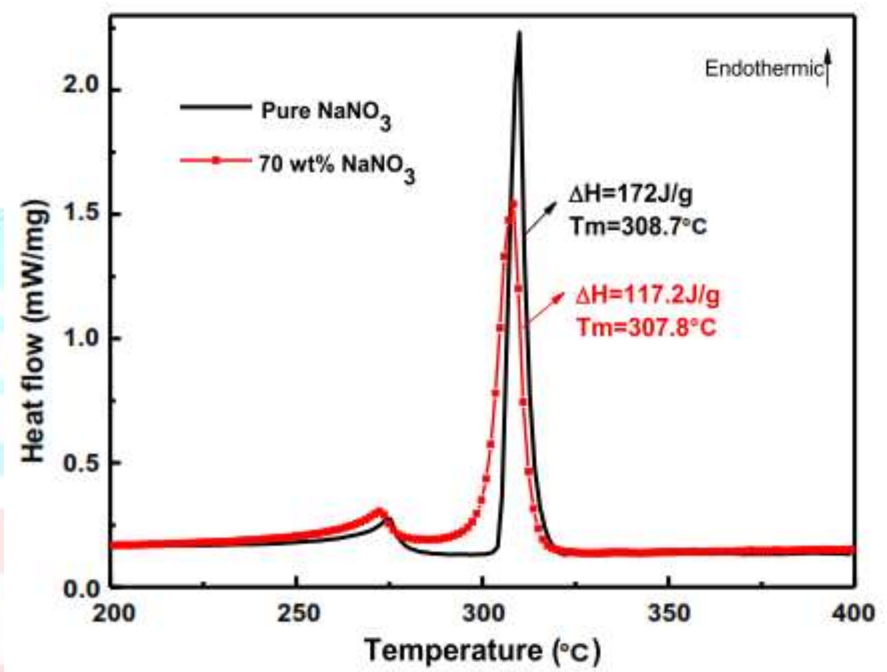

Fig. 16. DSC analyses of pure NaNO3 and Sample A5 containing 70% of NaNO3.

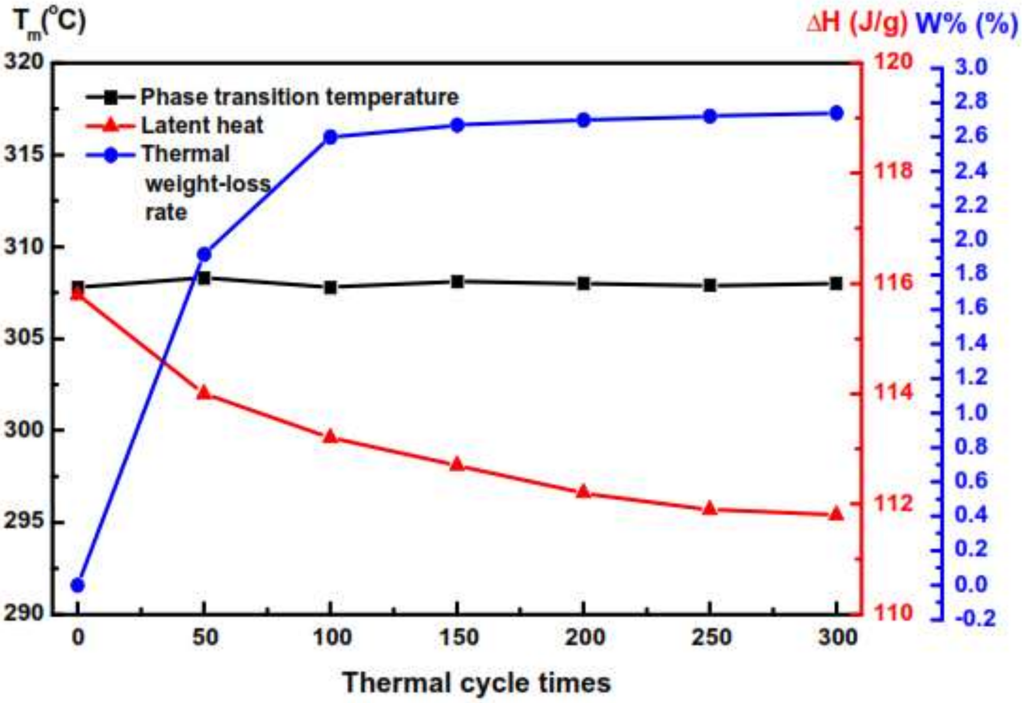

Fig.17. DSC and TGA analyses of the Sample A5 as a function of thermal cycle number; measurements done on the sample every 50 cycles.

