PERFORMANCE ENHANCEMENT OF SOLAR STILL THROUGH MODIFICATIONS BY VARIOUS TECHNIQUES: A REVIEW

Abstract

Lack of clean and pure drinking water has always been the biggest problem in many growing nations. Because of the presence of germs and other dangerous species, drinking water should never be taken directly from the source. It also has the contained dissolved salts which make it unusable for drinking purposes. While there is an adequate supply of seawater in many countries near coastal region, but there is not an enough supply of drinkable water. In such situations desalination can bring miraculous results by increasing the availability of sufficient quantity of usable water. Amongst various technologies, solar desalination proves to be less expensive methods to supply usable water to such communities. Solar stills can be used as a key method to such problem which will reduce the scarcity of potable water. Solar stills use abundantly and freely available solar energy and hence the problem of shortage of potable water can be addressed using them. The productivity & efficiency of the solar stills have been the key research area and many researchers have tried to improve them. This chapter include the work carried out by researchers on the solar still to enhance the performance of solar stills. Various techniques of improving the productivity & efficiency of solar stills such as design modification, meteorological factors, incorporation of metallic fins, use of thermal energy storage material either sensible heat storage (Pebbles, gravels, sand etc.) or latent heat storage materials (phase change material (PCM), nano embedded PCM) to enhance the distillate output have been discussed in this chapter.

Keywords: Phase change material, Efficiency. Solar still, Energy, Thermal, Productivity

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NOMENCLATURE	
Symbols	
TSS CSS MSS PCM SWF hfg mp A Ab I(t) Tw Tb Tgi Exe,w-g hc,w-g hr,w-g he,	Traditional solar still Conventional solar still Modified solar still Phase change material Steel wool fibre Latent heat (KJ/Kg) hourly productivity (Kg/s) Internal glass area (m2) Basin liner area (m2) Solar irradiation (KW/m2), Water temperature (◦C) Basin temperature (◦C) Internal glass temperature (◦C) Exergy of evaporative Convective coefficient of heat transfer Radiative coefficient of heat transfer Evaporative coefficient of heat transfer Total coefficient of heat transfer
Greek	
εe σ ηd ηexe	emissivity Stefan Boltzmann constant Daily average energy efficiency Daily average exergy efficiency
Subscripts	
d b w w-g gi a t c e r	daily basin water water-glass interface inner glass ambient total convection evaporation radiation

I. INTRODUCTION

The development of any country depends upon two important parameters energy and water that directly correlated with the basic necessity of human population. Now days, the availability of potable water is of primary concern as the deficiency of pure and fresh water in many countries is a common problem. Because of the presence of germs and other dangerous species, drinking water should never be taken directly from the source. It also contains dissolved salts which make it unusable for drinking purposes [1]. Around 41% of the earth's total population from the coastal areas where the availability of saline water is in large quantity but the scarcity of fresh water always remains there. Potable water apart from domestic purpose also utilized in heath and industrial sector such as hospitals, commercial offices, schools, electronic equipment's etc. [2]. Utilization of contaminated water results in variety of severe diseases, and in certain cases, it turns in death too [3-6]. Therefore, for cost effective and continual water management system, the major requirement was to provide water at plentiful quantity and acceptable quality [7-9].

More than 1 billion population of the world facing serious water shortage problem whereas approximately 41% of the world community lives in coastal regions with abundant availability of saline water but the availability of fresh water sources was limited [10]. Several attempts have been taken to provide the fresh potable water for drinking and other uses and it primarily considers the techniques to recover the fresh water [11]. Desalination proves to be the prominent technology to converts salty water into fresh water and hence one of the viable solution to obtain fresh water [12]. The overall desalination scope for the entire world was approximately 67.6 million m^3/d as of today, and it is anticipated to reach approximately 100 million m^3/d (GWI 2009). The countries with leading capacity of desalination plants are Saudi Arabia with total desalination capacity of 17.4%, USA with 16.2%, the United Arab Emirates with 14.7%, Spain with 6.4%, and Kuwait with 5.8% [11].

Desalination is the procedure used to purify contaminated or salty water so that it is fit for drinking and other uses. It includes the removal of dissolved impurities from the water by the application of thermal, electricity or membrane system.

Desalination technology primarily consists of two processes namely phase transformation process and constant phase process. In phase transformation process, heat energy was used for purification of saline water. It involves the additional heat source to transform the phase of saline water; the vapour thus formed gets condensed and collected as fresh water output. Traditional desalination techniques include phase change which depends on distillation process. They are mainly classified as Multi Effect Distillation (MED), Multistage Flash Distillation (MSF) and Vapor Compression (VC) as thermal VC or mechanical VC. MSF and MED processes successfully include temperature and pressure reduction steps. The MSF method relies on the sudden reduction in pressure that occurs when saline water enters the evacuated chamber, which causes water vapour to be produced. These steps are repeated continuously at subsequent reducing pressure. Additional steam supply is needed, often at a temperature of approximately 100 °C. In MED, evaporation is caused by the consumption of heat energy by saline water. Steam produced in one phase increases the temperature of the solution in the later phase because the temperature and pressure of later phase is quite lower than previous one. The effectiveness of the process directly depends on the number of stages.

In Thermal and Mechanical vapor Compression, after the generation of initial vapor from the brackish water produced, this vapors was further again compressed mechanically or thermally to achieve additional yield whereas, phase transition was not involved in membrane based technologies such as electro-dialysis (ED) and reverse osmosis (RO). The pressure of the saline water in both RO and ED was increased by using electricity or shaft power driven pump and the amount of pressure required rely on the salinity concentration in water. Generally, for sea water desalination 70 bar pressure is required. Both RO and ED are used for desalination of salt water whereas distillation works throughout the range of salinity of seawater. Undoubtedly, it is the most reliable method that can eliminate any organisms (bacteria, viruses and pyrogens) from the input water.

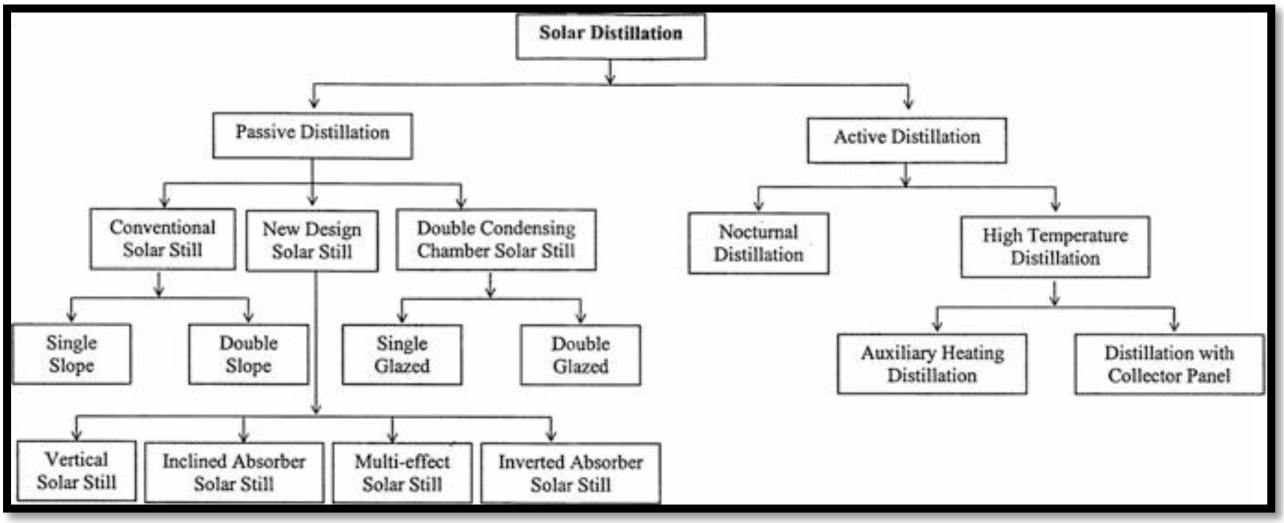

Figure 1: Classification of solar still

In regions where solar radiation is abundant in nature but the quality of the water is unsuitable for drinking and other uses, solar desalination may be a feasible option. Solar stills are economical, with low operating and maintenance cost but the major drawback was low fresh water yield. Hence, it may be used for lower capacity requirement and self sustainable water system, due its dependency only in the solar energy and not any other sources such as electricity and fuel. India is a country with hot climate, which receives solar radiation for most of the year except for a few cold and foggy days. Thus it can be used for more than 80% of the total 365 days of the year. Solar still can be one of the most reliable approaches to meet the demand for potable water in the recent circumstances. Fig. 1 depicts the classification of solar still.

II. WORKING PRINCIPLE OF SOLAR STILL

The working of solar still relies on two basic principles of evaporation and condensation. It uses the solar radiation from the sun to transform the saline water into fresh water. Solar still consist of basin which is fully insulated and is filled with saline water. It consists of transparent inclined glass cover on the top to allow the solar energy to strike on the water surface. As the saline water temperature increases, it begins to evaporate and the vapors get collected in the internal portion of the glass cover. The vapors condensed into fresh water on the top of glass cover and drips down, and the distillate output was collected with the channels placed in the lower portion of the glass cover. Fig 2 depicts the line diagram of the double slope solar still. The 1 m^2 basin surface area of the solar stills was formed from 1.5 mm thick galvanised iron sheet. The inside walls of still and the liner of the basin were painted black to absorb the most sun energy. To stop heat from dissipating into the atmosphere, the base and side walls of the stills were lined with 4 mm thick plywood and rock wool, respectively. To prevent any vapour leakage, rubber gaskets and silicone gel were used as sealing agents. The slanted tube built into the lower side of the glass is used to collect the condensate, which is then collected in a 2 litre bottle and monitored hourly using a measuring flask.

