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Developments and modifications in passive solar still: a review

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ABSTRACT

Due to the increment in pollution as well as global warming, the scarcity of potable water is increasing day by day. There are several ways to obtain pure water, but solar desalination with use of solar still is the cheapest way. The purified water production from passive solar remains lower; hence the research requires to increase it. Researchers tried different ways to enhance the pure water production from the passive solar still. Present work shows the numerous developments and modifications done in passive solar still to increase distillate output. From the review paper, it has been found that passive solar still is an essential device and it has many scopes of research work to increase distillate output.

Keywords: Potable water; Distillate output; Passive solar still

1. Introduction

Due to the increment in population day by day, the consumption of water is also increasing. Hence the sustainable solution is required to supply potable water. Potable water is available in lakes, rivers and wells but human activities near them increase the pollution of water [1–3]. Solar distillation or desalination is a process to distill the saline water into the potable water with the help of available sun radiations. Solar still is a device, in which the condensation, as well as the evaporation process, occurs inside it to produce potable water [4]. Passive and active are the main two types of solar still [5–11].

2. Physical parameters affect the passive solar still

2.1. Water depth

Water depth inside the passive solar still is a main physical parameter. Lower water depth has lower volumetric heat capacity, and it is responsible for the release of heat during sunshine hours and less storage effect. Higher water depth has higher volumetric heat capacity, and it is responsible for the lower release of heat during sunshine hours and higher storage effect. To examine the effect of lower and higher water depth in passive solar still, a study of variations of water depths such as 0.1, 0.2 and 0.3 cm has been conducted by use of three separate passive solar stills for 24 h of the time interval. It has been found that the 0.1 cm water depth found highest distillate output as compared with 0.2 and 0.3 cm [13,14].

2.2. Inclination angle and orientation of glass cover

Passive solar still is not moving towards the sun rays to receive maximum solar rays. Hence the inclination angle, as well as the orientation of glass cover, is an essential factor. The lower inclination of the glass cover and higher inclination of glass cover both reduces the output of potable water from the passive solar still. Hence, the angle of glass cover should be equal to the latitude of the particular place, where passive solar still is used for study [15,16]. The orientation

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of glass cover should be towards the south direction if the place of solar still is located at Northern hemisphere and should be north of the southern hemisphere. India is located at the Northern hemisphere. Hence the direction of solar still should be towards the south direction [17,18].

2.3. Temperature of glass cover

Distillate output of potable water from passive solar still depends on the temperature of the water inside the basin and temperature of inner glass cover temperature. Higher water temperature inside the basin enhances the higher evaporation of water and lower inner glass cover temperature leads to better condensation. Hence, the temperature difference between the water and inner glass cover temperature should be higher, that is, higher water temperature and lower inner glass cover temperature increase distillate output of potable water [19,20].

3. Developments and modifications of passive solar still

Only sun rays are required for the production of potable water in the passive solar still. Hence, the development and modifications are necessary to increase freshwater production. There are several ways to enhance the distillate output of passive solar still such as the use of floating plates, solar reflectors, wick and stepped solar still, fins, sensible as well as latent heat materials inside the basin water, unconventional shapes, etc. studied here.

3.1. Passive solar still with floating plates

Fig. 1 shows conventional passive solar still [21]. In a passive solar still, sun rays heat the whole water inside the basin; it takes time. But in place of an entire heating mass of water, only a small thickness of water increases in temperature and gets heated quickly and hence, distillate output is increased [22]. Solar still comparison integration with the copper plate and aluminium plate were carried out in climate conditions of Mahesan. Results express that copper plate inside still shows higher potable water production compared with other configurations [23]. Mica plate in the solar still has been examined in climate conditions of Patan, Gujarat, and compared with conventional solar still. Results express that, potable water production increased by 15% by use of mica plate with the passive solar still [24] (Fig. 2). Use of perforated plate integrated with the passive solar still has been carried out for better evaporation as well as the increment of surface area. Mathematical modelling was also carried out for comparison purpose and found a fair agreement between experimental and mathematical modelling results [25]. Fig. 3 shows experimental set-up of perforated plate with the passive solar still.

