Latent Heat Storage for Solar Still Applications

Abhishek Anand, Karunesh Kant, A. Shukla and Atul Sharma

Abstract Water is critical and inevitable for all forms of life, which is available in copious but not suitable for direct ingestion. Also, the existing technologies are costly, bungling, and energy inefficient. They trip on fossils fuel which is infecting. The technology we are considering here exploits direct solar energy for water desalination. This greener technology further concentrates on the latent heat storage through phase change materials (PCMs). The PCMs are profusely available at reasonable rates. The technology transition will reduce the carbon footprint safeguarding the energy security and environmental sustainability.

Keywords Solar energy · Latent heat storage · Solar still · Phase change materials · Desalination

1 Introduction

The available water resources on the earth are projected to be nearby 1,386,000,000 cubic kilometers (km^3). Out of this, total freshwater is about 35,000,000 km^3 which is only 2.5% of the total stock of the water in the hydrosphere. A large fraction of this freshwater about 24,000,000 km^3 (68.7%) is in the form of permanent snow cover in the Arctic and Antarctic region (Figs. 1 and 2). The surface water flowing in the rivers and lakes is nearly 90,000 km^3. This is used for multiple purposes like municipal, irrigational, and industrial supply. Most of this water is contaminated, and to make it palatable, multiple treatment processes are sine qua non. A little more than 30% exists as groundwater. Much of the groundwater is inaccessible for extractions. Global water withdrawals stand at 3900 km^3 per year or 10% of the total global renewable energy resources. The consumptive use of water is estimated to be about 1800–2300 km^3 per year. The intermittent and unreasonable extraction of water is detrimental to the natural hydrological cycle. Most of the aquifers are

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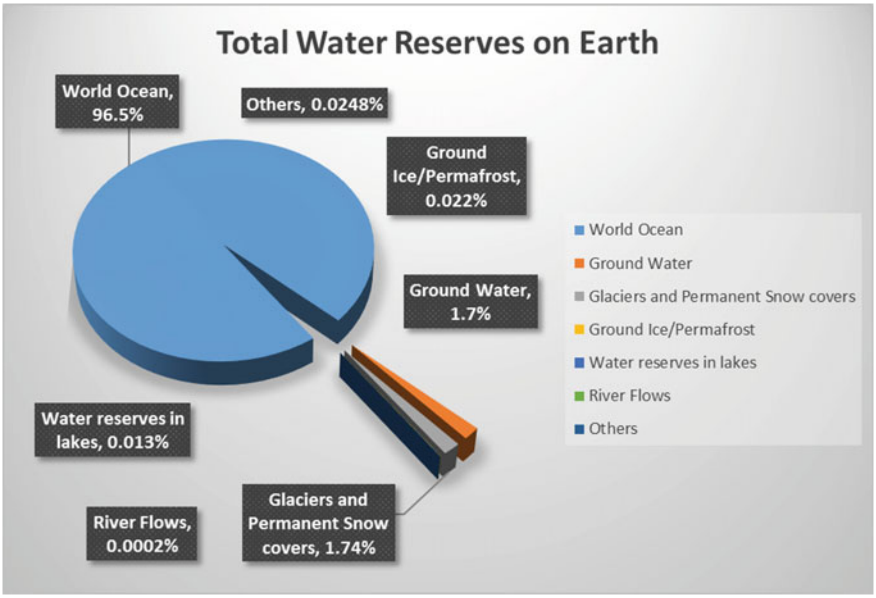

Fig. 1 The total water reserves on earth

prone to industrial pollution and salt intrusion. The adversity of water treatment with existing technology is apparent. Linking water desalination with the renewables will moderate our reliance on conventional resources with superfluous advantage combating climate change.

2 Water Desalination Technologies

The basic water desalination process is classified into two types, i.e., thermal desalination process and membrane desalination process (Fig. 3). The thermal process works through the application of heat, and the membrane process utilizes some kind of semi-permeable membrane. The broader discussion of each is carried out in the subsequent section with their further sub-classification.

2.1 Thermal Technologies

As the name indicates, these types of technologies include the heating of saline water and gathering the condensed vapor to yield pure water. These technologies have seldom been used for saline water purification since it involved extraordinary

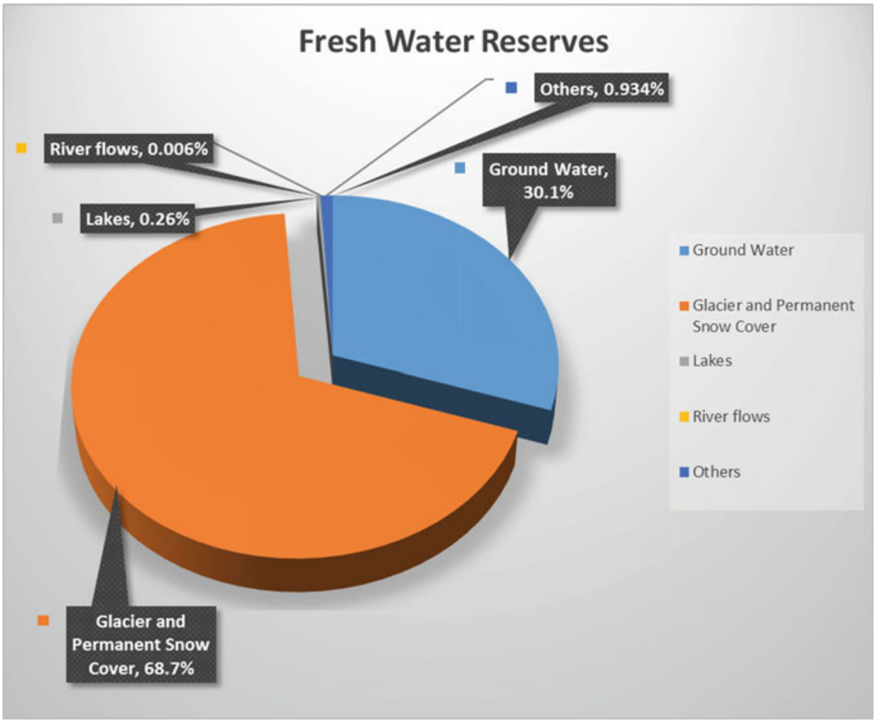

Fig. 2 The freshwater reserves

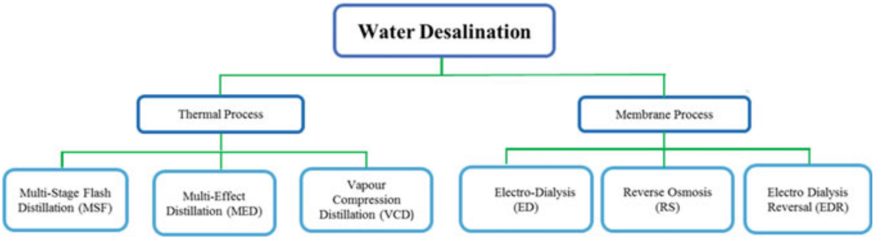

Fig. 3 Water desalination process

operating cost. These types of technologies can be further classified into the following groups:

- Multi-stage Flash Distillation (MSF)
- Multi-effect Distillation (MED)
- Vapor Compression Distillation (VCD)

2.1.1 Multi-stage Flash Distillation (MSF)

The MSF process works in steps. The pressure is lowered at each sequential step. The water underneath high pressure is directed to first "flash chamber" where the pressure is dropped that boils water instantaneously results in rapid vaporization called flashing. The flashed vapor is changed into freshwater by condensation through the heat exchanger. The process has a working efficiency of around 20%. The MSF makes available 60% of all desalinated water worldwide. As the efficacy is low, with the MSF only trivial amount of brackish water is converted into freshwater.

2.1.2 Multi-effect Distillation (MED)

Since the late 1950s, the MED process has been in practice. The process takes place in multiple of vessels. A series of the evaporator is positioned each producing "effect" that produces water at reduced pressure. The vessels located hitherto assists as a heating device for the succeeding vessels. The adeptness of MED can be enriched by adding more vessels in the chain. MED can be categorized into horizontal, vertical, stacked tube depending on the organization of tubing of the heat exchanger.

2.1.3 Vapor Compression Distillation (VCD)

The VCD process works independently or in combination with MED. The compression of the vapor engenders the required heat. The mechanical compressor is extensively used for this purpose. VCD units are installed in hotels, resorts, etc. because of its compact size.

2.2 Membrane Desalination

The membrane desalination process makes use of a semi-permeable membrane to purify water. The process is energy consuming and not environmentally sound. The membrane desalination process is further classified into three types which are described below.