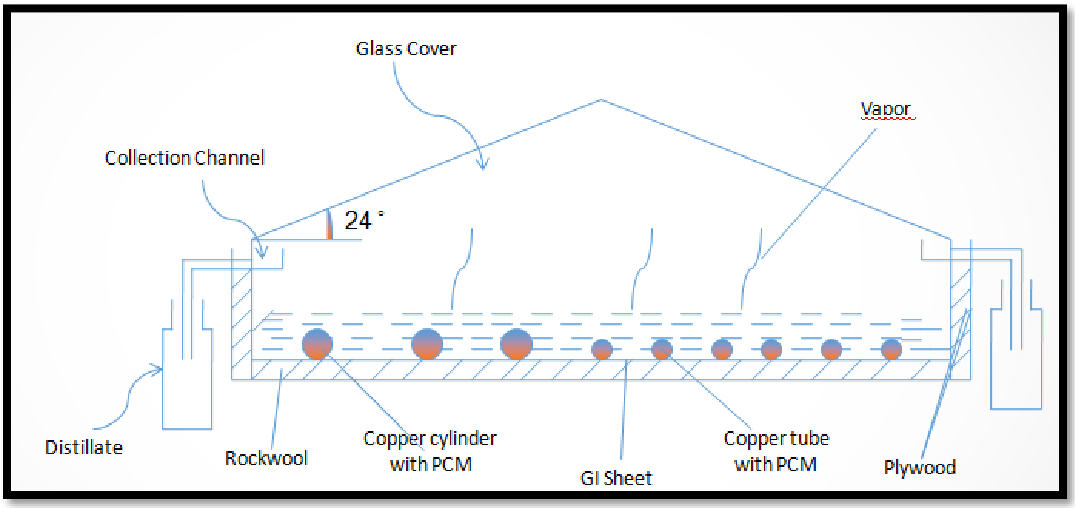

Figure 2: Schematic representation of components and working of solar still

III. MATHEMATICAL EQUATIONS FOR SOLAR STILL ANALYSIS

1. **Thermal Energy :** The efficiency of system was evaluated by using the equation given below:

$$\eta_d = \frac{\sum \mathrm{hfg} \times \mathrm{m_p}}{\sum \mathrm{A} \times \mathrm{I(t)}}$$

- Where, mp stands for the hourly fresh water output in (Kg/s), hfg is the latent heat (kJ/kg), and calculated from mathematical equation (2), [13],

$$h_{fg} = 10^3[2501.9 - 2.40706T_w + 1.192217 \times 10^{-3}T_w{}^2 - 1.5863 \times 10^{-5}\, T_w{}^3]$$

- Where, T_w is the water temperature (°C)

2. **Exergy :** Exergy efficiency can be determined by using [14]

$$\eta_{exe} = \frac{E_{x,out}}{E_{x,inp}} = \frac{\mathrm{Ex_{e,wg}}}{E_{x,inp}}$$

- *Where,* $Ex_{,inp}$ = exergy from sun, and can be computed from Equation

$$E_{x,inp} = A_b \times \mathrm{I(t)}[1 - \frac{4}{3} \times \left(\frac{\mathrm{T_a} + 273.15}{\mathrm{T_s}}\right) + \frac{1}{3} \times \left(\frac{\mathrm{T_a} + 273.15}{\mathrm{T_s}}\right)^4]$$

- The exergy through Evaporation ($Ex_{e,w\,g}$) was obtained by equation (5)[15]

$$Ex_{e,w\,g} = h_{e,w-g} \times A_b \times (T_w - T_g) \times (1 - \frac{Ta}{Tw})$$

$$h_{e,w-g} = 16.273 \times 10^{-3} \times h_{c,w-g} \times [\frac{[P_w - P_g]}{[T_w - T_g]}]$$

$$h_{c,w-g} = 0.884 \left\{ (T_w - T_g) + \frac{[P_w - P_g][T_w + 273.15]}{[268900 - P_w]} \right\}^{1/3}$$

IV. INVESTIGATION OF DESIGN MODIFICATIONS IN SOLAR DESALINATION SYSTEMS

Numerous variables, including available solar radiation, air temperature, wind speed, basin water evaporation area, feed water temperature, glass inclination, and depth of saline water, affects the productivity of solar desalination system. The metrological parameters like solar radiation, atmospheric temperature, wind speed cannot be controlled whereas other discussed factors may be controlled to enhance the performance of solar desalination system[16–18]. Kabeel et al in his review paper discussed about the various design configuration of solar stills such as double slope single basin solar still, stepped solar still, inclined solar still associated with external condenser system, weir type solar desalination system and many more[19].

1. **Glass cooling technique:** Sherwood et al. discussed about the heat transfer phenomenon in single basin single slope solar still due to enhancement in water dispersal rate with glass cooling technique. Fig 3 represents the line diagram of modified solar still.

   To increase the distillate production of the solar still, the hot water after cooling the glass cover was utilised as make-up water in the basin of the solar desalination system. According to the research, using glass cooling conditions effectively might increase still efficiency by 20%[20].

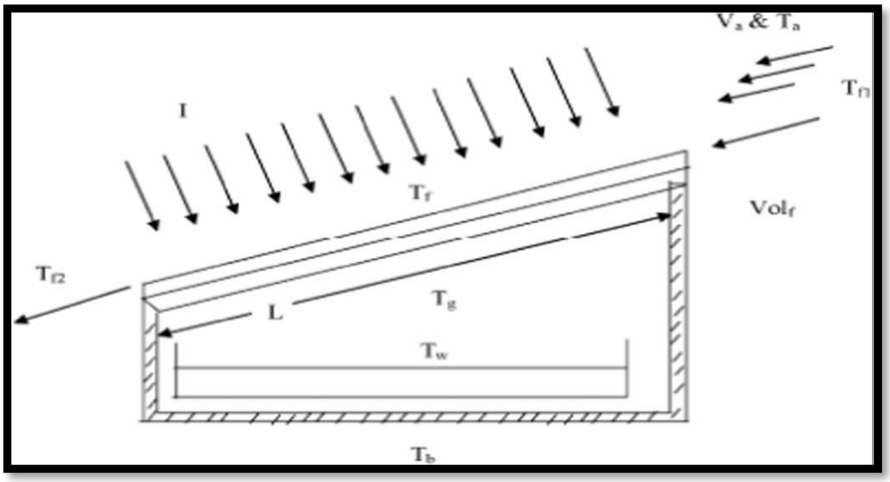

Figure 3: Represents the Line Diagram Solar Still with Glass Cover Cooling [20]

Abu-Hijleh carried out experiment by adopting the fresh water to reduce the temperature of glass cover by providing a skinny layer of water over it. The efficiency of the still was enhanced by 6% when effective cooling takes place otherwise it shows the declination in still efficiency with poor combination [21].

Aneesh and Anil fabricated and considered the effect of glass cover cooling integrated with air cooler. Authors used two different methods to cool the water such as desert cooler and normal available water. After cooling, the warm water can be reused as makeup water in a still basin. The experimental results reveal the increment in yearly productivity with evaporative cooling arrangement and with atmospheric water was 41.3–56.5% and 30.1–21.8% respectively. Fig. 4 represents the experimental setup integrated with evaporative cooler [22].

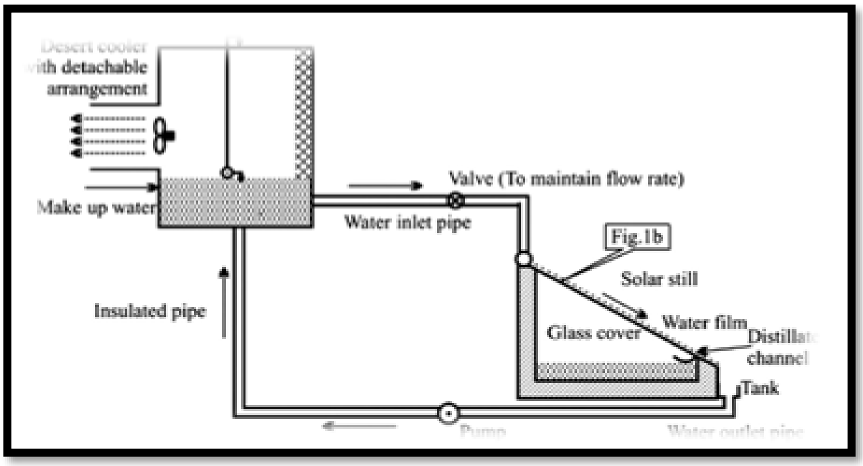

Figure 4: Experimental Setup of Still Integrated with Evaporative Cooler [18]

Abdullah designed and fabricated stepped solar still and carried out experiments by comparing traditional solar still and modified still associated with glass cover cooling. Fig. 5 depicts the line diagram representation of stepped solar still associated with solar heater. The basin area for both the still were same as 0.5 m^2. Also, to augment the distillate output, aluminium filings as energy storage materials were incorporated under the basin liner. The constant flow rate of 0.03 kg/s of cooling water was used. The solar still efficiency was enhanced by 65% when associated with air heating and 53% with glass cover cooling. By incorporating both the modifications, the efficiency of stepped still was enhanced by 112% as comparison to traditional still [23].

