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Solar distillation of water employing thermal energy storage medium: A review

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ABSTRACT

Population explosion and the development of industrial as well as agricultural sector in the last decades caused the exponential growth in portable water need. Additionally, Climate change and global warming can contribute to the desertification and the increase of the sea level, which lead to the fresh water scarcity. Over the years, harnessing solar energy for desalinizing sea water has become one of sustainable and economical technique to supplement into global clean water resource. There are numerous efforts to improve the productivity as well as thermal efficiency of passive solar still for commercialize in large scale. Amongst these technological advancements, approach applying energy storage materials has been received much attention for an efficient performance of solar still, which can be a key solution to help solar application operate at off sunshine hours. In this work, the performance of thermal energy storage materials including sensible and latent heat storage material in a solar still was reviewed. The best design for increment the PCM's thermal conductivity is the hollow-cylinder fins. The additional time as using phase change materials depends on the amount of brackish water in basin and phase change materials. Paraffin wax showed the best improvement in the daily distilled yield of a conventional solar still within used phase change materials. The low thermal conductivity of Paraffin wax can be solved with the hollow cylindrical pin fins in the design of basin.

KEYWORDS

solar energy, distillation of seawater, sensible heat storage, phase change material, distilled productivity.

INTRODUCTION

Exponential growth of population and the development of industry as well as agricultural field resulting to the energy crisis, environmental concerns, and potable water scarcity for human activities, which are recent urgent issues need be addressed around the world. Indeed, there is an exponential increase in consuming global energy over the years that leads to the amount of greenhouse gases emitted to the environment. Consequently, harnessing alternative energy sources has received more attention and become a sustainable and effective method [1]. It is apparent that there is an increasing development of utilizing alternative energies such as wind, wave especially the sun in an effort of reaching net-zero emissions through manage energy rationally and effectively [2]. The promising of solar energy is undeniable. Solar energy is population free, virtually no maintain, which may help us reduce our dependence on fossil fuel [3]. Moreover, solar energy is applied for a variety of purposes such as electrical generation (solar photovoltaic cell), maritime transportation, solar dryer, biodiesel production, air and water heating, and ventilation [4-12].

Solar distillation of water has emerged as one of an interesting system over the years which may play an additional resource to supply portable water for human activities [13]. It is able to remove hazardous heavy metals, inorganic and organic substances, and bacteria from the water by solar still [14]. Solar distiller is one of the low-carbon technologies because there is no greenhouse gas exhausted from them [15]. Regions acceptable to use sunlight power can build solar still on a large scale to supply drinkable water for the community [16]. A passive solar distiller has the simples construction that generally consists of a basin with a single glass cover on its top [17, 18].

Impure water will be filled inside the basin which can be insulated on all its own sides. When the sun appears, the rays will transmit through the cover and the basin will absorb this energy to evaporate the brackish water [19]. The water vapor touches the cover with lower temperature and then gets condensed into droplets on the cover surface. As these droplets grow heavier, they will flow down to a collector due to gravity effects (top cover usually inclines a specific angle). Water is distilled by solar still can reach Total Dissolve Solid (TDS) of 30 PPM, which meets the standard for drinking water [20,21].

Heat loss through top cover is an essential factor for condensing water vapor rapidly and completely [22]. Meanwhile heat loss through the bottom and sidewalls should be minimized or utilized to improve the system's efficiency as well as productivity [23]. Such heat losses can be utilized by energy storage mediums which also store excess heat as solar irradiation reached a peak. Stored heat can be reused as a good solution for the intermittent characteristic of the sun which is a disadvantage for its commercial scale [24]. Thermal energy storage can be categorized into thermal and thermos-chemical types [25]. Thermal storage materials can be classified as sensible heat storage and latent heat storage materials (or PCM). The sensible heat storage materials (SHSM) improve the solar thermal devices in operational time such as the sensible storage material in solar dryers can enhance its performance and keep the quality of the product in good, especially color quality.