2.2.1 Electro Dialysis (ED)

ED is a membrane process, in which ions are elated through a semi-permeable membrane, under the impact of an electric potential. These membranes are ions selective which means that either of the two positive or negative ions can pass through it depending on the type of electrolytic membrane used. Multiple membranes are used in this process which ultimately removes positive or negative ions that flow through it, and then, these ions are removed from wastewater.

2.2.2 Reverse Osmosis (RO)

In the process of osmosis, solvent molecule moves from the lower salt concentration to the higher concentration through a semi-permeable membrane until the equilibrium is reached. It is a spontaneous process. But the reversal of it, i.e., reverse osmosis, pressure equal or greater than osmotic pressure is applied on the higher salt concentration side so that the solvent molecules move to the lower concentration leaving behind the salt residue. In this way, desalination is achieved.

2.2.3 Electro Dialysis Reversal (EDR)

In the Electro Dialysis Reversal process, we need to change the polarity of the electrode at the continuous interval. EDR technology offers higher water recovery. It has the higher potential to prevent scaling and fouling arises out of the high salt concentration of Calcium (Ca) and Magnesium (Mg). It is quite effective in treating Barium (Ba) and Strontium (Sr) ions.

3 Solar Still

Solar still uses the direct energy of the sunlight to purify water. It is generally a thermal desalination process. The technology is quite energy efficient as it requires no additional energy inputs. Water is allowed to evaporate, and the vapor is then allowed to condense which is then collected. The process is the same as we see during precipitation. The solar still is categorized into two types, i.e., active process and passive process and is shown in Fig. 4.

3.1 The Passive Solar Still

The passive still works in direct heat of the sunlight with no other additional source of heat. The temperature achieved is relatively low, so the productivity is quite meagre. The basic design of the passive solar still is shown in Fig. 5.

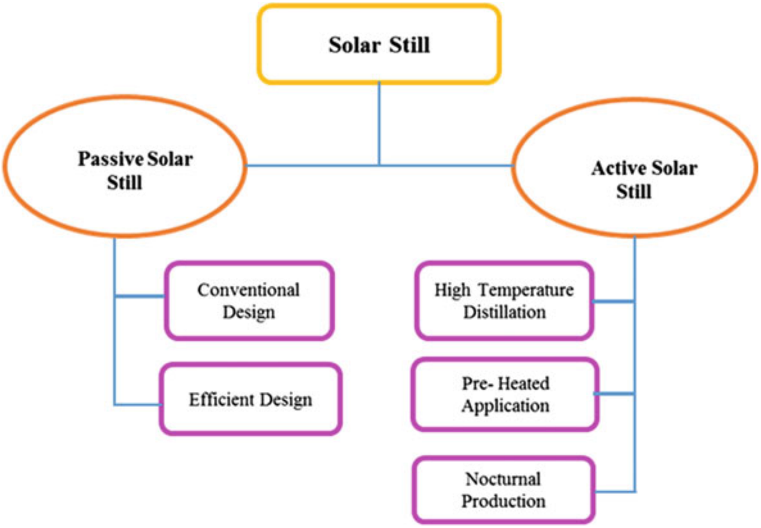

Fig. 4 Classification of solar still

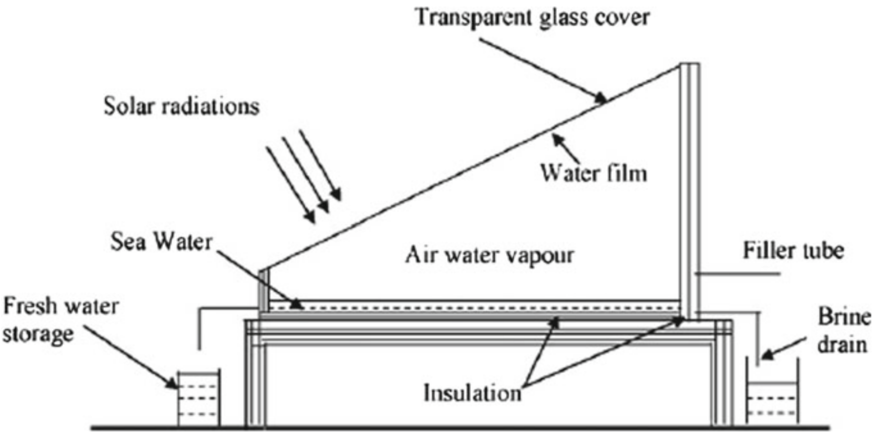

Fig. 5 Passive solar still [4]

3.2 *The Active Solar Still*

As the efficiency attained in the passive design is low, the passive design is supported with additional heat supplying mechanism making it active solar still. The high temperature at the basin gives better productivity after amelioration and refining. The prototype of active solar still is shown in Fig. 6.

The active solar still is further categorized into three types which are described below.

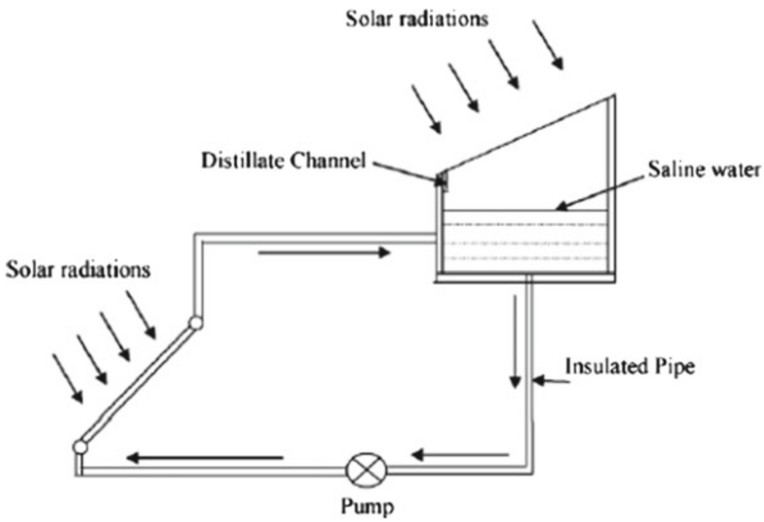

Fig. 6 Active solar still [4]

3.2.1 High-Temperature Distillation

In this process, additional heat energy to the collector is provided through the application of the solar collector, parabolic concentrator, heat pipe, solar ponds, etc.

3.2.2 Pre-heated Water Application

This process uses pre-heated water. The water used generally is wastewater. The wastewater is available from some thermal power plant or chemical plant. This heated wastewater can be feed into the basin of the solar collector for further heating.

3.2.3 Nocturnal Production

The nocturnal production works in the absence of sunlight during the dark. For this, solar energy stored during the daytime can be utilized or some waste heat from other sources can also be used.

4 A Brief Description of Conventional Solar Still

The typical conventional solar still has a collector to store water and absorber with transparent glass to trap the maximum heat falling on the glass material. The water is

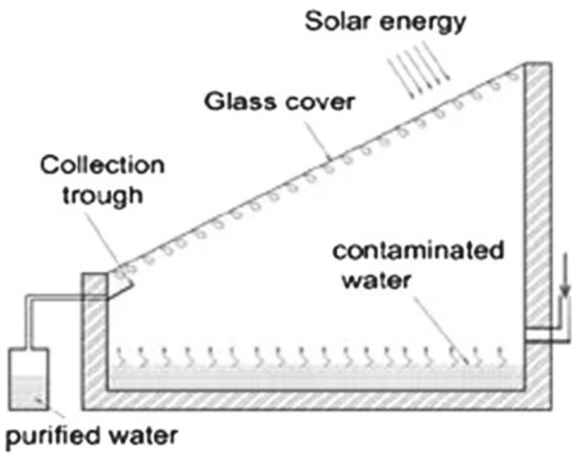

Fig. 7 A typical solar still

stored in the collector basin painted black to absorb the heat. There is a considerable gap between the collector basin and the upper surface of the glass cover for the efficient evaporation and condensation to take place. The collector basin is connected through the external water pipeline for the continuous supply of water. The distillate is then collected which is purified water. A model of this is shown in Fig. 7.

5 The Solar Still Basin Design

The various basin's designs are discussed in successive sections.

5.1 The Spherical Solar Still

The spherical solar still as shown in Fig. 8 has spherical collecting basin as well as spherical absorber plate. The collector is made up of steel which is coated with black to absorb the heat. The whole system is supported by aluminum mesh covered with low-density polyethylene (LDPE) material.