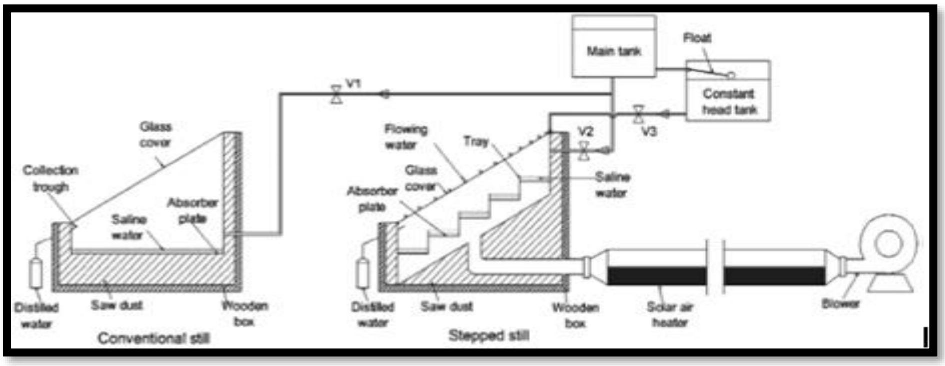

Figure 5: Depict the Schematic Representation Of Stepped Solar Still Associated With Solar Air Heater [23]

2. **Variation in basin water depth:** Amrit Kumar et al. performed experiment and aims to determine the consequences of associating concentrator of V shape with conventional solar still (CSS). The application of V type concentrator is to increase the temperature of basin water, which results in augmentation in the daily productivity compared to conventional still. The experiment was carried out by varying the basin water depth and the energetic, exergetic and economic evaluation was determined. According to the experimental findings, the daily fresh water yield of stills connected to V-shape concentrators (VCSS) was 5.47 for water depths of 1 cm, 5.10 for water depths of 2 cm, and 4.89 L/m2/day for water depths of 3 cm, while with conventional still was 3.73 for 1 cm, 3.27 for 2 cm, and 2.91 L/m^2.day for 3 cm water depth. The daily energy and exergy efficiency of conventional still in case of 1 cm was 38.5 and 1.9%, 33.5 and 1.5 % in case of 2 cm, 29.4 and 0.97% in case of 3 cm water depth. Fig. 6 depicts the daily fresh water yield of conventional still and modified still (VCSS) [24].

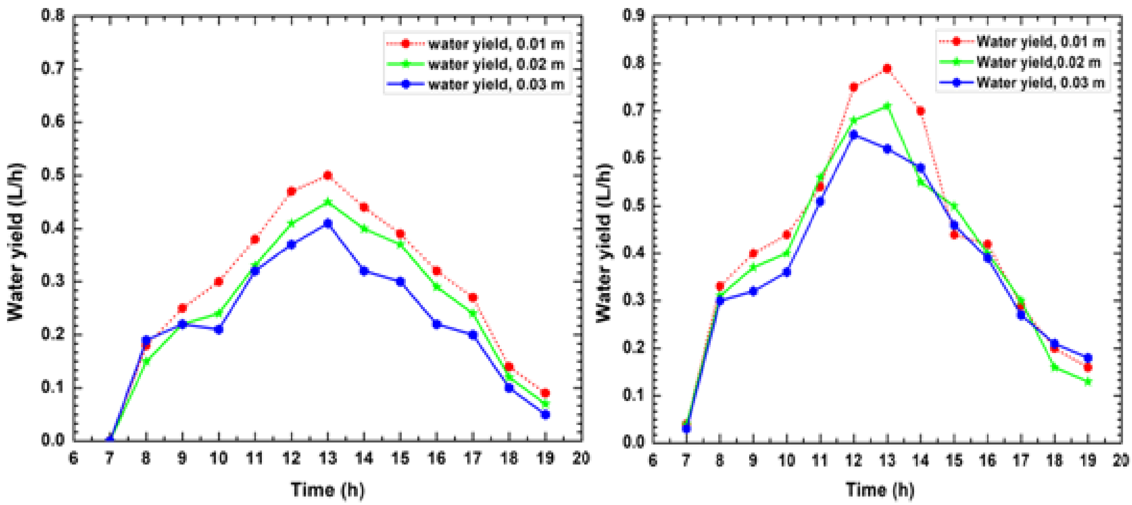

Figure 6: Freshwater Yield of CSS and VCSS with Varying Water Depth

Kaviti et al performed experiment on experimental setup of dual slope solar still and integrate truncated cone shaped fins in still liner to increase the heat transfer rate. Fig. 7

depicts the picture of solar still with and without truncated conic fins. Energy and exergy analysis was performed at different basin water depth and comparison was made with traditional still. 18 aluminum conical shaped fins with height and diameter of 50 mm and 30 mm was used in basin liner. The results show that in varied water depths of 1, 2, and 3 cm, the highest energy efficiency of still integrates with truncated conic fins were 54.11, 45.52, and 33.12%, respectively. When compared to a conventional still, the highest exergy efficiencies were increased by 6.20, 10.52, and 14.51% at 1, 2, and 3 cm, respectively. The daily fresh yields obtained for modified still were 830, 640 and 555 ml at 1, 2 and 3 cm respectively. Fig. 8 shows the variation of TCFS and CSS energy efficiency with time at 1, 2, and 3 cm of water. [25].

Figure 7: Depicts the Pictorial View of Experimental Setup with and Without Truncated Conic Fins

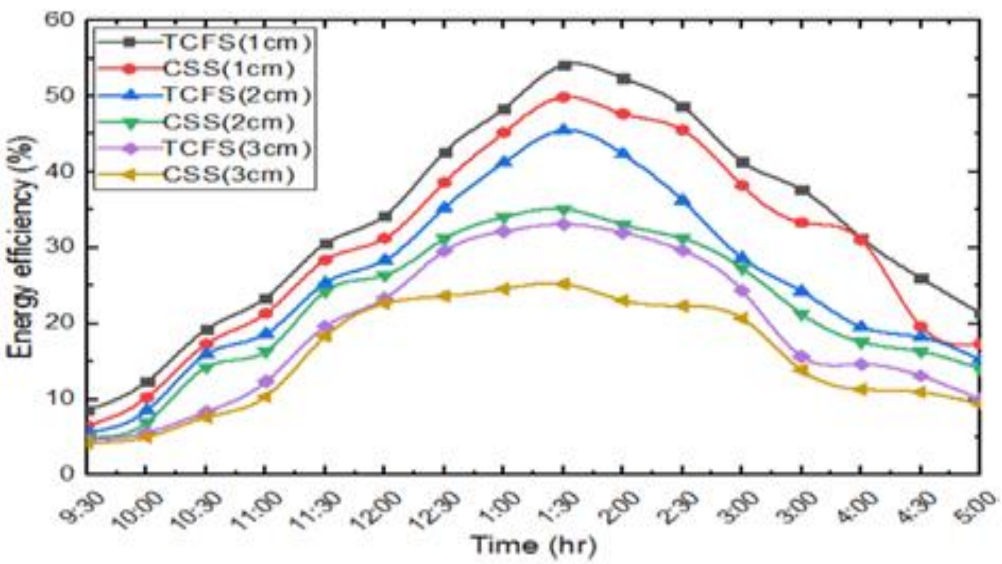

Figure 8: Hourly Variation of Energy Efficiency of TCFS and CSS with Time At 1, 2 and 3 Cm Water

Kabeel et al. performed experiment by improving the daily fresh water yield by integrating the glass cooling cover technique with tubular solar still (TSS). Experimental setup consist of translucent solar tube to augment the quantity of incident solar insolation and the black painted still liner for maximum consumption of sun's radiation which infers high water evaporation rate. The experimental setup for the tubular-shaped solar still is shown in Figure 9. In this research work, experiment was carried out to obtain the optimum water depth by performing the experiment with varying depth of water. Furthermore, considering different cooling water flow rate of (1, 2, 3, and 4 L/h) on the glass cover, to achieve the best flow rate [26].

The findings reveals that the TSS with 0.5 cm water depth, shows the maximum productivity and obtained cumulative yield was 4.5 L/m^2, while the still with 3 cm water depth produce daily productivity of 3 L/m^2. The maximum efficiency obtained was around 54.9 % under ideal circumstances with 5 mm basin water depth and discharge of 2 L/h. The cumulative productivity and energy efficiency was enhanced by 31.4% and 32.6% respectively, for modified still as compared to traditional tubular solar still. The cost of fresh water per litre for TSS with glass cooling technique was 0.019 $ and without glass cooling technique was 0.023 $ [26]. The impact of changing basin water level on the cumulative yield and hourly productivity of a tubular still is shown in Figure 10.