The application of sensible heat materials helps several solar applications to be able to operate after sunset. Several natural substances in term of solid (such as granite, rock, sand, dry brick, fire brick, waste concrete, pebbles) and liquid medium as water have been employed as sensible heat material. The common advantage of using sensible heat storage is to extend daily drying time, however, there is the reductant of efficiency in the storage system due to the air temperature is not constant in the discharging process. Unlike SHSM, the time between energy supply and demand can be reduced by the latent heat storage materials (LHSM) usage approach which plays an important key in conserving energy as well as enhancing the reliability of solar devices. PCM provide heat for distillation process of impure water after sunset. Recently, phase change materials have emerged as a potential and suitable support material for not only solar applications but thermal devices also such as photovoltaic thermal systems, passive cooling in the building, solar dryers , solar water heater, heat exchanger, solar cooker, automotive applications [26-32].

As a result, Various latent heat storage materials employed in solar still have been studied for example variety of paraffin, saturated fatty acids. Widespread reviews have been published by many researchers on solar stills applying the energy storage mediums to for example Fernandez et al. reviewed potential sensible storage materials [33], Dsilva Winfred Rufuss et al. work paid attention on material properties, prioritization, selection and future research potential for LHSM for solar desalination devices [34], A review of phase change materials (PCMs) with phase transition temperatures between 0 and 250^{o}C is presented by Cunha and Eames [35], Shukla et al. reviewed latent heat energy storage in solar still [36], Dinker et al. reviewed various kinds of heat storage materials, their composites and applications investigated [37], the thermo physical properties along with applications of PCM was reviewed by Mukherjee [38], A summary on solar still employing sensible and latent heat was caried out by Gugulothu et al. [39], Bait and Si-Ameur presented a comprehensive outlook about the role of nanofluids in solar energy desalination technologies [40], Bose and Amirtham reviewed methods improved paraffin wax's thermal conductivity [41], Parikh reviewed application of nanoparticle in solar distillation system [42], Improving the solar still performance by using thermal energy storage materials: A review of recent developments [43]. Nevertheless, there is a lack of a comprehensive investigation on the use of sensible heat storage system in solar still and literature related to latent heat storage material do not perfectly recommend the most excellent phase change materials for solar distiller. Consequently, it is necessary to evaluate the best performance and efficiency of PCM for efficient solar still. Comparing the productivity and thermal efficient of various types of passive solar stills employing SHSM is the aim of this review work to determine the most appropriate PCM for solar still.

HEAT STORAGE MATERIAL

Sensible heat storage

Utilizing intermittent energy sources to meet global energy needs can be solved by applying energy storage, especially renewable resources like solar. Energy can be stored in terms of mechanical, electrical as well as thermal energy by various techniques [44]. The charging and discharging process in the sensible heat storage system is performed due to utilizing the heat capacity of solid or liquid for a temperature change of the material. The parameters affect how much heat is stored including the specific heat, the temperature change, and storage mediums [45]. The sensible heat storage capacity of some commonly selected materials is shown in Table 1. Water is well known as the best SHS liquid due to its low cost and high specific heat. However, for temperature is more than 100ºC, molten salts, oils, and liquid metals, etc. are used above. Rocks are employed for applications to increase air temperature. The storing heat energy ability of the material depends on their heat capacity (multiple between specific heat and density)

Latent heat storage

Latent heat storage (LHS) refers to two processes namely energy absorption and energy release by a material changing state at a constant temperature. Transferring heat is performed since the chemical bonds in the material were broken up and changes from the solid-state to the liquid state, or vice versa [46]. Figure 1 illustrates the function of phase change materials. Firstly, in the solid-liquid change, their temperature increases by absorbed heat. when materials reach melting temperature, large amounts of heat were absorbed without hotter. The temperature remains unchanged till completing the melting process. The majority of PCMs are melted with a specific fusion heat at any requested range [47]. Nevertheless, in order to utilize for storing heat, the certain desires for these phase change materials have to include thermal, kinetic, physical as well as chemical properties [48]. Additional importantly properties need to be considered consisting of economical effective and large-scale availability. Phase change materials can be divided into three groups consist of organic, inorganic and eutectic compounds as shown in the Figure 2. The pros and cons of PCM's group also was described in this figure.