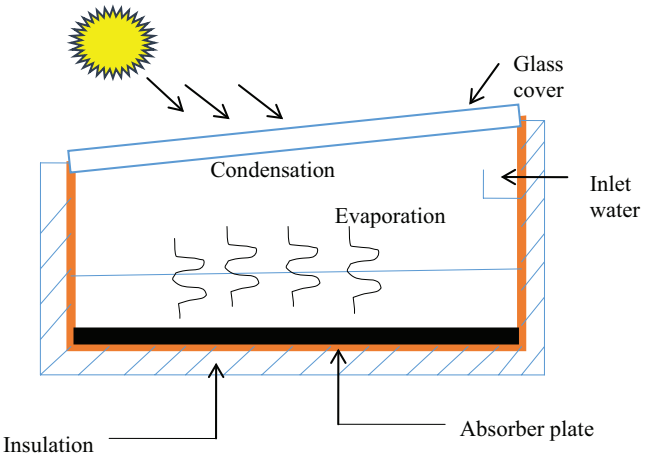

Fig. 1. Conventional passive solar still.

3.2. Solar reflectors

Around 10% of sun rays are lost from the solar still, and the loss can be reduced by use of solar reflectors with the passive solar still [26]. The solar reflector is one of the most straightforward approaches to minimise the loss of sun rays and hence, increase the distillate output of passive solar still [27]. Integration with a reflector as well as the black dye was investigated. The primary objective was to determine the percentage increment of distillate output with the aid of reflector

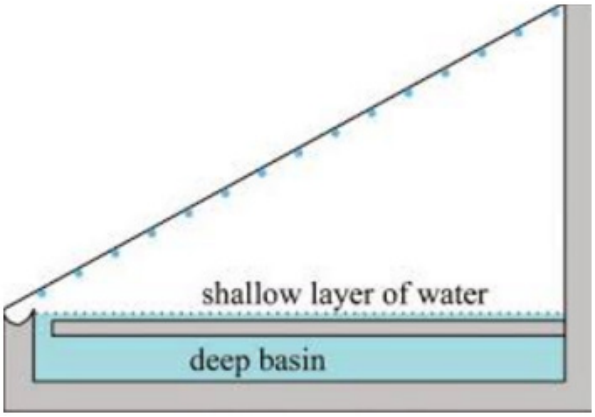

Fig. 2. Schematic diagram of mica plate inside passive solar still.

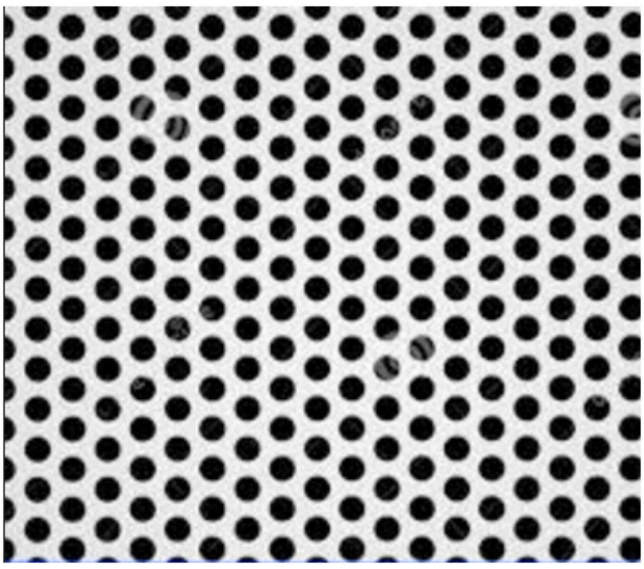

Fig. 3. perforated plate used in the passive solar still.

and black dye and obtained a 20% increment in distillate output [28]. Researchers have worked on passive solar still with an outer reflector, but researchers have studied the effect of both the inner and outer reflectors on performance analysis of passive solar still. After 1 year of continuous research work, a 25% increment as compared with conventional solar still was found [29]. Fig. 4 shows the experimental set-up of solar still with internal and outer reflectors.

3.3. Stepped and wick solar still

3.3.1. Stepped type

Latent heat of condensation and latent heat of vaporisation are responsible for the conversion of water vapour to water droplets and water to water vapour. Whenever the water vapour is converted into water droplets, then the loss of latent heat of condensation occurs. Hence, if the loss of latent heat of condensation is reduced, then definitely the distillate output is increased, and stepped type passive solar still can reduce the loss of latent heat of condensation [30].