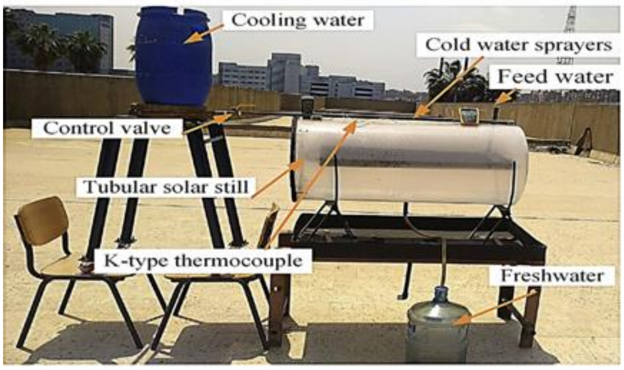

Figure 9: Photograph of the Experimental Setup

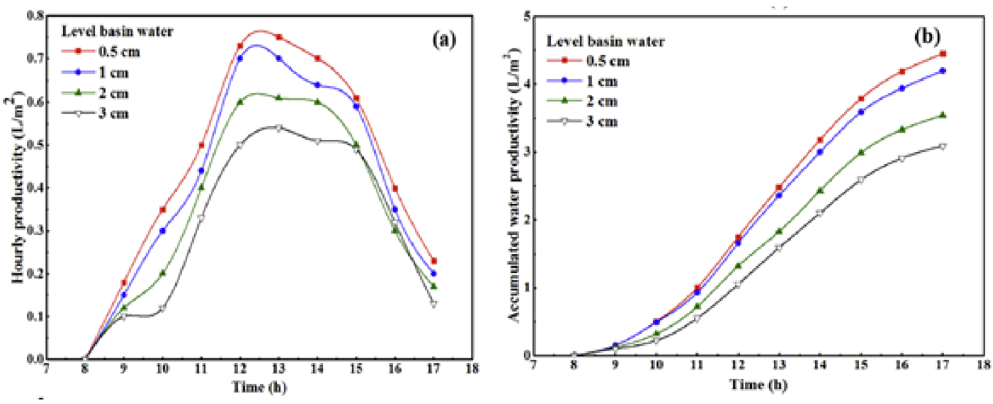

Figure: 10 Impact of Changing Basin Water Level on the Cumulative Yield and Hourly Productivity

V. INVESTIGATION OF SOLAR STILL INCORPORATED WITH METALLIC FINS

According to previous research, it has been discovered that adding metallic fins to the solar still's basin is a potential way to boost its efficiency. The literature review shows that many researchers had carried out experiments with metallic pins, strip fins, porous fin, pin fins and fins with wick material to enhance the absorptivity rate of solar radiation and productivity and efficiency of solar still.

Hardik et al. incorporate two different types of hollow fins (circular and square) in shape to investigate energetic behaviour of dual slope solar still. Circular hollow fins and square shaped hollow fins made of mild steel were integrated on the basin liner made of mild steel of two different solar still. Figure 11 represents the solar still 3D solid model with circular and square shaped fins.

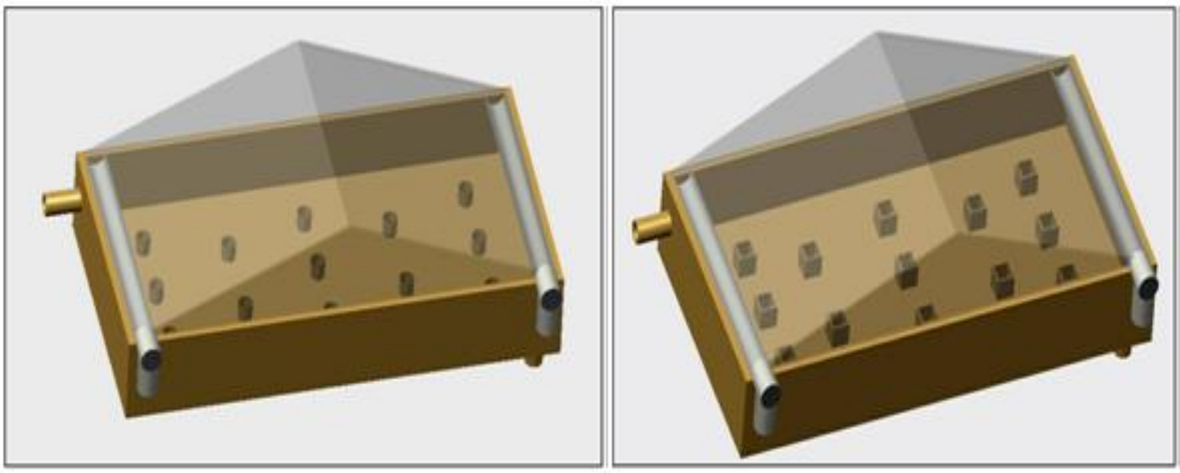

Figure 11: Solar Still 3D Solid Model with Circular Fins and Square Fins

Energetic performance was evaluated for modified solar still with square and circular fin with varying water depth. The experimental findings reveal that 1 cm water depth is more effective for the both solar stills as compared to other basin water depth. The maximum daily fresh water yield obtained was 1.4917 and 0.9672 kg/m^2-day for circular and square fins respectively. Fig. 12 and 13 shows the fluctuation of distillate yield and efficiency with time of Square Fins and Circular Fins with varying basin water level [27].

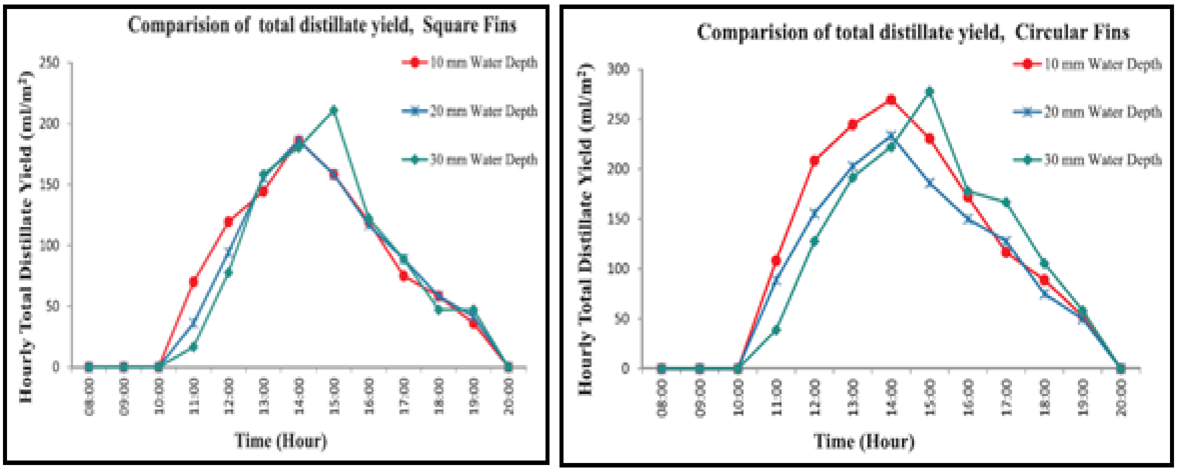

Figure: 12 Hourly Variation of Fresh Water Yield of Square and Circular Fins

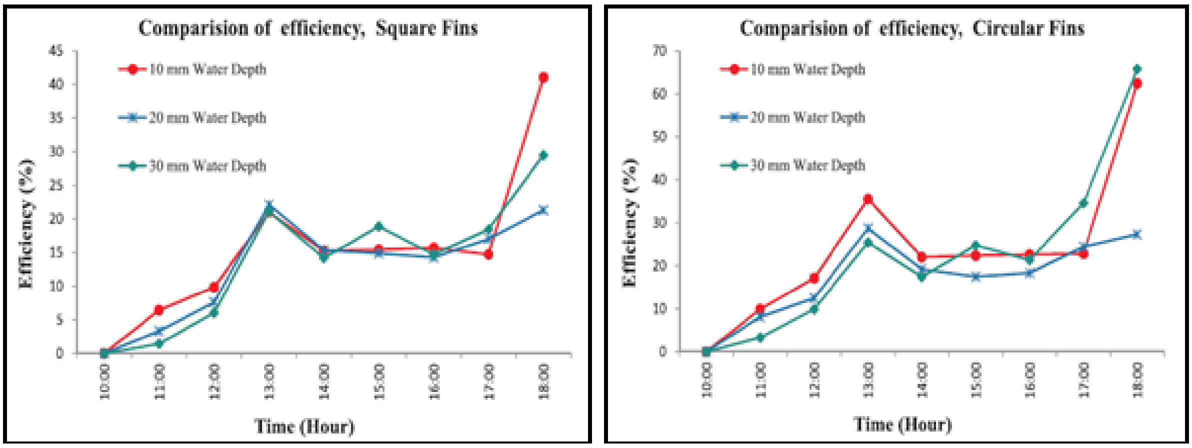

Figure 13: Variation of Efficiency with Time of Square Fins and Circular Fins

Velmurugan et al. carried out experiment by incorporating three different types of materials to enhance the yield and efficiency of still. Fins were used to enhance the heat transfer rate whereas the sponge and wick was integrated to improve the free water surface area which results in higher evaporation of water. Experimental findings shows that the cumulative yield enhances by 29.6% of still with wick material in comparison with conventional still, whereas 15.3% and 45.5% increment in productivity when sponges and fins were used.Table 1 represents the experimental and theoretical productivity comparison of different solar stills [28].

Table 1: Comparison in productivity of solar still with different cases

No.	Modification	Date	Average solar radiation in W/m^2	Production rate in $kg/m^2/day$		% Deviation
				Experimental	Theoretical	
1	Still only	16.08.06	545	1.88	2.07	10.1
2	Still with sponge	13.08.06	527	2.26	2.4	6.2
3	Still with wick	06.04.06	620	4.07	4.5	10.6
4	Still with fin	28.08.06	533	2.81	3.09	9.8

El-Sebaii performed research work on finned plate solar still to observe the consequences of fin arrangement parameters; height of fin Hf, number of fins nf and thickness of fins xf on the performance rate of solar still. Experiments were performed during June and August 2014 in the weather conditions of Tanta, Egypt. Additionally, the shadow area effect of fins (depends on the number of fin nf) on the solar radiation availability.