5.2 The Pyramidal Solar Still

It has a flat water collecting basin as shown in Fig. 9. The absorber plate is pyramidal in shape. The cost of fabrication of pyramidal still is less. The insulating materials

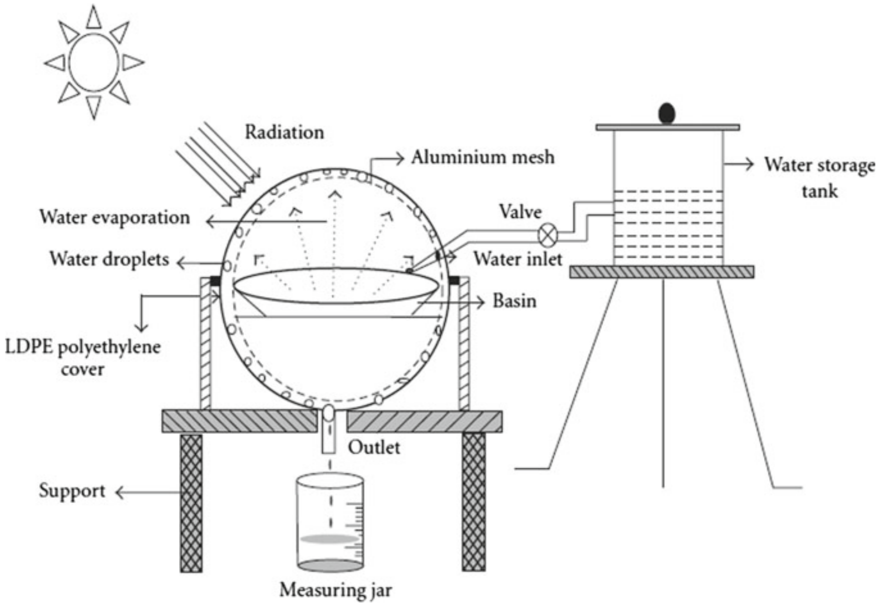

Fig. 8 Spherical solar still [4]

can be made up of sawdust which reduces its cost. Also, the sawdust is eco-friendly material.

5.3 *The Hemispherical Solar Still*

The water collecting bowl of the hemispherical still is constructed with mild steel materials. The storage bowl is coated black to enhance its absorbing power. The top hemispherical shield is made up of the acrylic sheet which is transparent with a solar transmittance of more than 80%. The external box of the still is built up of wood of thickness 4 mm with the dimension 1.10 m × 1.10 m × 0.25 m. The bottom surface of the basin is packed with sawdust (to support the weight of the basin) up to a height of 0.15 m. A glass wool material is used to coat the sides of the basin. Figure 10 describes a typical model for this type of solar still.

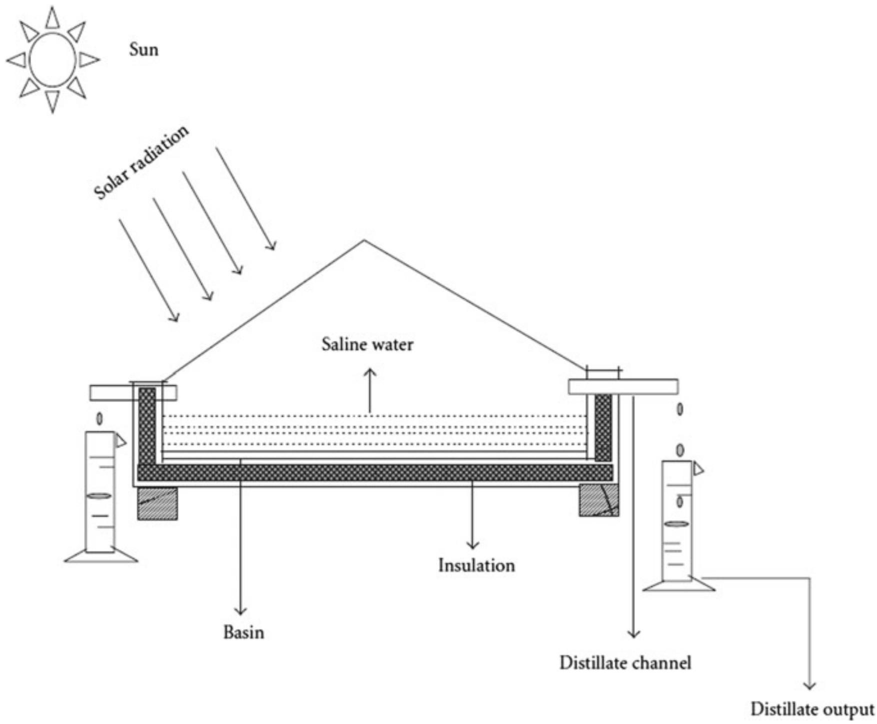

Fig. 9 Pyramidal solar still [4]

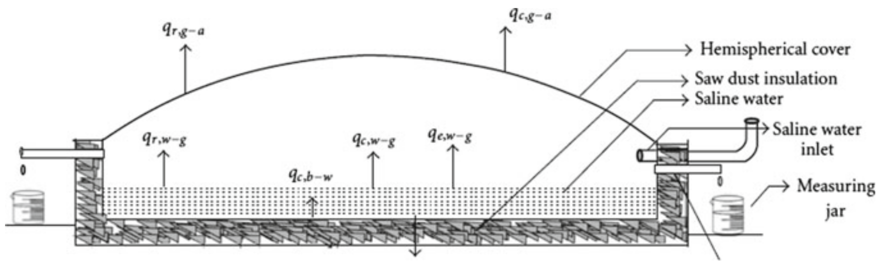

Fig. 10 Hemispherical solar still [4]

5.4 The Double-Basin Solar Still

As depicted in Fig. 11, the type of solar still consists of an upper basin and a lower basin. The upper basin is divided into three fragments to evade the formation of dry spots on the upper portion of the interior glass cover. Silicone rubber sealant is used to cap and avoid any water leakages. There are inlet and outlet at the opposite side of the wall for the incoming saline water and outgoing distilled water.

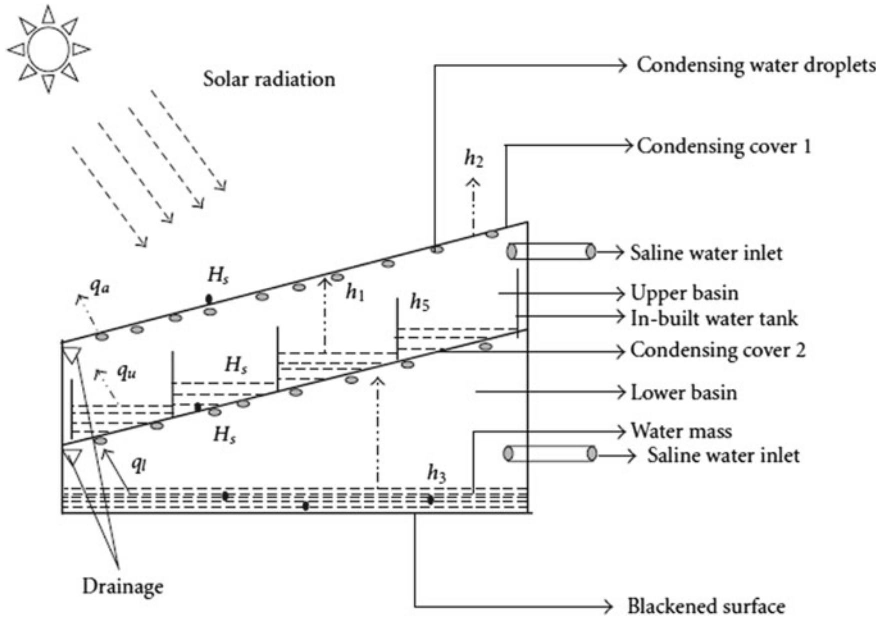

Fig. 11 Double-basin solar still [4]

5.5 *The Tubular Solar Still*

A CPC TSS design with a rectangular absorber is shown in Fig. 12. The outer and inner circle is placed with a gap for the following water and air. The tube is designed to maintain the constant flowing of water which not dependent on the evaporation rate. A storage tank is also designed which provides the continuous supply of water to the still. The distillate is stored in another collector.