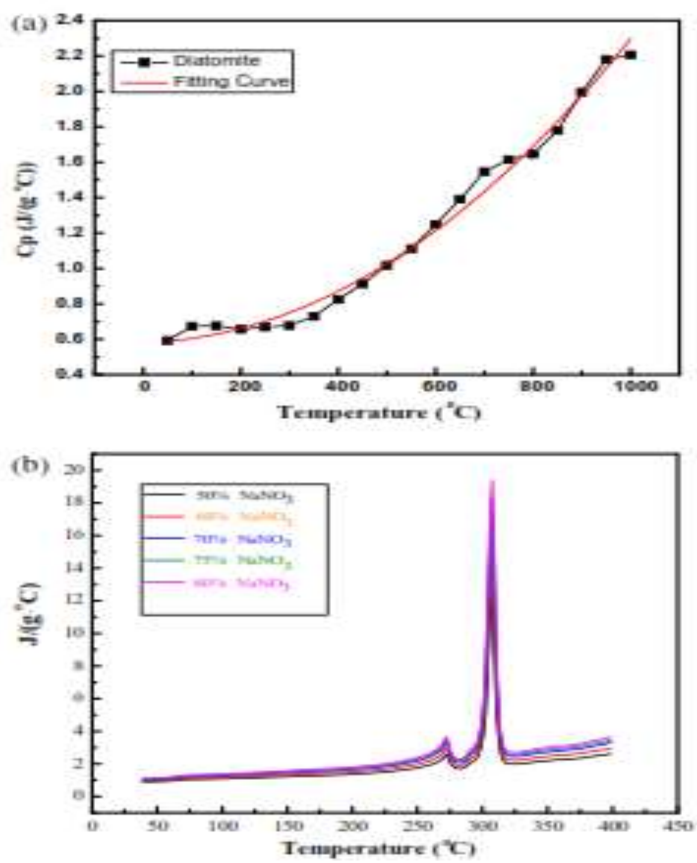

Fig.18. Specific heats of the diatomite (a) and the composite materials containing different mass percentages of NaNO3 (b).

HITESH N. PANCHAL [8]

A thermal energy storage materials are not only used to store the excess thermal energy, but also helps to increase distillate output and efficiency during off sunshine hours. Various thermal energy storage materials used by various researchers are shown below.

1. Dyes

   Rajvanshi represent the analytical and experimental study of the effect of adding dyes to a solar distillation unit. Different dyes like Black napthylamine, Redcarmoisine and Dark green used. It was found that Black napthylamine dye found to be most sui- table which increase the distillate output by 29%, when the absorption of dye up to 500 ppm inside solar still. Panchal and Shah [52] also used various dyes like black, Sky blue and green dye in solar still and found black dye more productive. Fig. 19 shows a comparison of various dyes inside solar still. Sodha et al. [38] used Red, Violet and Black dyes inside the solar still. They found that, the Black and Violet dyes more effective than other used dye in the experiments.