The findings shows that production rate of fresh water yield enhances by increasing the height of fin, whereas the productivity decreases with increase in fin number and fin thickness. Maximum cumulative fresh water yield of 5.377 (kg/m2day) was achieved when 7 number of fins was inserted with 0.04m height and thickness equal to 0.001 m, respectively. Fig. 14 represents the schematic diagram of finned solar still [29].

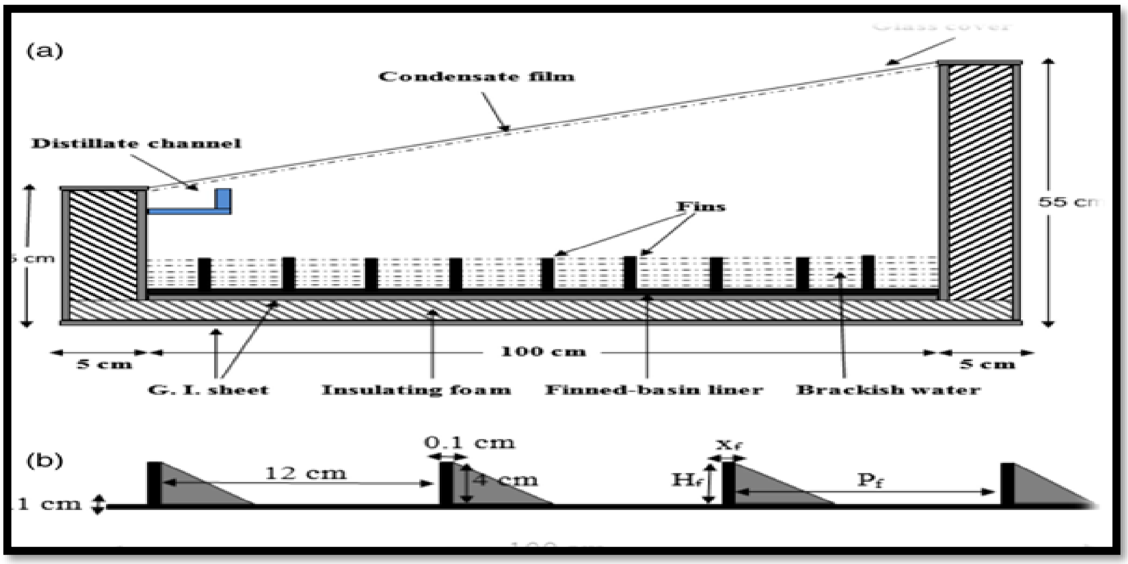

Figure 14: Schematic Representation of Finned Solar Still and Detailed Dimensions of the Fins

Yourself et al. investigated the performance study of solar still integrated with phase change material in basin liner using two distinct techniques. Firstly, pin fins were associated in basin liner with PCM to enhance heat transfer rate. Secondly, steel wool fibers (SWF) were integrated in basin liner with PCM to increase the water evaporation area. Fig. 15 depicts the pictorial representation of the experimental setup associated with PCM and SWF [30].

Four different cases of solar still were studied and compared. It includes conventional solar still (CSS), still embedded with PCM material (CSS-PCM), still with PCM and pin fins (CSS-PCM-PF) and still with PCM and SWF (TSS-PCM-SWF). The findings reveals that distillate yield of (CSS-PCM), (CSS-PCM-PF), and (CSS-PCM-SWF) were higher by 9.5%, 16.8%, and 13% than TSS respectively. Furthermore, the addition of pin fins enhances the energetic and exergetic efficiency as comparison to conventional still by 17.9 and 13.2%, respectively. Fig.16 depicts the productivity and energy efficiency for the four different cases.

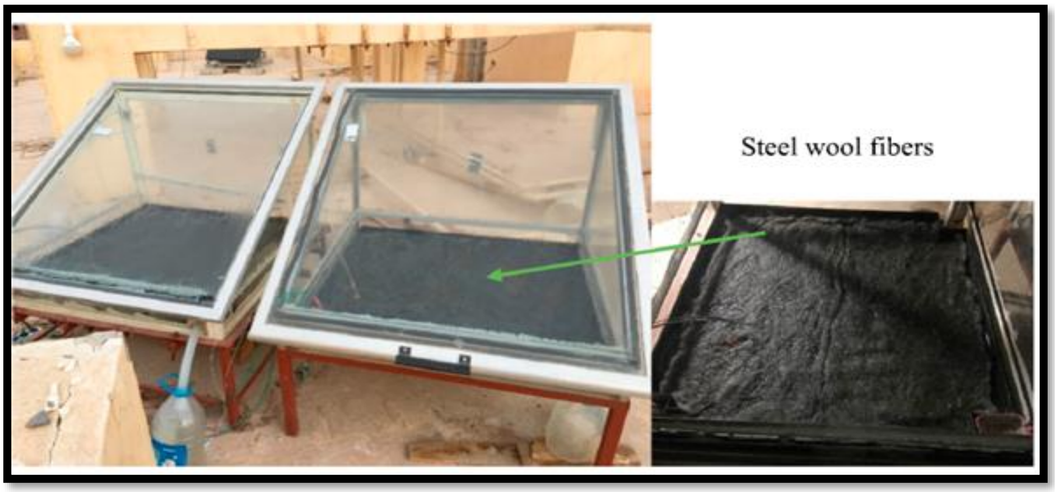

Figure 15: Experimental configuration of the solar still with SWF in basin liner

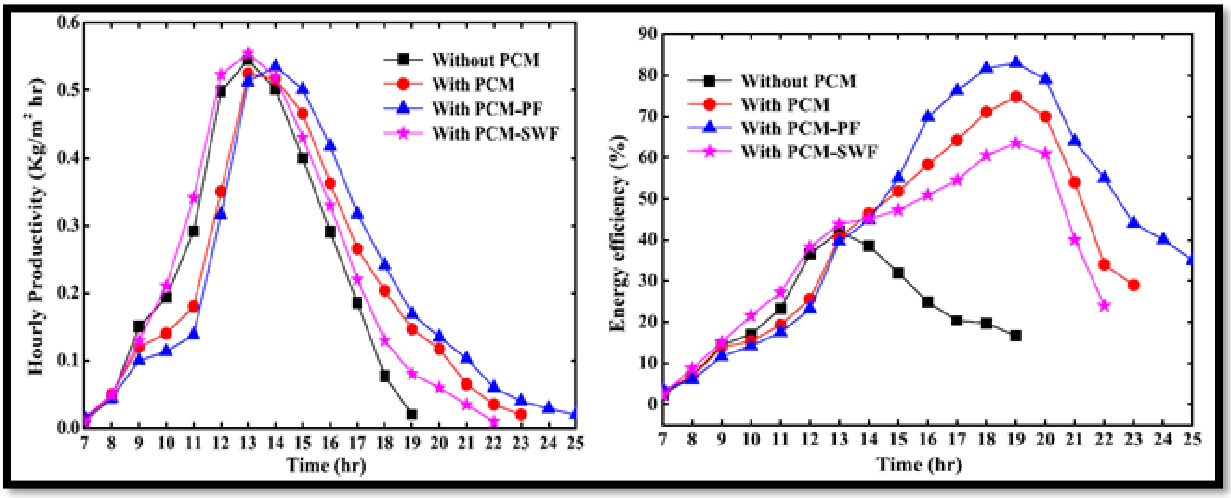

Figure 16: Variation of Productivity and Efficiency with Time

VI. APPLICATION OF HEAT STORAGE MATERIALS TO ENHANCE PERFORMANCE OF SOLAR STILL

1. **Effect of sensible heat storage material:** Shanmugan et al. design and fabricated single slope solar still by using basin liner made from copper sheet and system has incorporated with the mechanism of providing the feed water by dripping method into the basin. Additionally, the performance evaluation was done by incorporating different types of materials that stores sensible heat such as black stones, pebbles, calcium stones and iron scraps. Findings show that the calcium stones as sensible heat storage material with dripping mechanism have a significant effect on the performance of solar still. Fig. 17 presents the daily productivity of solar still with different energy storage materials. Fig. 18 shows various types of materials that stored sensible heat used in experimental study. Table 2 represents the thermal parameters of various sensible heat storing materials used [31].