6 The Need of Energy Storage in Solar Distillation

As it is well-known that freshwater contains a lot of impurities in it, water cannot be used as it is. It has to be treated before making available for the daily use. To remove such impurities, a thermal process is generally used. As we are well aware that in the thermal process, evaporation condenses to give clean water. The process is energy intensive with severe environmental impacts. The power crisis with increasing energy cost limits its further use. All over the world, the scientists are looking for newer technology by which they can reduce the dependency on fossil fuel. In this regard,

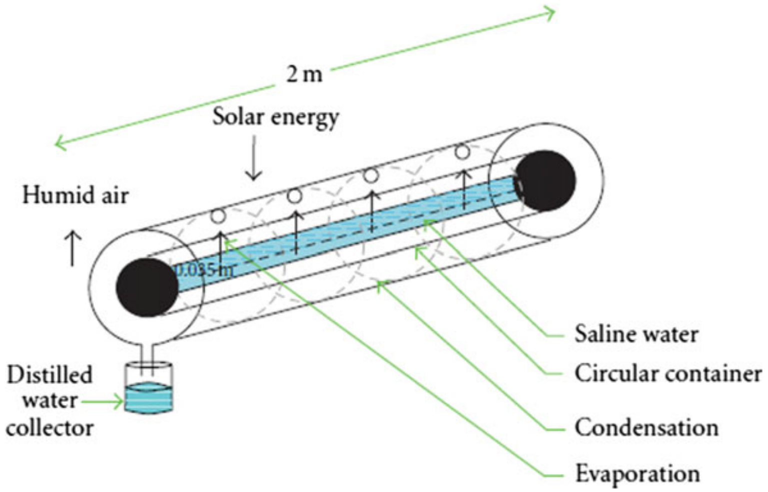

Fig. 12 Schematic view of tubular solar still [4]

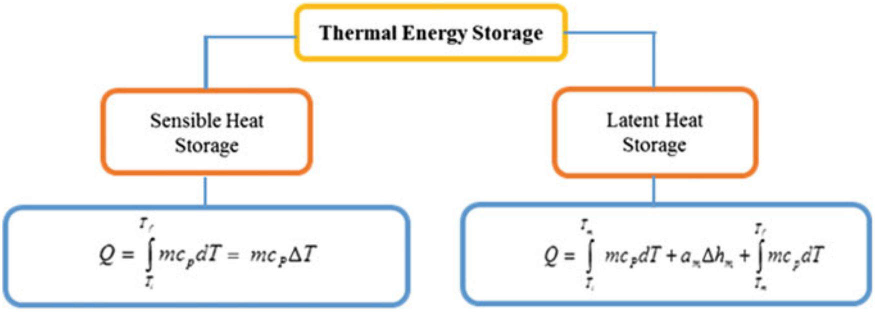

Fig. 13 The classification of thermal energy storage

thermal energy storage though PCMs can play an imminent role in saving energy and providing energy sustainability.

6.1 *Thermal Energy Storage*

Thermal energy in a material is stored with the alteration in the internal energy of the system. This is stored as sensible heat (SH) or latent heat (LH) or the combination of both. The classification for each type with their basic equation is shown in Fig. 13.

6.2 Sensible Heat Storage

In the process, the energy is stored with the change in the temperature of solid or liquid. Specific heat determines the amount of energy stored in the material which is different for different material. The equation governing the sensible heat storage is as follows:

$$Q = \int_{T_i}^{T_f} mc_p \mathrm{d}T = mc_P \Delta T,$$

where Q is the heat energy stored in (J), m is the mass of the material in (kg), c_p is Specific heat of the material in (J/kg K), T_i is the initial temperature in (°C), and T_f is the final temperature in (°C).

Water is one of the best materials for the sensible heat storage because it has high specific heat and abundant availability. The major constraint with water is that it can be used only up to 100 °C. For the higher temperature applications, molten salts can be used.

6.3 Latent Heat Storage

Latent heat storage depends on the heat change during the phase change undergone by the material. The heat storage potential of a material undergoing phase change is governed by,

$$Q = \int_{T_i}^{T_m} mc_P \mathrm{d}T + ma_m \Delta h_m + \int_{T_m}^{T_f} mc_p \mathrm{d}T,$$

where a_m is the fraction melted, h_m is the heat of fusion per unit mass (J/kg) and rest has the meaning discussed above.

6.4 Classification of Phase Change Materials (PCMs)

The PCM is mainly classified into three types, viz. organic, inorganic, and eutectic. The broader classification is given in Fig. 14.

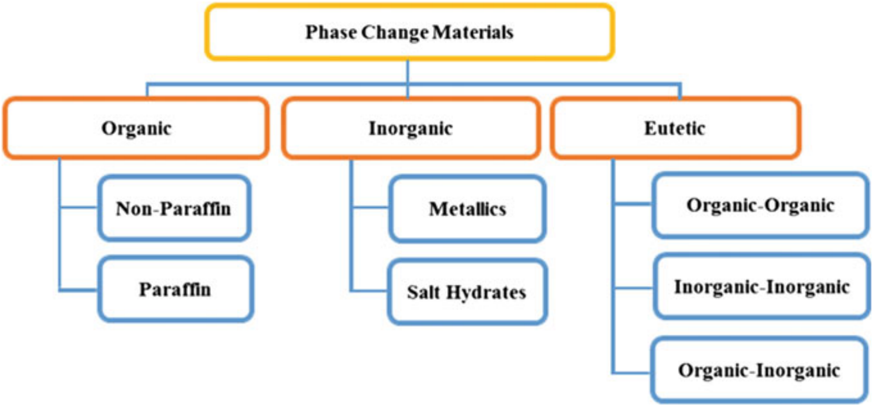

Fig. 14 Classification of PCM

7 Solar Stills with Latent Heat Storage Materials: A Recent Trend

There are several solar stills available in the market, and all can be categorized on the basis of their design and modification. Generally, these are classified into two "Passive" and "Active" as already discussed. The modification with the PCM can be carried out with both types to augment its performance. The PCM material is fitted on the bottom or sides with the basin of the still. A brief description (Table 1) and review with various PCM is discussed in subsequent sections.

Al-Hamadani and Shukla [2] carried out an experiment with lauric acid as PCM (Fig. 15). The objective of the experiment was to analyze the influence of changing the mass of PCM and basin's water on its efficiency and productivity. They found that the diurnal productivity could be improved by using the relatively greater mass of PCM with a lesser mass of water in the basin. They further reported the efficiency and productivity with PCM increased by 127 and 30–35% at day and night, respectively, as compared to without using PCM.

Ramasamy and Sivaraman [17] designed a Cascade Solar Still with and without Latent Heat Thermal Energy Storage Sub-System (LHTESS) for testing and enhancing its productivity (Fig. 16). The solar still consists of a stepped absorber plate with LHTESS and a single-slope glass plate. This setup was fixed at an angle of 25° to the horizontal. Paraffin wax was the choice for LHTESS for carrying out the experiment. They found out that the hourly productivity was somewhat greater in the case of solar still with no LHTESS during sunny days. But at night, solar still with LHTESS gave better productivity. The performance of solar still was also dependent on wind speed, ambient temperature, water temperature, etc. There was a certain constraint of using salt hydrates as the PCM because of their corrosiveness and cycling stability. Salt hydrates as PCM create corrosion effect with the base material such as aluminum, copper, galvanized iron, etc.

Table 1 Solar still with latent heat storage

Type of solar still	Type of study	PCM/energy storage materials	Main findings	Reference
Single-basin double-slope solar still	Experimental	Paraffin wax	The productivity is increased by 11.6% and the peak yield is increased by 9.5% with PCM	Sundaram and Senthil [22]
Integrated single-basin solar still	Experimental	Beeswax	Overnight productivity is increased with the use of PCM	Deshmukh and Thombre [5]
Rectangular solar still	Experimental	Paraffin and copper oxide nanoparticles	There is an overall 35% improvement in the performance with the use of NPCM over PCM	Iniyan and Suganthi [9]
Pyramidal solar still	Experimental	Stearic acid	The maximum temperature is obtained for stearic acid which is 65 °C	Dube [6]
Single-basin solar still	Experimental	Honey beeswax	The performance is increased by 62% by the use of PCM	Sonawane [21]
Stepped basin solar still	Experimental	Stearic acid	The productivity is increased when evacuated solar still with PCM and intermittent water collector is used	Hari and Kishore [7]
Tubular solar still	Experimental	Stearic acid	20% increase in the productivity	Rai and Sachan [15]
Single-basin solar still	Experimental	Bitumen	The efficiency solar still with PCM is about 20%	Kantesh [11]

(continued)

Table 1 (continued)