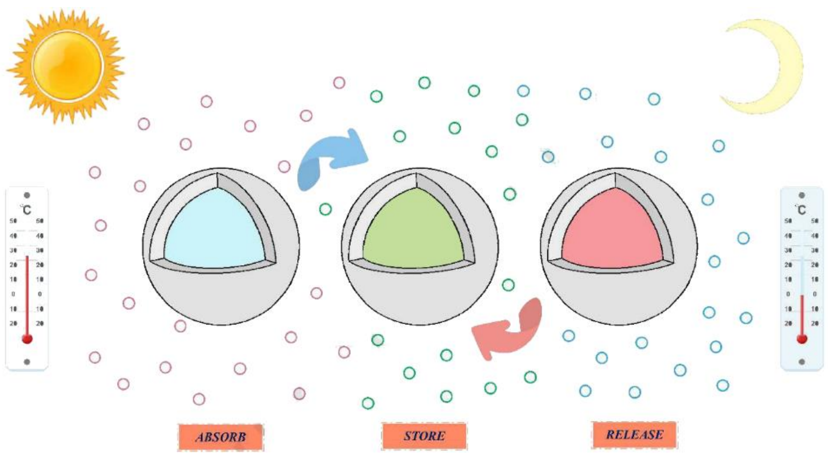

Figure 1. Function of phase change materials [49]

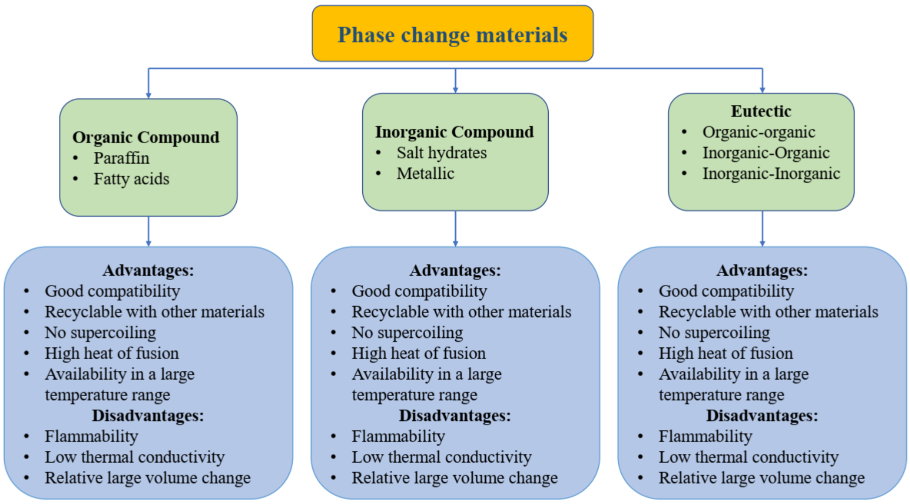

Figure 2. Classification of phase change materials [49]

Solar still with sensible heat materials

Raj et al. [50] experimented sand stone, stone chip and calcium oxide in the conventional solar stills simultaneously. Sand stones and stone chip were placed on the basin of solar still, while calcium oxide reacts with water in a box to preheat water before flowing inside solar still. Their experimental data revealed that the calcium oxide obtained the highest yield of 3 L/m^{2}day, flowing by, stone chip and sand stone and the use of thermal heat storage improved the performance of solar still by 18.41% with sand stone, 19.8% with stone chip, and 26.98% with calcium oxide. Samuel et al. [51] investigated a single basin single glass solar distiller with two methods. The first method is applied rock salt which was encapsulated in spherical balls for storing heat and the second method used sponge for capillary effect. In the first method, there are 15 balls and each ball contained 127 grams of rock salt. From observed results, the solar distiller produced the highest portable water of 3.7 kg/ m^2 with rock salt, following by with sponge 2.7 kg/m^2 and without storage materials 2.2 kg/m^2. Kanchey marbles was tested as heat storage material in a double glass solar still by Saravanan et al. [52].