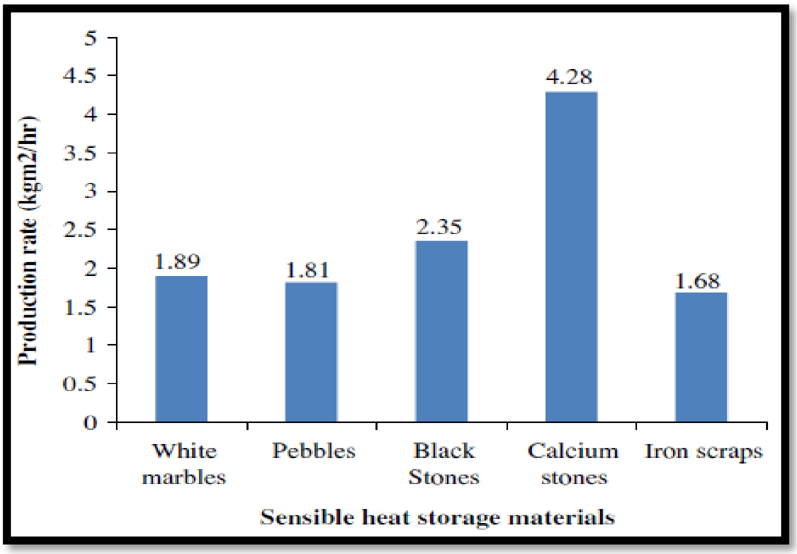

Figure 17: Fresh Water Yield with Various Types of Heat Storing Materials

Figure 18: Types Heat Storage Materials Incorporated in Experimental Setup

Table 2: The Thermal Characteristics of the Sensible Energy Storage Materials

Materials	Density (kg/m^2)	Thermal conductivity (W/mK)	Specific heat capacity (J/kg K)
Calcium stone	2560	1.26–1.33	910
Black stone	3070	2.06–2.90	750
White marbles	2160	2.08–2.94	880
Pebbles stone	3300	2.4–2.6	880
Iron scraps	8000	16	500

Elashmawy et al. performed experimental study by fabricating tubular shaped solar still associated with solar concentrator of parabolic type with sun tracking system (PCST). Productivity and efficiency of the solar still was evaluated by comparing the still with and without gravel as energy storage material. Fig. 19 depicts the key elements of the experimental setup TSS with PCST. The findings reveal that the efficiency with and without gravel were 36.34 and 31.9%, whereas, the fresh water yield with and without gravel were 4.51 and 3.96 L/ m2.day respectively. Fig. 20 represents the productivity comparison of TSS without gravel and PCST, TSS with gravel and TSS with gravel and PCST. Furthermore, the association of PCST system with gravel enhance the distillate yield of the traditional system by 890.4% and decrease in cost per liter (CPL) of distillate by 12% [32].

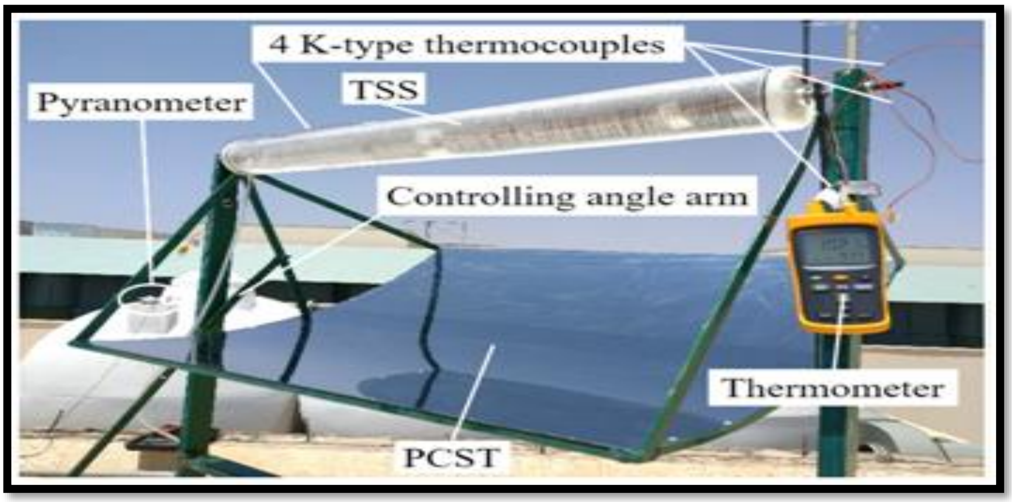

Figure 19: Experimental Setup Showing Main Components of TSS with PCST

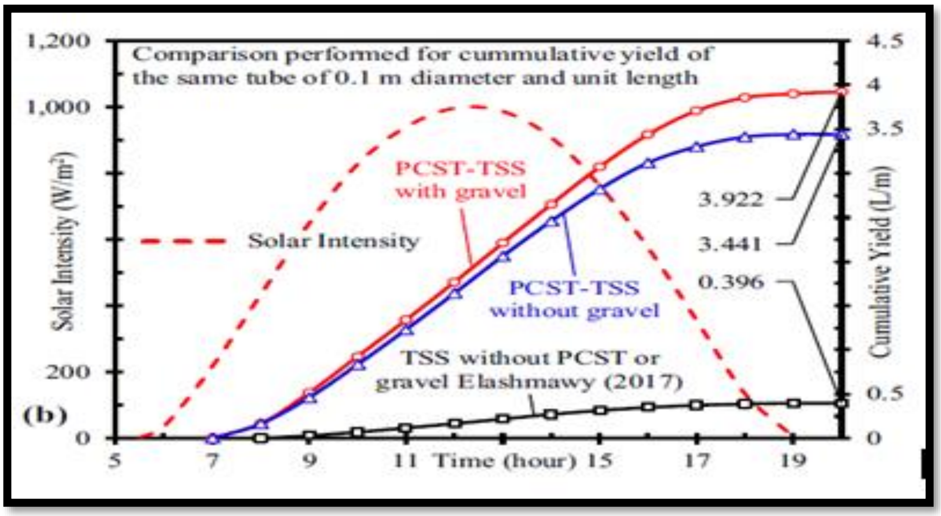

Figure 20: Productivity Comparison of Various Studied Cases

Dumka et al. compared the productivity of a conventional solar still and still incorporated with 100 cotton bags filled with sand. To increase the heat carrying capacity and surface area of the basin water, two identically sized solr stills were developed, constructed, and the sand-filled bags were stored vertically at equal distances within. Fig. 21 shows the Schematic representation of a cotton bag filled with sand. Experiment was carried out with different amount of basin water as 30 kg and 40 kg in the January and February month of 2019, at Guna, India. Experimental findings shows that the productivity of developed still was enhanced by 27.55 and 31% respectively. The overall energy efficiency was also increased by 28.96 for 30 kg and 31.31% for 40 kg [33].

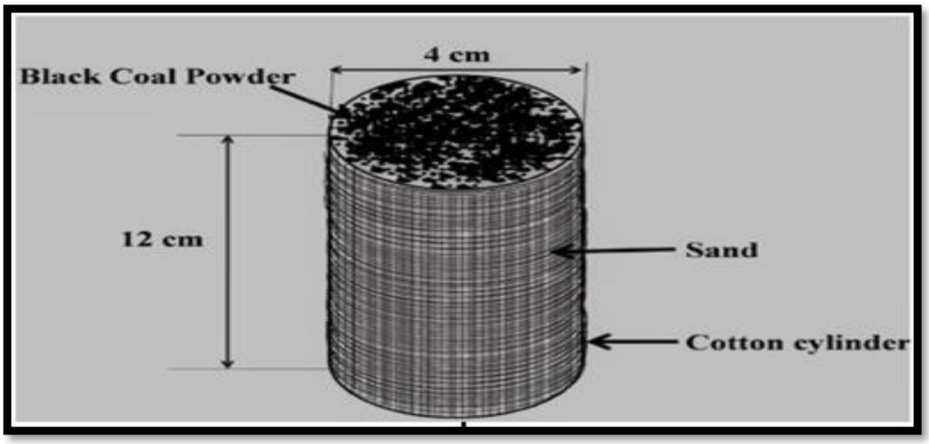

Figure 21: Schematic of a Cotton Bag Filled with Sand

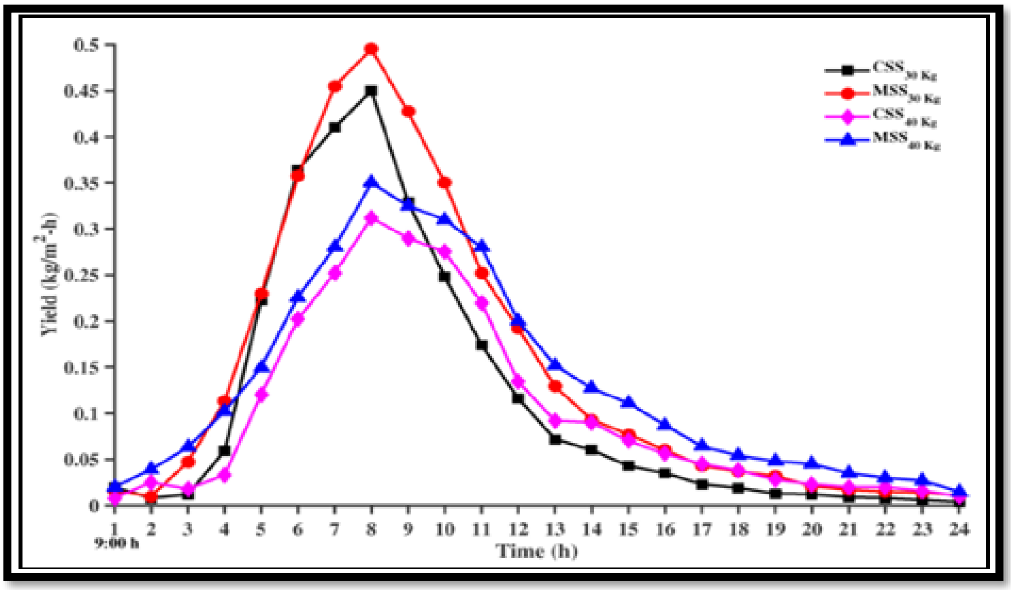

Figure 22: Fresh Water Yield Variation for CSS and MSS

The maximum fresh water yield obtained for 30 and 40 kg basin water for modified still was 10 and 12.18% greater than conventional still respectively. The daily fresh water yield obtained in case of MSS and CSS for basin water of 30 kg were 3.493 & 2.717 litres and for 40 kg basin water were 3.14 & 2.397 litters respectively as shown in Fig. 22.