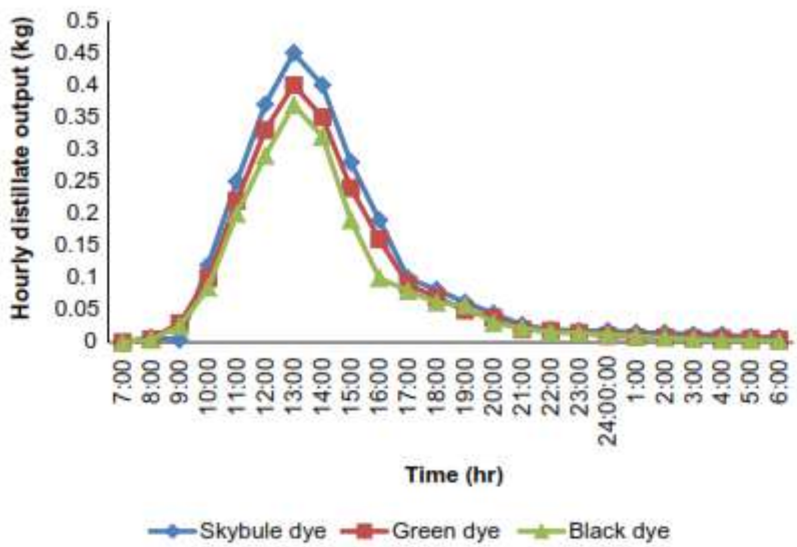

Fig. 19. Effect ofvariousdyesondistillateoutputofsolarstill.

2. Black rubber matt, Black ink and Black dyes

   Akash et al. studied different thermal energy storage materials like Black rubber matt, Black ink and Black dyes inside the solar still. They found black rubber mate more productive compared with other thermal energy storage materials and obtained 38% increment in distillate output. Black ink and Black dye found 29% and 25% increase in distillate output.

3. Black gravel and Black rubber as thermal energy storage materials

   Nafeyetal. Forthe investigation of the productivity of solar still, Different sizes of black rubber (2, 6 and 10 mm) thickness and black gravel materials (7–12,12–20 and20–30 mm) size used as thermal energy storage materials as shown in Fig.20 (a) and(b). They found that, Black rubber with size of 10 mm thickness, improved the productivity by 20% at brine volume condition 60 l/m2 and black gravel material with a size of 20–30 mm improves the productivity by 19 % at brine volume condition 20 kg/m2. Sakthivel et al. used Black granite gravel as thermal energy storage material to investigate the performance of a solar still in it. An experiment was taken with different depths of the gravel layer in steps of 12, 18, 20 and 25mm.They received 17% growth in distillate output by use of gravels inside solar still.