Type of solar still	Type of study	PCM/energy storage materials	Main findings	Reference
Passive solar still	Experimental	Paraffin	The choice of the PCM is based on the maximum of the temperature reached by the brackish water in the basin	(Ansari et al. [3]
Double-slope single-basin solar still	Experimental	Paraffin wax	The efficiency is increased by 10–25% with the use of PCM	Husainy et al. [8]
Single-slope stepped solar still	Experimental	Paraffin wax	The performance is increased by 35–40% with the use of the PCM	Agrawal [1]
Triangular pyramidal solar still	Experimental	Paraffin wax	The performance is increased by more than 20% with the use of PCM	Ravishankar et al. [18]
Pyramidal double glass solar still	Experimental	Paraffin wax and titanium oxide	The overall performance is increased with the use of PCM	Kumar et al. [13]
Single-slope solar still coupled with parabolic concentrator	Experimental	Beeswax	The overall performance is increased by around 62% with the use of PCM coupled with the parabolic concentrator	Kuhe and Edeoja [12]
Normal solar still	Theoretical	Stearic acid, capric–lauric acid mixture, paraffin wax, and calcium chloride hexahydrate	The system productivity is increased by about 120–198%	Kabeel and El-maghlany [10]

(continued)

Table 1 (continued)

Type of solar still	Type of study	PCM/energy storage materials	Main findings	Reference
Single-basin solar still	Experimental	Palmitic acid	The efficiency was considerably increased by use of PCM	Raj [16]
Double-slope single-basin solar	Experimental	Paraffin wax	The productivity increased in different cases	Patil and Dambal [14]
Conventional type solar still	Experimental	Lauric acid	The productivity increased in different cases	Shukla [20]
Cascade solar still	Experimental	Paraffin wax	The productivity increased and decreased in different cases	Ramasamy and Sivaraman [17]

Fig. 15 A solar still with PCM (right) and without PCM (left) [2]

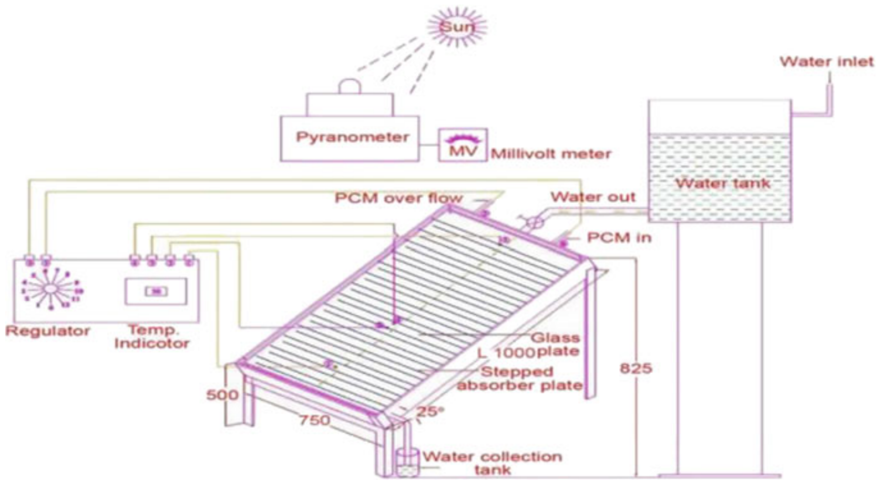

Fig. 16 Schematic diagram of the experimental setup [17]

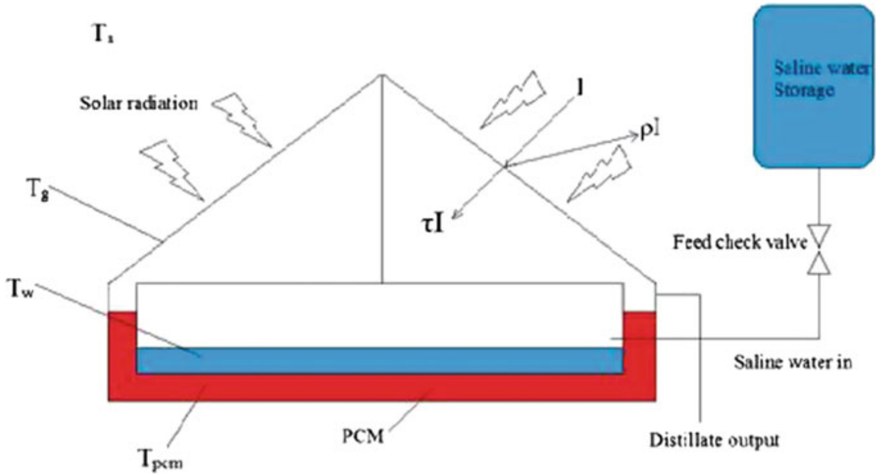

Fig. 17 Schematic diagram of the triangular pyramid solar still [18]

Ravishankar et al. [18] worked on the triangular pyramidal solar still. They selected paraffin wax as PCM. They performed their work in the sultry weather of Chennai, India. The model diagram is shown in Fig. 17. The PCM was placed at the bottom of the basin which was smeared with black paint to minimize the heat loss. The thickness of the PCM was kept at 10 mm. The experiments were carried out from 7 to 12 h. They concluded that the performance increased by more than 20% with the use of the PCM.

Ansari et al. [3] had designed a passive solar still and chose paraffin wax as PCM shown in Fig. 18. The system of 1 m^2 area was considered for several elements. The basin was fed by the saline water. The water was heated by the radiation received by the condensing glass cover. The gap between the condensing plate and the evaporation surface should be maintained for the efficient evaporation and condensation. The water was fed through the inlet on one side and collected through the outlet on the bottom of the opposite side. The PCM was placed on the foot of the absorber plate. The whole setup is cloistered to minimize the heat loss. They obtained that the selection of the PCM was based on the extreme of the temperature reached by the briny water containing in the basin.

Rai and Sachan [15] had carried out an experiment on tubular solar still with the use of PCM. Energy storage medium (stearic acid) was used in the still to produce distillate during off sunshine hours. A prototype solar still having a horizontal tray which acts as an absorber was designed and constructed. The tray was made of a galvanized sheet of and painted black to engross the solar radiations during the course of the experiment. Overall, they found out that the productivity of solar still increased by 20% when PCM was used.

Sarada et al. [19] made stainless steel basin with an area of 1 m^2 (Fig. 19). The solar still was made up of stainless steel. The stainless steel used had the thickness 8.8 mm. The top is covered with the clear glass with a slope angle of 32°. The surface bottom and side was smeared with black paint to avoid the heat loss. The still was placed

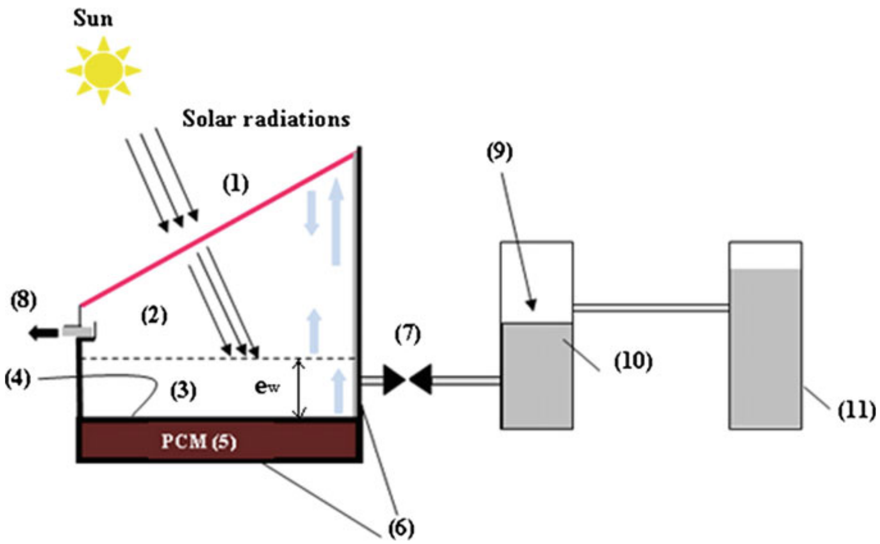

Fig. 18 System schematic diagram: (1) Condensing glass cover; (2) mixture of heated air and steam; (3) basin; (4) basin liner (absorber); (5) storage medium (PCM); (6) thermal insulation (7) non-return valve; (8) outlet of distilled water; (9) floating water level switch; (10) feed tank; and (11) brackish water reservoir [3]

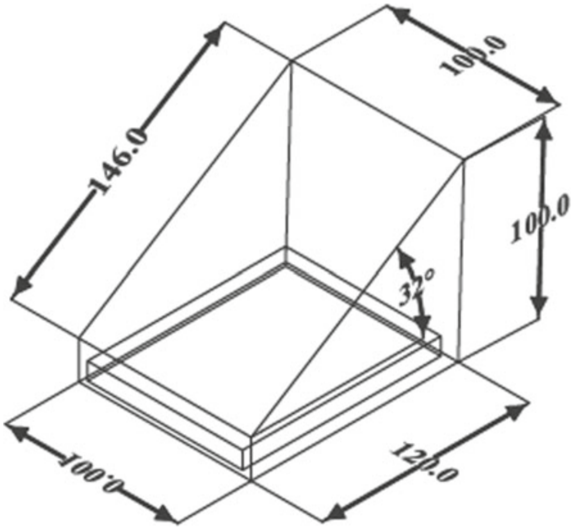

Fig. 19 Single-slope solar still [19]

in the south direction to carry out the experiment. The author focused on the use of sodium sulfate decahydrate ($Na_2SO_4 \cdot 10H_2O$) and sodium acetate ($NaCH_3COO$) as PCM. They showed that the presence of sodium sulfate provides healthier yield as compared to sodium acetate as the PCM.