2. **Effect of Latent Heat Storage Material:** Many studies have considered using storage of latent heat by adding phase change material (PCM), and PCM has emerged as the most promising and dependable method to store significant amounts of energy during melting and freezing processes. [34]. Fig. 23 represents the variation in temperature of PCM and the temperature remains constant during phase change process. The study also reveals that the PCM material has the ability to capture and deliver enormous quantity of latent heat during phase change period [35].

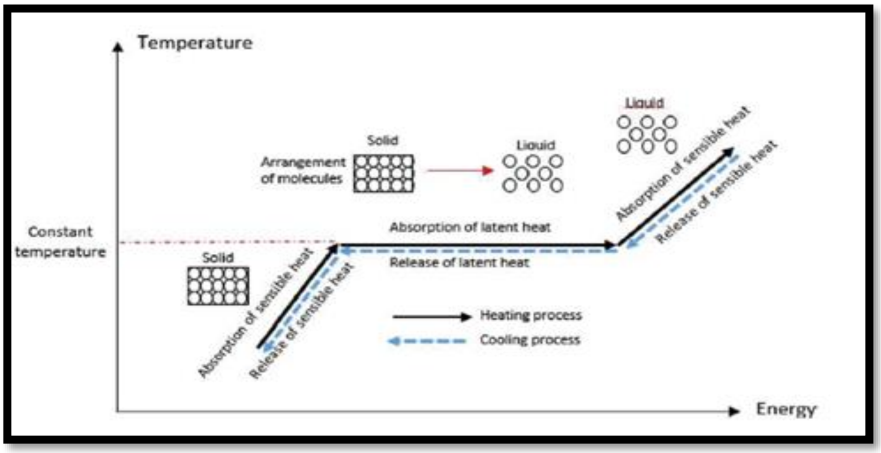

Figure 23: Variation of PCM Temperature in Phase Change Process (Ideal Case)

Kateshia et al. carried out experimental study by fabricating single slope solar still and carried out energetic, exergetic and economic analysis using palmitic acid as PCM materials associated with and without pin shaped fins. Three different types of solar stills were considered, Case-I- Traditional solar still, Case-II- Still with palmitic acid as PCM, Case-III- Still integrated with PCM and pin shaped fins. The daily cumulative yield increase by 24% and 30% for case II case III respectively as compared to traditional still [36].

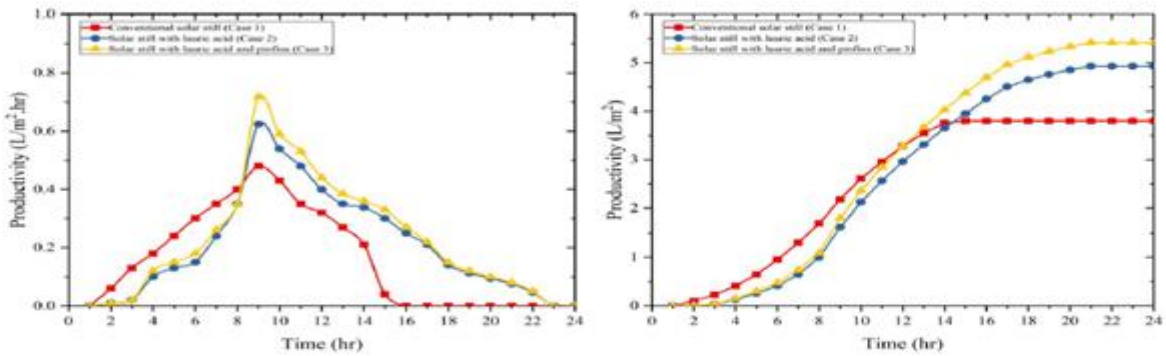

Figure 24: The Hourly and Accumulated Yield for three Different Cases

Figure . 24 depicts the hourly variation and accumulated fresh water yield of the above discussed three cases. The fresh water yield for the solar still with PCM and with PCM and fins was less at early hours but overnight yield and total yield was high in comparison to traditional still. The obtained cumulative fresh water yield for the three cases, I was 3.8, for II was 4.9 and for III was 5.4 L/m^2.

The passive single slope solar still was developed by Sonker et al. To improve the distillate yield, three different forms of PCM—paraffin wax, stearic acid, and lauric acid—stored in copper cylinders were evaluated and compared with solar stills. The effects of variation of water depth were also taken into consideration. It has been found that the basin water temperature decreases with increase in water depth, with paraffin wax water temperature drops by 9.2% whereas for stearic acid by 17.6% and lauric acid by 21.5%. The cumulative yield has been enhanced by 1.202 for paraffin wax, 1.015 for stearic acid, and 9.30 Kg/m^2-day for lauric acid [37].

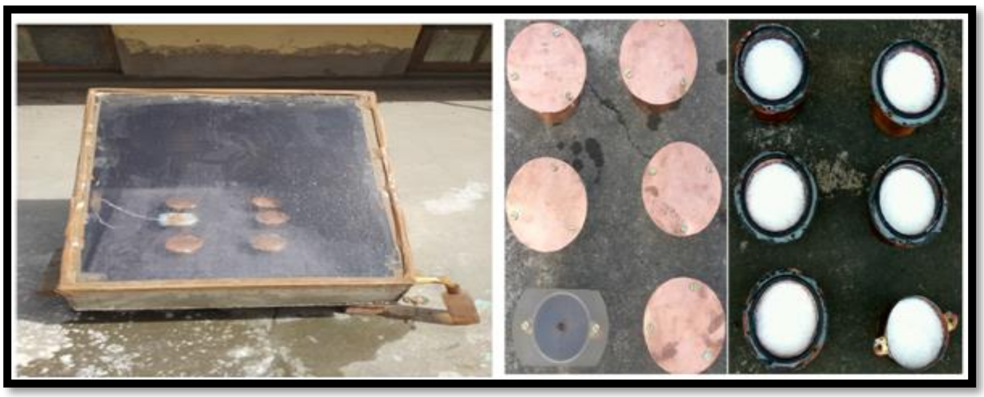

Figure: 25 Pictorial Representation of Single Basin Solar Still and Copper Cylinder Filled With PCM

Kabeel et al. carried out investigation to increase the productivity of drinkable water of tubular still (TSS) by incorporating PCM embedded with nano particles. The performance evaluation was done by using three different experimental setup namely TSS, TSS incorporated with PCM and TSS embedded with nano enhanced PCM under the atmospheric condition of Chennai, India. The use of graphene oxide as a nanomaterial significantly increased the thermal conductivity of the nano enhanced PCM by 52%. Fig. 26 represents the thermal conductivity variation and its enhancement with varying mass proportion of nanoparticles, it also shows that beyond 0.3% of nanoparticle addition, no significant enhancement in thermal conductivity achieved. The total fresh water yield obtained from TSS, TSS with PCM, and TSS with nano enhanced PCM was 2.59, 3.35 and 5.62 kg/m^2 respectively. The daily thermal efficiency of TSS with nano enhanced PCM was increased by 116.5% as compared to TSS. The hourly fluctuation of fresh water output for the studied cases is compared in Fig. 27. Table 3 presents the work that has been already carried out with different types of solar still embedded with different types of PCM [45].

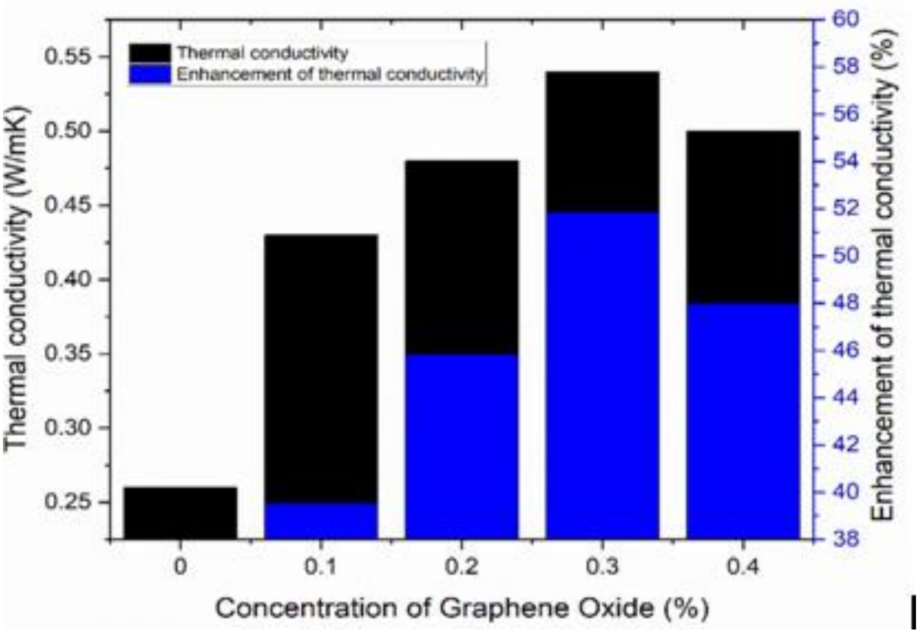

Figure 26: Thermal Conductivity Variation and Enhancement with Varying Mass Proportion of Nanoparticles