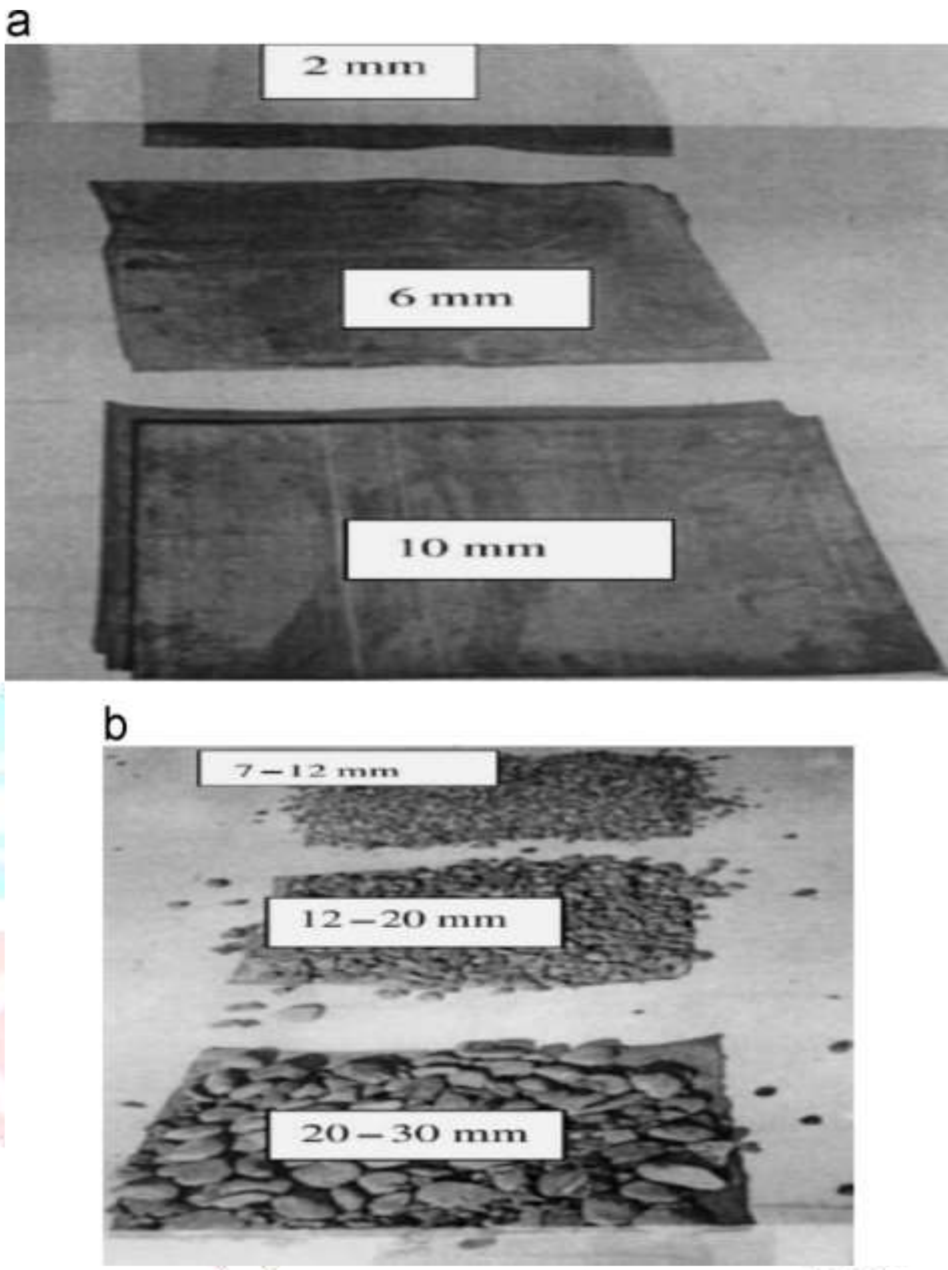

Fig. 20. (a) Black rubber as thermal energy storage material (b) Black gravel as thermal energy storage material.

4. Micaplateasthermalenergystoragematerials

El-Sebaii etal. were used aluminum, copper, stainless steel and mica plates as suspended absorber material in a single basin solar still during the experiment. The single-basin solar still with suspended absorber as shown in Fig. 21. It was found that using metallic plates as suspended absorbers (Aluminum, Copper and Stainless steel) the daily productivity of stillabout15–20% higher than that of the conventional still. But they found problems of corrosion to use metallic plates as suspended absorbers. They obtained an average daily production of still with mica plate and conventional still at 4.796 and 4.065 (kg/m2-day) with daily efficiencies of about 43.8 % and 35.12 %.

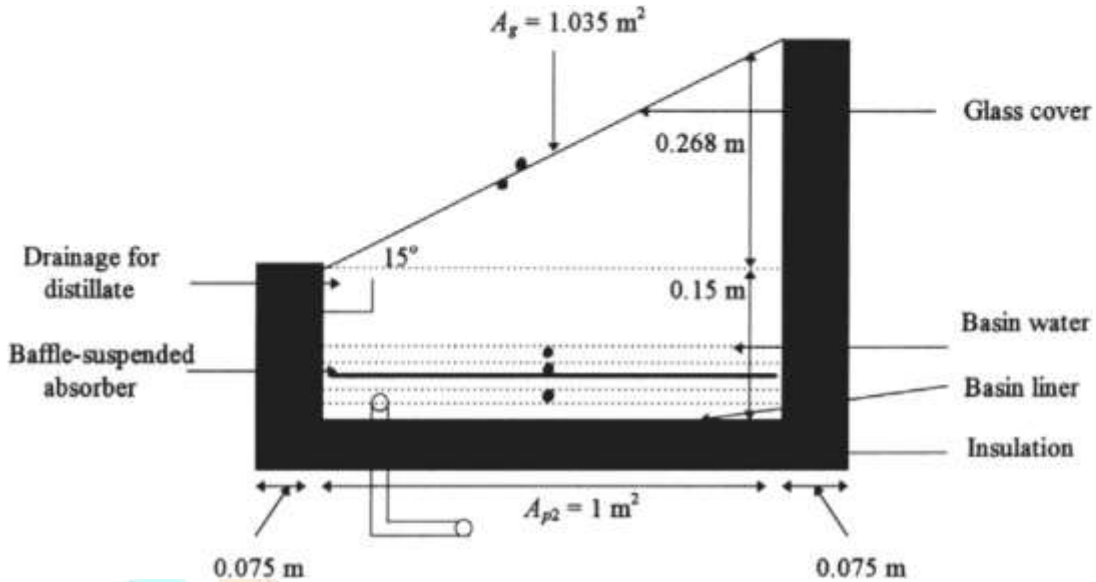

Fig. 21. single-basin solar still with suspended absorber.