Deshmukh and Thombre [5] had shown the use of bee wax as the PCM (Fig. 20). The basin area was 0.5 m^2. The outcome of varying depth of storage and water in the basin was investigated. With increasing the depth of storage and the depth of water, increased overnight productivity substantially but the daylight productivity was found to be less than that of conventional solar still. Overall, solar still with least depth of storage and water was found to give the highest daily productivity in summer. PCM was found not suitable for use in winter.

Sonawane [21] performed an experiment with Honey beeswax as the PCM as shown in Fig. 21. The system with 1 m^2 of surface area was considered to perform the experiment. The basin was fed with the brackish water. The water was heated by the solar radiation received through the condensing glass cover of the solar still. The water evaporation rate was increased by keeping a large gap between the condensation surface and the evaporation surface. The water was collected by the outlet placed at the foot of the solar still. They found that the output was enhanced by 62% by the use of PCM than the conventional method. The higher distillate was obtained at an inclination of 34° as compared to other angles.

Hari and Kishore [7] designed an experiment with evacuated solar still with intermittent water collector. A 20-L stepped basin was fabricated for this purpose and was redesigned by adding a heat reservoir of material stearic acid and intermittent water collector to collect more water (Fig. 22). The inner dimensions of the basin

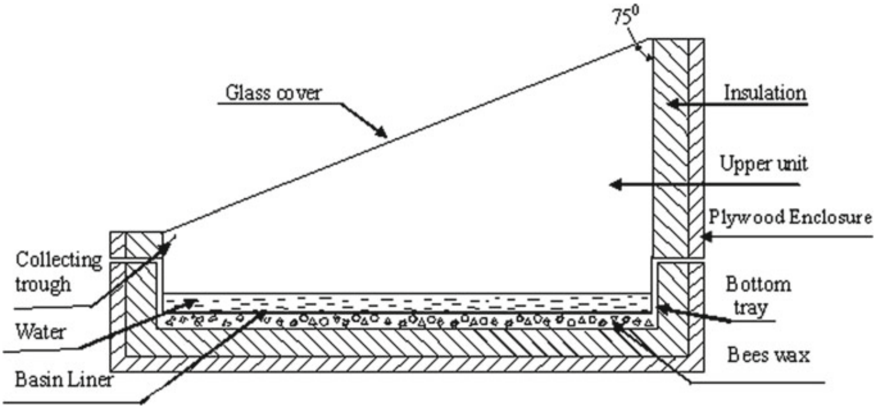

Fig. 20 Single-slope single-basin solar still [5]

were made 100 × 100 cm^2. The upper glass cover was tilted at 20° with respect to the horizontal. The arrangement was stationed in North–South direction during the course of the experiments. Copper-constantan thermocouples were used for temperature measurement. The Condenser surface of the still was made of 4 mm ordinary glass. The bottom of this still was insulated. The water was filled up to 8 cm in depth. Performance analysis of the stepped basin solar still with heat reservoir and without heat reservoir was done by conducting the experiment. The experiment mainly studied the variation of solar energy, the effect of vacuum, the effect of the heat reservoir,

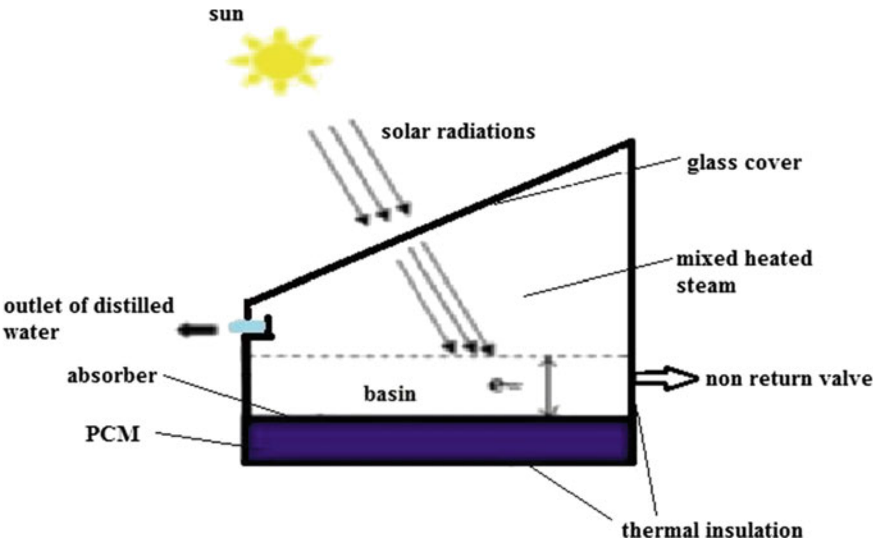

Fig. 21 Solar modeling using PCM [21]

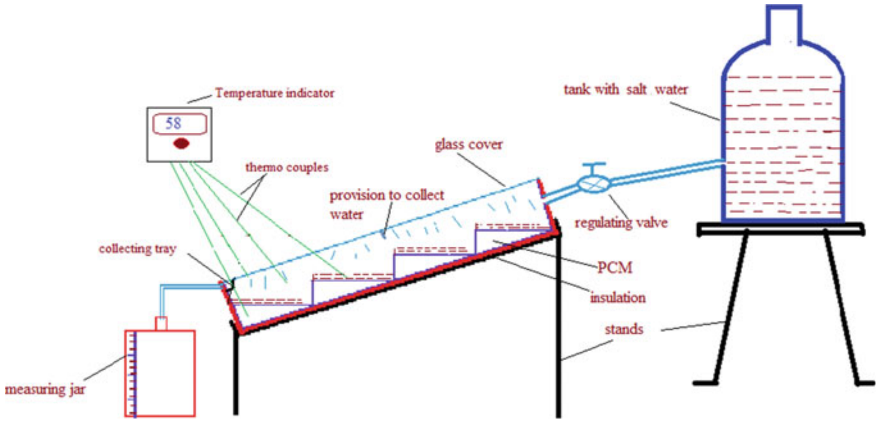

Fig. 22 Schematic diagram of evacuated solar still with PCM and intermittent water collector [7]

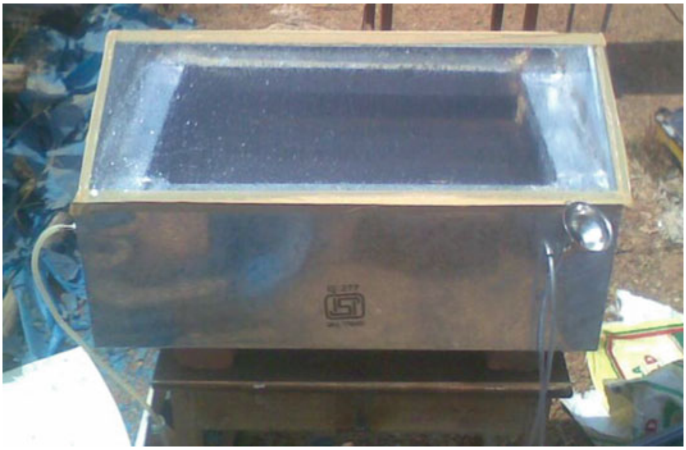

Fig. 23 Solar still with PCM [11]

and intermittent water collector. Compared with stepped basin type solar still, it was found that its productivity was increased when evacuated solar still with PCM and intermittent water collector was used.