Table 3: Experimental Work Carried out by Various Authors with Different Design Configuration and PCM in Solar Still

Sl. No.	References	Type of Solar Still	PCM Used	Result
1	S. Ravishankara (2013) [38]	Triangular pyramid solar still	Parafin wax	Productivity increased by 20%
2	Mousa and Gujarathi (2016) [40]	Still with external solar collector	PCM with melting temp. range from 40 to 50^{0}C	Increase in productivity & efficiency
3	Shalaby et al (2016) [39]	Single slope solar still associated with V-corrugated absorber plate	paraffin wax	Cumulative productive enhance by 12 %
4	Kabeel et al. (2016) [41]	Single-basin still	PCM	Productivity enhanced to 7.54 for modified still in comparison to traditional solar still 4.51 L/m^2 day.
5	Faramarz Sarhaddi (2017) [42]	Two weir type cascade solar stills	PCM	Energy and Exergy efficiencies for conventional still in sunny day were 76.69% and 6.53%, whereas with PCM for a semi cloudy day were 74.35% and 8.59%.
6	Meysam Faegh (2017) [43]	Single-basin still associated with evacuated tube collectors	Paraffin as PCM)	External condenser without PCM yield obtained was 56% whereas the yield augments by 86% by using external condenser filled with PCM.
7	Kabeel et al. (2019) [26]	Single slope solar still	PCM	Cumulative fresh water yield, energy and exergy efficiency by incorporating PCM were 3.27L/m2, 48.22 % and 3.08 % with an increment about 37.56 %, 38 % and 37 % respectively.
8	Cheng (2019) [44]	Single basin single solar still	New shape-stabilized PCM	Cumulative fresh water productivity obtained was 3.41 L/m2, which was 43.3% higher than that of traditional solar still.
9	Dsilva Winfred Rufuss Da (2018) [47]	Single basin solar still	Paraffin with TiO2, CuO and GO	Conventional still, Still with TiO2, Still with CuO and Still with Graphene oxide yielded 3.92, 4.94, 5.28 and 22 3.66 l/m2 /day respectively.

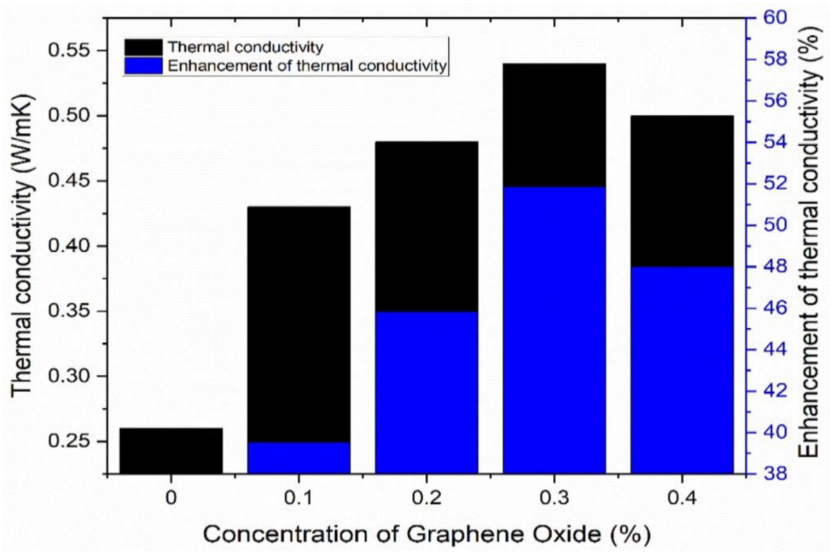

Figure 26: Thermal Conductivity Variation and Enhancement with Varying Mass Proportion of Nanoparticles

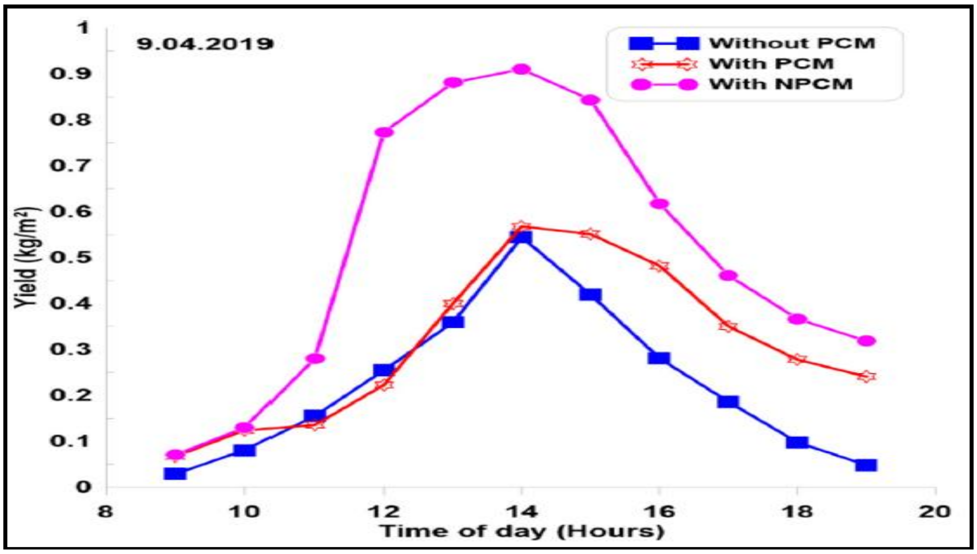

Figure 27: Comparison of Hourly Variation of Fresh Water Yield from Studied Cases

Thalib et al. investigated the performances of tubular-shaped Solar Stills (TSS), TSS included with PCM, and TSS embedded with nano enhanced PCM using paraffin wax as an energy storage medium and grapheme as nano materials. Pictorial depiction of the experimental setup is shown in Fig. 28. The fresh water yield for TSS, TSS with PCM, and TSS with nano enhanced PCM was 4.3, 6.0, and 7.9 kg, respectively, while the corresponding stills energy efficiency was 31, 46, and 59%. The fluctuations in fresh water production of TSS, TSS combined with PCM, and TSS embedded with nano enhanced PCM over time are depicted in Figure 28 [46].

Figure 28: Pictorial Representation Of Experimental Setup

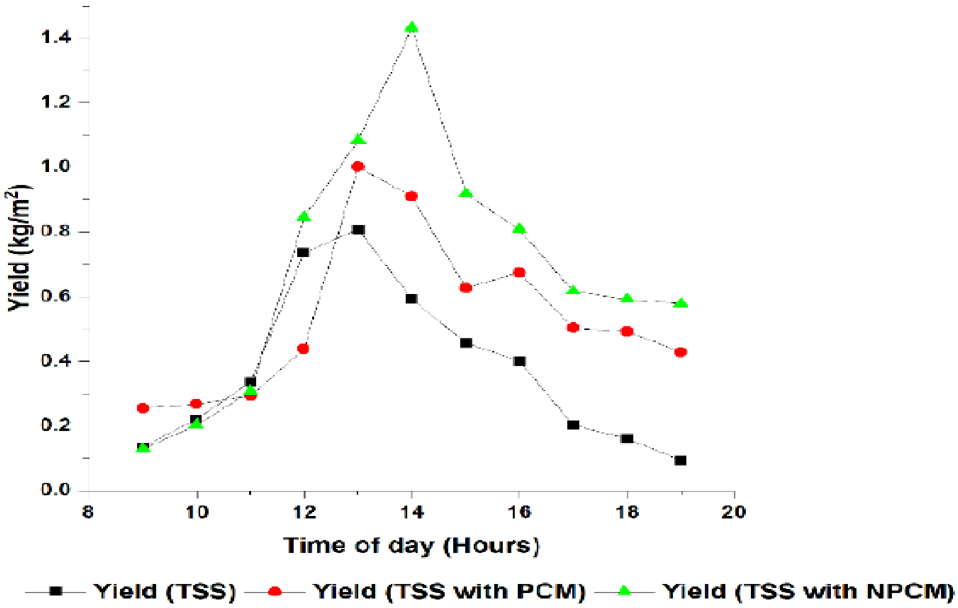

Figure 28: Hourly Variations of Fresh Water Yield of Different Cases

VII. CONCLUSION

The current chapter exhibits the reviews of various relevant papers associated with development and modification of solar still to enhance the efficiency and performance of solar still. The parameters that affect the still performance are meteorological parameters, design modification, incorporation of metallic fins, and integration of energy storage material either in sensible or latent heat form was considered in this study.

The meteorological parameters includes solar radiation, air temperature and wind velocity that directly correlated with the productivity of solar still. The design modification

considers different design configuration of solar still such as dual slope solar still, stepped solar still, wick type solar still, , inclined solar still associated with external condenser system, weir type solar desalination system, glass angle inclination, basin water depth variation and glass cover temperature. The study reveals that the productivity of solar still highly depends on water depth which is a strong function of water basin initial temperature.
The effect of incorporating sensible heat storage material (Gravel, Pebbles, White marbles, Sand filled cotton bags) in the basin liner was also presented in this chapter. Table 3 shows the experimental and numerical analysis carried out by various authors with PCM and Nano enhanced PCM in different design configuration of solar still. Experimental and analytical investigations of various papers on different types of solar still associated with variety of phase change materials (Paraffin wax, Lauric acid, stearic acid, palmitic acid) and Nano enhanced PCM's have been reported in this chapter.

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