The solar still with kanchey marbles attained approximately 4.1 L/m^{2}day which was higher than that without marbles (3.52L/m^{2}day). The overall improvement of thermal efficiency was 16.32%. Kabeel et al.[53] used composite thermal storage material which was combination of paraffin wax and black gravel, sandwiched between basin and a fiber glass insulation layer. The daily distilled fresh water from such system was 3.27 L/m2 which was increased that from solar still with only PCM by 37.55%. The enhancement in energy efficiency was 38% while that in exergy efficiency was 37%. It is interesting that 1 liter of fresh water produced from the use of composite thermal storage had the price of 0.0014 US$/m2 which reduced to 27% compared to the use of PCM. Kanchey marbles was tested as heat storage material in a double glass solar still by Saravanan et al. [52]. The solar still with kanchey marbles attained approximately 4.1 L/m^{2}day which was higher than that without marbles (3.52L/m^{2}day). The overall improvement of thermal efficiency was 16.32%. Kabeel et al.[53] used composite thermal storage material which was combination of paraffin wax and black gravel, sandwiched between basin and a fiber glass insulation layer.

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It is reported that the optimum storage mass for sand as well as SM oil is around 0.5 cm depth. The maximum daily productivity of solar still with sand and oil was approximately 2.53 L/m^{2}day and 2.61 L/m^{2}day at water depth of 0.6 cm and storage medium thickness of 0.5 cm. The influence of basalt, pebbles, sandstone, granite, and blue metal stone was studied in the work Balaji et al.[56]. The conventional solar still with SHSM was tested with three different water depth of 1 cm, 2 cm and 3 cm. The highest productivity belonged to the use of sand stone at 1 cm and 2 cm of water depth (614 ml and 482 ml, respectively), basalt at 3 cm of water depth (550 ml). They suggested the water depth of 1cm, sand stone material with 15 mm size and 1 kg of mass was optimum parameters to achieve higher efficiency. Sand was filled in jute cloth bags filled was used as heat storage material in the study of Kabeel et al. [57]. The output of solar still with storage material was 5.9 L/m^{2}day, whereas that without storage material was 5 L/m^{2}day. The integration between capillary effect by applying jute wicks along with energy storage enhanced the daily yield. The solar distiller productivity was augmented through employing graphene in Kabeel et al. work [58]. 26.55 kg of graphene was used in the study, which improved daily yield of solar still from 4.41 L/m^{2}day to 7.73 L/m^{2}day.

The higher thermal conductivity of graphene was explained for the enhancement in productivity. Mohamed's group [59] experimented solar still with basalt stones in a solar still. Their result showed 1.01 L/m2.day of distilled water produced with the basalt stones which is higher than the reference solar distiller (0.79 L/m^2day). Basalt stones has high specific heat capacity, that improved the evaporation process. Additionally, the experimental and theoretical investigation of permanent magnets in the solar still was carried out by Dumka et al. [60]. According to their report, the solar still with magnets obtained 49.22% higher distillate yield in comparison to the conventional solar still. Arunkumar et al. [61] elucidated the influence of various absorbing materials in the conventional solar still. Polyvinyl alcohol sponges, pebbles, spherical clay balls and CuO nano-coated absorber plates were employed in their study. The accumulated yields of the solar still was maximized with CuO nano-coated plates (2.9 L/m^2day), following by pebbles (2.8 L/m^2day), spherical clay balls (2.6 L/m^2day), and polyvinyl alcohol sponges (1.9 L/m^2day). The calculation of thermal efficiency was 53%, 44%, 39%, and 32%, respectively.