Kantesh [11] developed a solar still which consist of a basin made up of tin of 0.54 m^2 area, having a dimension of $90 \times 60 \times 30$ shown in Fig. 23. Inside this basin, author fixed another basin with a distance of 8 cm leaving a gap from bottom and sides, and in between this gap, an insulating material (glass wool) was placed to prevent loss of heat. The inner box was filled with bitumen used as PCM with a thickness of 7 cm. The author reported that the efficiency of the solar still without PCM was about 25.19%; however, in the presence of PCM, it was 27.00%

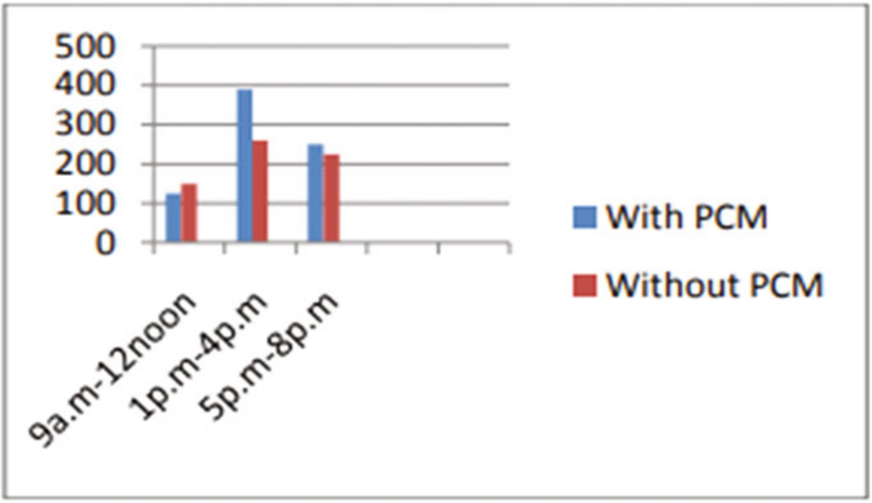

Fig. 24 Distillate obtained by solar still with and without PCM [1]

Agrawal et al. [1] constructed two single-slopes stepped solar still with and without PCM in order to compare the productivity of stills at the day as well as night during sunny days (Fig. 24). Paraffin wax was chosen as PCM. Their experiment was in the interest of producing clean water at an affordable rate in rural and urban areas. It was found that the higher mass of PCM with a lower mass of water in the basin significantly upsurges the diurnal output and efficacy. Therefore, the distillate yields at night and day with PCM increased by 127% and 30–35%, respectively, than the one without PCM.

Raj [16] studied single-basin solar still with palmitic acid as PCM (Fig. 25). They used the different TDS (Total dissolved solids) water and different absorbing materials. The basin area was designed to be about 2.47 m^2 for production of 5.5 L of water per day, and chromium paint was used for absorbing the solar radiation. The basin area required for the production of 5.5 L per day of freshwater was determined as 2.47 m^2. A tilt angle of 240° was created for the required basin area. The experiment was conducted using seawater and bore well water to compare which water has the highest yield and higher efficiency. They reported that hourly yield of seawater without PCM was 1870 ml and with PCM 3400 ml. The hourly yield of bore water without PCM was 2050 with PCM 3595 ml. The efficiency obtained after the experimental work of hourly yield of both bore well and seawater with PCM was 39.18 and 37.15% and without PCM was 27.24 and 24.64%, respectively. By comparison, it was established that the hourly yield of bore water was better than the seawater.

Sundaram and Senthil [22] had studied single-basin double-slope still leaning in East–West direction with and without PCM shown in Fig. 26. Authors used paraffin wax as PCM in these experiments. The experiment was performed at different basin, i.e., 10, 20, 30 mm with and without PCM. They reported that the throughput of

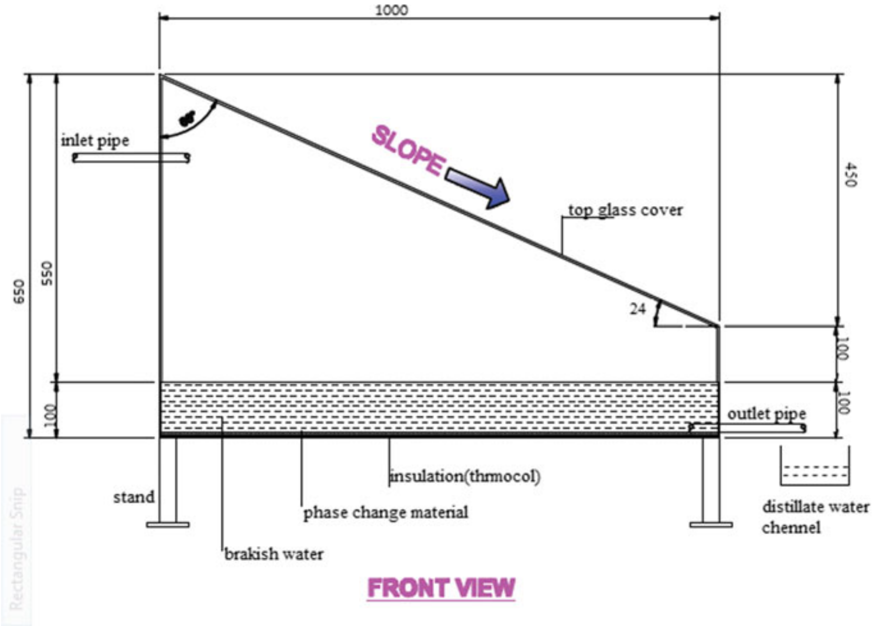

Fig. 25 2D model of solar still [16]

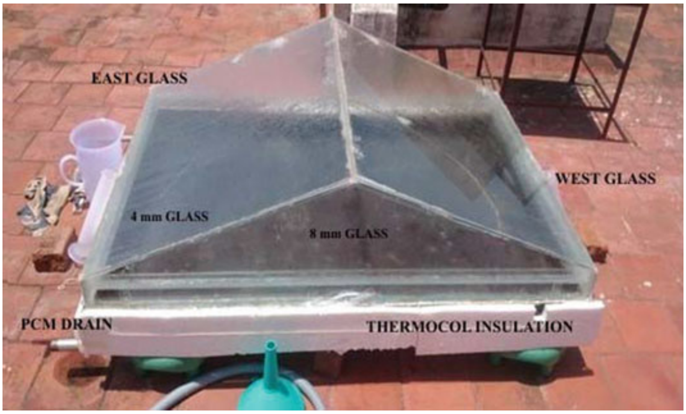

Fig. 26 The photographic view of the single-basin double-slope solar still [22]

water at the depth of 10 mm was greater than that of 20 and 30 mm. The production was improved by 11.6%, and the peak yield was improved by 9.5% with PCM.

Kuhe and Edeoja [12] had used beeswax as the PCM in a single-slope still joined with a parabolic concentrator (Fig. 27). They used 14 kg beeswax for as PCM placed between the absorber plate and the bottom of the basin. For comparison, a solar still

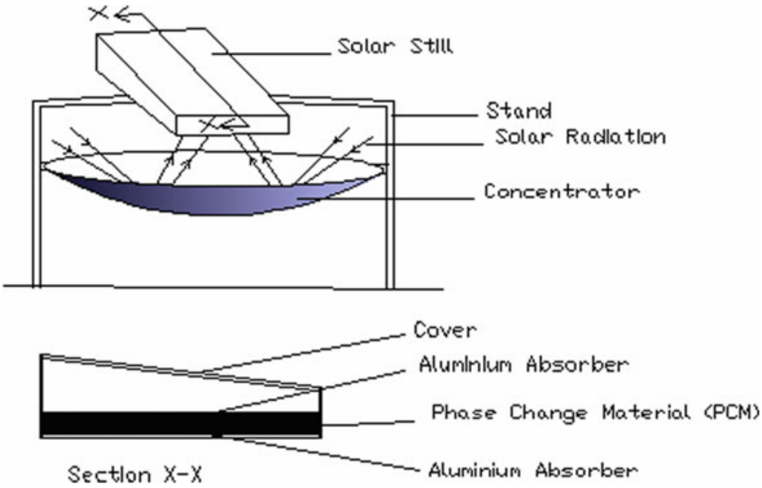

Fig. 27 Schematic diagram of parabolic reflector dish coupled single-slope basin solar still [12]

without PCM was also used. They reported that the performance was boosted by about 62% with the use of PCM coupled with the parabolic concentrator.

Patil and Dambal [14] worked on double-slope single-basin still with paraffin wax as PCM and black pebbles as the sensible heat storage material (Fig. 28). The basin area was chosen to be about 0.7 m^2 fabricated with aluminum sheet. An aluminum tray of area 0.40 m^2 was placed inside the still giving a gap of 10 cm. Thermocol was the insulating material between the gap and material. The two glass material was placed at the top. Three experiments were conducted (black coated aluminum tray, with PCM, with SHSE) using pyranometer and K-type thermocouple. It was stated that 1100 ml of distilled water was obtained when paraffin PCM was used, 954 ml when black pebble as sensible heat storage element (SHSE) was used, and 795 ml when the black coated tray was used. The percentage of productivity obtained for paraffin wax and the black coated tray was 30%, black pebble and the black coated tray was 18%, paraffin wax and black pebble was 13%.