5. Charcoal particles as thermal energy storage materials
Naima etal specially designed solar still as shown in Fig. 22 with different sizes of charcoal particles like (Coarse, medium and fine) used in their research work to investigate the productivity. It has been demonstrated that the solar stills with charcoal particles as absorber medium found 15 % advance in productivity over wick-type yet. Also coarse size charcoal particles give acceptable results at high flow rates in their results.

Fig. 22. Experimental setup of solar still having charcoal as thermal energy storage material.

III. CONCLUSION

Various research works done on solar still with various thermal energy storage materials to improve distillate output. Following conclusions has been withdrawn from the present study:

- Thermal energy storage materials have good ability to store the energy during the sunshine hours and release it during off sunshine hours for increment in distillate output.
- The annual productivity, energy, and exergy were found to be significantly higher for the passive DSSS system loaded with nanofluids following the order of Al2O3 > TiO2 > CuO water based nanofluid.
- The experimental results showed that the accumulated distillate yield for modified pyramid still with PCM is higher than that of conventional pyramid still. The accumulated distillate yield reached approximately 6.6 L m^{-2} d^{-1} for modified pyramid still with PCM, while its value was 3.5 L m^{-2} d^{-1} for conventional pyramid still.
- All the units with passive storage such as sand and SM oil give higher overnight productivity.
- Charcoal particles acts as good heat storage materials and gained 15% higher yield compared with conventional solar still.
- By introducing plates inside solar still found productive in distillate output compared with conventional solar still.
- The distillate output was increased by 38 %, 45 % and 60 % respectively when energy absorbing materials like black rubbermat, black ink and black dye.
- Diatomite and sodium nitrate have an excellent chemical compatibility and are suitable for formulating composite phase change materials. Graphite is highly chemically compatible with both diatomite and sodium nitrate, making it an excellent thermal conductivity enhancer for the composite materials.

REFERENCES

[1] Kuldeep H. Nayi, Kalpesh V. Modi, Pyramid solar still: A comprehensive review, Renewable and Sustainable Energy Reviews 81 (2018) 136–148.

[2] A. Shukla, Karunesh Kant, Atul Sharma, Solar still with latent heat energy storage: A review, 10.1016/j.ifset.2017.01.004.

[3] Lovedeep Sahota , Shyam , G.N. Tiwari. Energy matrices, enviroeconomic and exergoeconomic analysis of passive double slope solar still with water based nanofluids, Desalination 409 (2017) 66–79.

[4] A.E. Kabeel, Mohamed A. Teamah, Mohamed Abdelgaied, Gmal B. Abdel Aziz, Modified pyramid solar still with v-corrugated absorber plate and PCM as a thermal storage medium, 10.1016/j.jclepro.2017.05.195.

[5] S. Shanmugan, S. Palani, B. Janarthanan, Productivity enhancement of solar still by PCM and Nanoparticles miscellaneous basin absorbing materials, www.elsevier.com/locate/desal.

[6] H.S. Deshmukh, S.B. Thombre, Solar distillation with single basin solar still using sensible heat storage materials. Desalination 410 (2017) 91–98.

[7] Guizhi Xu, Guanghui Leng , Cenyu Yang, Yue Qin, Yuting Wu, Haisheng Chen, Lin Cong, Yulong Ding, Sodium nitrate – Diatomite composite materials for thermal energy storage, Solar Energy 146 (2017) 494–502

[8] Hitesh N. Panchal ,Use of thermal energy storage materials for enhancement in distillate output of solar still: A review, RenewableandSustainableEnergyReviews61(2016)86–96.