SOLAR STILL WITH LATENT HEAT MATERIALS

Solar still with fatty acids as latent heat storage mediums

Passive solar stills have simple construction, low cost, which is also easy for maintained. Generally, there is no external device support heat for their distillation process. The first study relating to employ PCM in a conventional solar still was conducted by Naim et al., [62]. They mixed paraffin wax (PW), paraffin oil and water was mixed to use for storing heat purpose and augment the performance of the multiple-basin solar still. Their system reached the daily yield of 4.53 L/m^2day at mass flow rate of 40 ml/min. the thermal efficiency of their system showed 36.20%. Investigation of paraffin wax in a steeped type solar still was carried out by Radhwan [63]. According to their results, the still with phase change material got 4.6 L/m^2day of daily distilled water with an efficiency of 57%. As reported in Murase et al., study [64], employment of PW in tube-type solar still increased the daily output by 15%. The productivity of the double-glass solar still was augmented by paraffin wax up to 24.52% in the work of Ravishankar et al., [65]. The thermal efficiency of solar still with PW was 60% while 45% was obtained in case of without PW. A triangular pyramid solar still was fabricated by Sathyamurthy et al., [66], which used paraffin wax as storage medium. It is noted that because of latent heat transfer, the temperature of PCM was constant in the afternoon. The daily yield was improved from 3.5 L/m^2day to 5.5 L/ m^2day and the thermal efficiency raised to 35% with the support of PCM.

Solar still containing paraffin wax was evaluated in Sonawane et al., work [67] the productivity was improved by 62% as compared to conventional solar still. Their finding remarked that the optimum tilted angle of top cover equal to zero degrees. However, as condensed water droplet become heavier will drop down to the basin. Hence, inclination of top cover is necessary to avoid this downfall. Transient performance of stepped solar still with paraffin wax was analyzed by Radhwan [63]. Their results showed that the still with PCM had the thermal efficiency of 57%, simultaneously, the overall daily productivity was 4.6 L/m^2day. Experimental and theoretical analysis of paraffin wax in weir type solar still was carried out by Tabrizi et al. [68].They indicated that increment of the flow rate lead to the decline of output and overall efficiency. The daily distilled yield was 7.4 kg/m^2day and 4.3 kg/m^2day at mass flow rates of 0.065 kg/min and 0.2 kg/min. The Both of them were reviewed by Yadav et al., [69]. They stated that the weir type solar still had more abundant residence time of water on the basin than the stepped type which lead to the higher in productivity of weir type solar still. Shalaby et al., [70] modified a conventional solar still with a v-corrugated basin and paraffin wax was placed under the basin. The use of v-corrugated shape enlarged area for energy absorption and evaporation rate of brackish water. They integrated copper tubes under the absorber also with vents to address the issue as volume of wax increased in melting and air bubbles was created in freezing process. They conclude that the daily yield of the solar still with the PCM was 12% better than the conventional still at a specified water mass.

Comparison between paraffin wax and black pebbles was conducted by Patil et al., [71] in a double glass solar still. They achieved an improvement of 30% and 18% in productivity with PCM, and black pebbles, while the mixture of them raised the productivity by 13% as compared to without storage material. It is indicated that paraffin wax is more useful than black pebbles. Their obtained experimental results showed that the maximum hourly distilled water was obtained at daytime for black pebbles while that was achieved at off-sunshine hour for paraffin wax. A pyramidal solar still was examined with and without paraffin wax in Sundaram et al., work [72].

They experimented with different water depth of 1, 2 and 3 cm. The productivity of solar still with PCM was optimized at a brackish water depth of 1 cm, with an 11.6% increment.