Winfred Rufuss et al. [23] have used nanoparticle impregnated PCM (NPCM) (Fig. 29). They showed that NPCM is better than PCM. They found out that solar still with PCM produced 1.96 kg/0.5 m^2 of distillate, whereas solar still with NPCM produced 2.64 kg/0.5 m^2. It was observed that there was an overall 35% improvement in the performance with the use of NPCM over PCM.

Dube [6] have used stearic acid as PCM. They studied the design of stepped pyramidal solar still shown in Fig. 30. They observed the maximum basin water temperature at 1 pm which was around 75 °C. The maximum temperature obtained for stearic acid was 65 °C. They also concluded that the performance of still gets affected by design parameters like basin area, the positioning of still, depth of water, the temperature of inlet water, water glass temperature difference.

Fig. 28 Solar still with black coated tray [14]

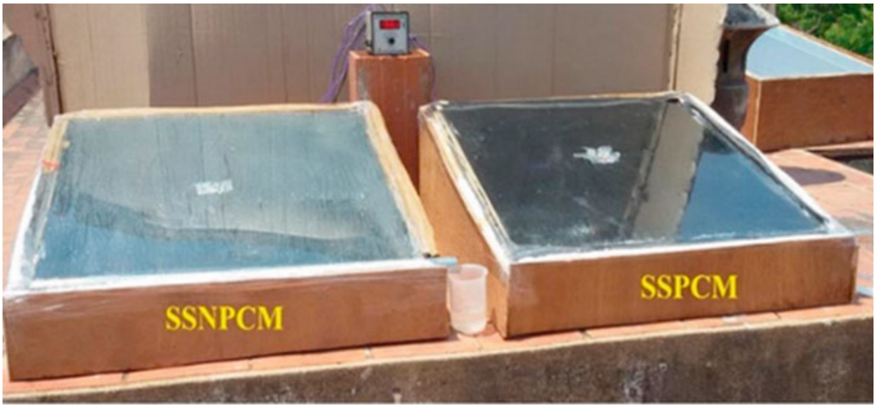

Fig. 29 Solar still with SSNPCM and SSPCM [23]

Husainy et al. [8] constructed two double-slope single-basin type solar still with the same design and tested under field conditions (Fig. 31). The experiments were conducted at open terrace at SIT COE Yadrav, Maharashtra. Five liters of wastewater (Mud Water) was used for the experiment. The total water depth was maintained at 1.5 cm. They used paraffin wax as PCM. The experiment was performed with and without PCM. Their result showed that the distillate production was increased by 10–25% by the use of PCM

Fig. 30 Experimental setup with solar still [6]

Fig. 31 Experimental setup [8]

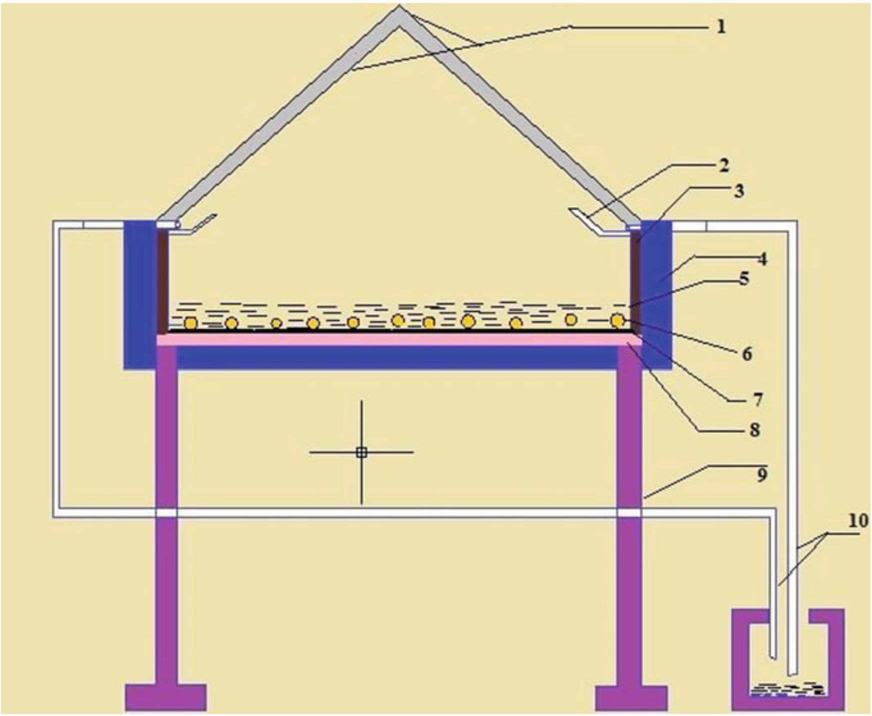

Fig. 32 1. Double glass solar still. 2. Projection for water drainage. 3. Wooden wall. 4. Polyurethane foam insulation. 5. Wastewater. 6. Packed copper tube. 7. Black stone bed. 8. Mild steel plate. 9. Stand. 10. Drainage tube [13]

Kumar et al. [13] carried out an experiment with paraffin wax and Titanium oxide (TiO_2) packed in the Copper tube as PCM (Fig. 32). The experiment was carried out in double glass solar still. They concluded that the presence of PCM and titanium oxide (TiO_2) made the production of 1.635 L/day of pure water from 12 L of salt water. The use of black stone as sensible heat storage medium also improved the production without any additional cost. The water production was high from 1:30 to 2:00 PM afternoon.

Kabeel and El-maghlany [10] have theoretically studied three different PCM, i.e., stearic acid, capric-lauric acid mixture, and paraffin wax, and the daily productivity of each PCM was studied. They also studied calcium chloride hexahydrate ($CaCl_2 \cdot 6H_2O$). They stated that the use of PCM increased the productivity and system working time. The system productivity was increased by about 120–198%, and the system working time was increased by about 2–3 h. This increase was based on PCM melting temperature, specific heat, thermal conductivity, and latent heat of fusion. They further concluded that capric–lauric mixture was the best PCM at which maximum productivity and minimum payback period was obtained. Their result is shown in Figs. 33 and 34.

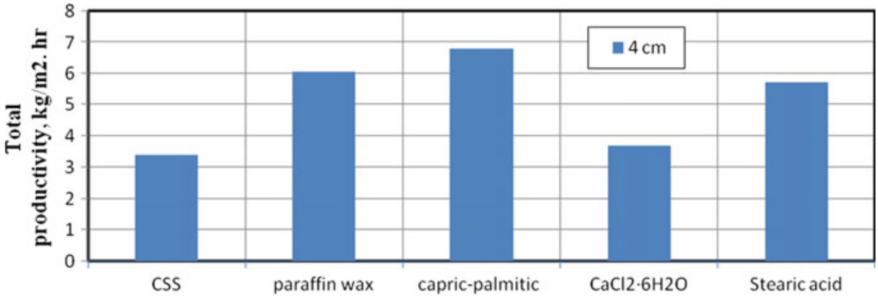

Fig. 33 Daily productivity for solar stills when using different PCM and without using PCM (CSS) [10]

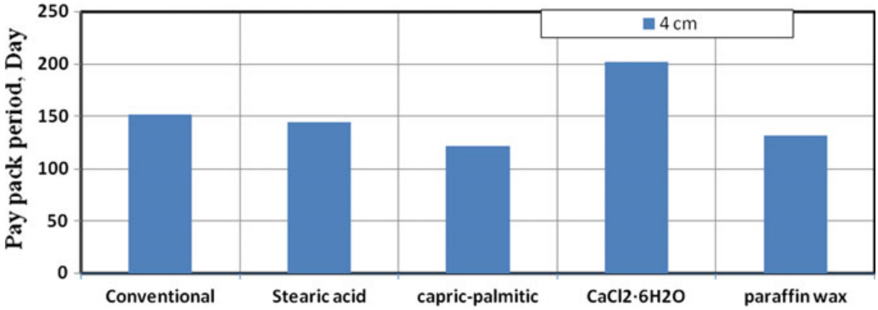

Fig. 34 The payback period for different PCM and without using PCM(CSS) [10]

8 Conclusions

As the freshwater requirement of the society is rising day by day in the existing time and will further increase in coming years because of the growing population and industrial development. Solar desalination will be indispensable for the future water purification technology. Different solar stills with numerous PCMs have been swotted in this chapter covering their different design aspects. It can be concluded that the throughput of solar still can be considerably improved by using PCM and can be proficiently used for longer time. The contemporary status of research with respect to this technology has been abridged. The sincere efforts in this field through research and social awareness will bring this technology to grassroots. This will also reassure new research in this field.

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