Paraffin wax was applied as a heat reservoir under an absorber of a double slope solar still in the research of Ashish Kumar et al., [73]. A glass faced to the east direction while the rest faced to the west direction and their experiment was conducted in 24 hours. They noted that the east side glass achieved the higher solar radiation than the west side till 14 o'clock while it was opposite at the rest of day time. Additionally, their data showed the higher difference between temperature of the west side glass and brackish water, hence freshwater condensed on the west side glass was higher than that on the east side glass. By contrast, in the night time, the distilled water from the west side glass was lower than that from the east direction glass. Overall, 61% gain in daily productivity was obtained with paraffin wax employment, while a 34% nocturnal and 64% gain in a day time. A similar type of solar still was studied with paraffin wax by Husainy et al. [74] which improve the daily yield by 25%. A double state double glass solar still with paraffin wax was fabricated and tested by Katekar & Deshmukh, [75]. The lower distiller was designed as a single basin, double slope solar still and the double slope of lower still played a role as the basin of upper still. The PA was placed under lower basin. Steps were designed on the upper basin to contain the brackish water. The brackish water in the upper basin utilized heat loss released from the lower basin. 4.59 L/m^2day of potable water was collected by their system with the efficiency of 27.21%.

Yousef and Hassan investigated the performance of a passive solar still loaded with paraffin wax and the impact of PCM on the still output [76]. Five cases were experimented in their study. Case 1: conventional solar still without any support (CSS), Case 2: solar still loaded with paraffin wax attached to the still base, Case 3: solar still with hollow cylindrical pin fins imbedded in the phase change material, case 4: solar still with PCM and steel wool fibers (SWF) in the still basin and case 5: solar still with only steel wool fibers in the still basin. According to their obtained results, the total accumulative productivity was 3.26, 3.57, and 3.81 kg/m^2 in cases 1, 2 and 3 as shown in **Figure 3**. The use of PCM enhanced the output of the solar still by 10%. Additionally, the hollow cylindrical pin fins also improve the performance of PCM. As seen in the **Figure 3,** the working time of solar still was extended up to 4 hours in case 2 and 6 hours in case 3.

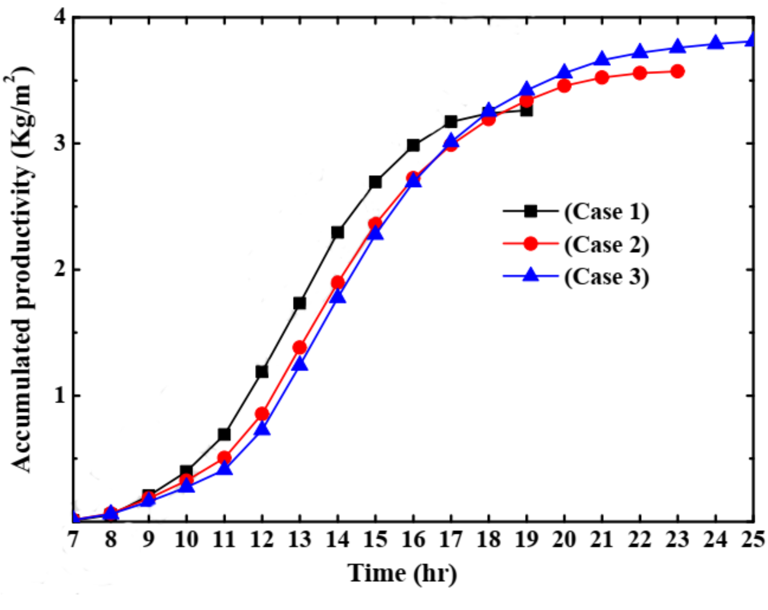

Figure 3. Accumulated productivity of case 1, 2 and 3 in the study of Yousef and Hassan [76].

Comparison of various passive solar distiller with paraffin wax are shown in **Table 1**. It is noted that the use of paraffin wax in a conventional solar still improve significantly the daily distilled yield up to 180%. According to this table, There is an considerable increment in the productivity of triangular solar still loaded with paraffin [66]. In addition, the effect of paraffin wax on the performance of double slope solar stills are not notable. The energy received by double glass was 8% and 5% lower than single glass cover in winter and summer seasons [65] [73] [74] [77].

Table 1. Investigating the performance of paraffin wax on different passive solar stills.

Ref.	Type of solar still	Productivity		Percentage increase (%)	Thermal efficiency		Percentage increase (%)
		With PA	Without PA		With PA	Without PA	
[65]	Double slope, single basin	5.3	4	24.52	60	45	33.33
[78]	Triangular solar still	6	3	100	-	-	35
[67]	Single glass, single basin	1.748	2.827	62	-	-	-
[69] [79]	Weir type solar still	3.4	2.1	35.31	-	-	-
[70]	v-corrugated basin, single glass	3.762	3.357	12	37.1	32.9	12.76
[80]	Single glass, single basin	4.21	1.512	180	-		-
[73]	Double slope, single basin	-	-	61	-	-	-
[76]	Single glass, single basin	3.572	3.26	10	-	-	-
[81]	Weir type solar still	7.44	4.41	68.71	86.6	51.3	68.81

Solar still with fatty acids as latent heat storage mediums

Lauric acid is a saturated fatty acid, which has low melting temperature, good thermal reliability and chemical stability [82] [83]. Al-Hamadani and Shukla [84] investigated experimentally a conventional solar still used lauric acid for storing heat purpose. In their work, the influence of the brackish water mass (30, 40, and 50 kg) along with lauric acid (0, 10, 20 and 30 kg) was examined. According to their report, the mass of water reduced leading to the rise of the daily distilled yield in daytime, nevertheless, in the night time the productivity was proportional with the quantity of water because water has high thermal capacity and PCM emits heat after sunset. It is observed that the PCM reduced the heat loss to surrounding air and enhanced the productivity of the system by 30%. 10 kg of PCM mass showed the highest productivity at brackish water mass of 30 kg. The productivity at night was increased by 127% with PCM.

Potassium permanganate is an inorganic compound usually is used in chemical industry. It occurs widely in the earth even in the natural waters. Potassium dichromate crystals are orange-red, monoclinic, plate-shaped crystals [85]. Investigation of different PCM including potassium permanganate ($KMnO_4$), sodium acetate ($C_2H_3NaO_2$), and potassium dichromate ($K_2Cr_2O_7$) was presented by Somanchi et al., [86]. Sodium acetate is a hydrated salt PCM. They concluded that presence of $KMnO_4$ in brackish water could provide higher daily yield in comparison to that of $C_2H_3NaO_2$ and K2Cr2O7 because the melting point of $KMnO_4$ is lower than $C_2H_3NaO_2$ and K_2Cr_2O7. Bitumen is well-known as asphalt is the historical engineering material which is sticky, dark viscous liquid or semi-solid form [86]. Bitumen was employed in a double slop solar still in Kantesh's study [87]. Their results showed the rise of the daily yield was to 2% and the increment of energy efficiency up to 7.1%.

Palmitic acid and stearic acid are the primary fatty acids extracted from petroleum ether [88]. El-Sebaii et al., [89] developed mathematical models to investigate the performance of a conventional solar still with and without steric acid loaded under the absorber. The numerical results indicated that the daily output of the still with steric acid was about 9 kg/m^{2}day and the daily efficiency was 84.3% with stearic acid's thickness of 3.3 cm while that of conventional solar still was approximately 5 kg/m^2 day. A single absorber solar distiller with palmitic acid was evaluated in the work of Palpandi and Raj [90]. They discovered that the salts and minerals present in seawater caused the lower quantity of distilled water. Distillation of sea water achieved 1.87 L/m^{2}day and 3.4 L/m^{2}day without and with PCM while 2.05 and 3.595 L/m^{2}day was obtained without and with PCM as distilling bore water.

The efficiency of solar still with PCM increased by 11.94% and 12.51% for bore well and sea water respectively. The effect of three latent heat storage materials consisted of Beeswax, Stearic acid, and Palmitic acid were tested in a weir type cascade solar still by Mahesh Kumar et al., [91]. They revealed that palmitic stored more energy than the other tested PCM. The highest daily yield belonged to the solar still with palmitic acid was 2.35 L/m^{2}day. Compared to conventional solar still, the daily distilled yield and energy efficiency increased by 33.69% and 35.46%, respectively with the support of PCM. A passive solar distiller with stearic acid and paraffin wax was evaluated by Subramanian [80]. The stearic acid usage enhanced the productivity by 164% while 180% in productivity improvement was obtained with paraffin wax.

Capric acid is widely available fatty acid-based PCM [92]. A conventional solar still was examined with paraffin wax, capric-palmitic acid, calcium chloride hexahydrate, stearic acid by the Kabeel's group [93]. Their obtained findings indicated that the best performance belonged to Capric-palmitic acid which increased the daily output of the solar still up to 100%, following by capric-palmitic acid, paraffin wax, stearic acid, calcium chloride hexahydrate. Myristic acid is a fatty acid found naturally in palm oil, coconut oil and butterfat (Konulu et al. 2019). Shruthi et al., [95] investigated a conventional solar still with myristic acid. 1.5 L/day of fresh water was produced from 14 liter in their experiment. The distilled water had the TDS level of 81 ppm, which is satisfy standard for drinking water. The energy-efficiency of solar still with myristic acid was 64.37%. Table 2 compare various PCM on different types of solar stills. First-time lauric acid was used as PCM other than paraffin wax in solar still and recorded a 30% increase in productivity [84]. Table 2 concludes that stearic acid is another attractive alternative to paraffin wax with a 160% improvement in productivity [80]. Bitumen shows little influence on the performance of solar still [87]. It can be easily recognized by comparing the results of Table 1 and Table 2 that the performance of all these PCM is inferior to paraffin wax.

Table 2. Comparison the performance of various PCM in the solar still

Ref.	Type of solar still	PCM	Yield		Percentage increase	Thermal efficiency		Percentage increase
			With PCM	Without PCM		With PCM	Without PCM	
[84]	Conventional solar still	Laudric acid	-		30	-	-	-
[87]	Double slope, single basin	bitumen	810	750	2	27	25.19	7.18
[90]	Conventional solar still for sea water	Palmitic acid	1.87	3.4	81.81	39.18	27.24	46.14
[90]	Conventional solar still for bore water	Palmitic acid	2.05	3.6	75.6	37.15	24.64	50.77
[91]	Weir-type cascade solar still.	palmitic acid	-	-	33.69	-	-	35.46
[96]	Double slope, single basin	Laudric acid	-	-	12.7	-	-	12.42
[80]	Conventional solar still	Steric acid	1.512	3.73	164	-	-	-
[95]	Conventional solar still	Myristic acid	1.5	0.9	64.37	-	-	-
[97]	Conventional solar still	PCM A48	6.6	3.4	92			-

CONCLUSIONS

The solar stills applied sensible heat storage materials and latent heat storage materials such as paraffin wax, lauric acid, bitumen, stearic acid, palmitic acid, capric acid and myristic acid was compared in this work to investigate the best performing sensible heat materials as well as PCM for solar stills. The use of thermal storage materials can extend operation time of solar still after there is no solar radiation. The additional time depends on the amount of brackish water in basin. The lower water depth was suggested to optimize the productivity of solar still. However, it should be not too low to prevent dry spot existence. The thermal conductivity and specific heat capacity should be high as selecting sensible heat material for solar still. The paraffin wax usage augmented significantly the daily yield, thermal efficiency as well as exergy efficiency of a conventional solar still up to 180%, 67.2% and 40%, respectively. The thermal conductivity of PCM normally is smaller than that of sensible heat storage material, however, the mixture of PCM and metallic micro/nanoparticles can be improved the heat transfer through PCM. The best design for increment the PCM's thermal conductivity is the hollow-cylinder fins. This work recommends that application of paraffin wax can help the passive solar still to be commercialized in domestic application with acceptable economic efficiency.

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