A researcher from Egypt tested stepped and passive solar still. They tested both solar still in the climate conditions of Egypt for 1 year. After a series of experiments, it was found that the water temperature, as well as distillate output, is increased in stepped solar still as compared with passive solar still [31]. Stepped solar still integrated with internal reflectors [32], external reflectors [33] also tested in Egypt and received 25% enhancement of potable water production. Fig. 5 shows the experimental set-up of stepped solar still.

3.3.2. Wick type passive solar still

Wick type passive solar still has wick surface which is used to enhance the surface area as well as increase the capillary action for a rise in production of potable water [34–36]. Researchers performed experiments on wick type solar still and conventional passive solar still. They used the same water depth and climate conditions for experiments. After a series of experiments, they found that the wick type solar still increases the distillate output around 19% as compared with the passive solar still [37]. Use of various wick materials inside conventional passive solar still. It was found that the passive solar still with silk is a suitable material for enhancement of potable water production [38]. Experimental set-up of passive solar still with different wick materials is as shown in Fig. 6. Multi-basin solar still found the advantage of heating of water from bottom heat and also use of different wick materials have been received 35% more potable water productions [39,40]. Experimental investigation on concave wick type of solar still with conventional wick type of solar still have been conducted in Egypt and found that the concave wick type solar still found 42% increment in distillate output as compared with passive wick type solar still [41]. Fig. 7 shows set up of concave wick type passive solar still.

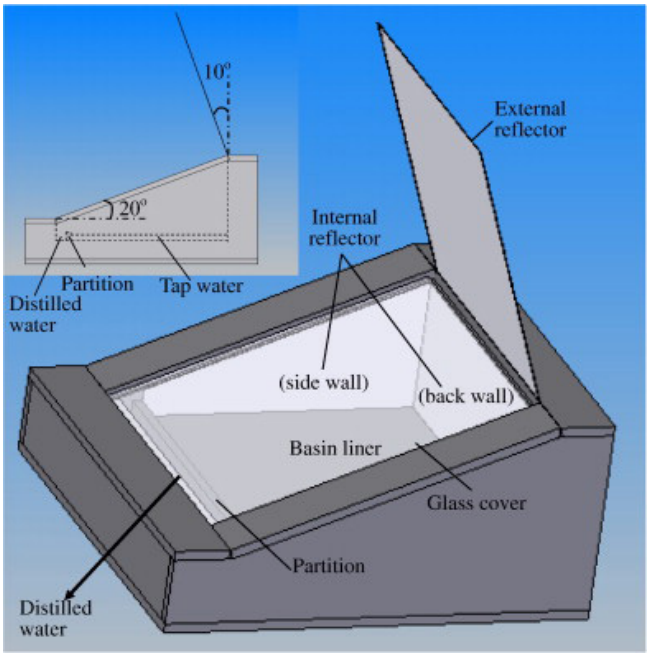

Fig. 4. Schematic diagram of the internal and outer reflector in the passive solar still.

3.4. Fins

Use of extended surfaces or fins can increase the surface area of water. An experimental investigation performed on the passive solar still was conducted, and experimental results show enhancement of potable water production around 30%,

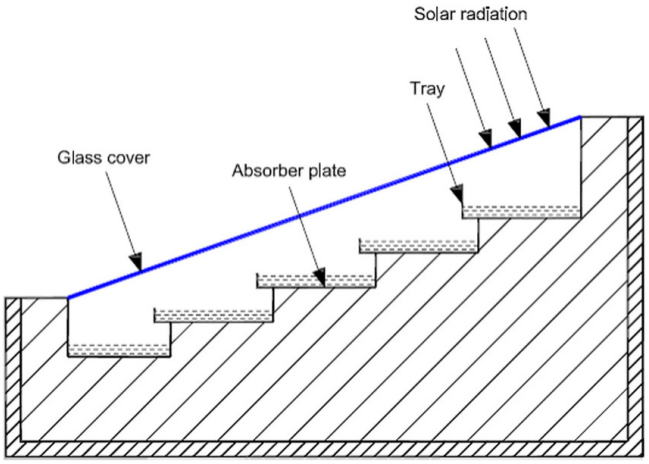

Fig. 5. Schematic diagram of stepped solar still.

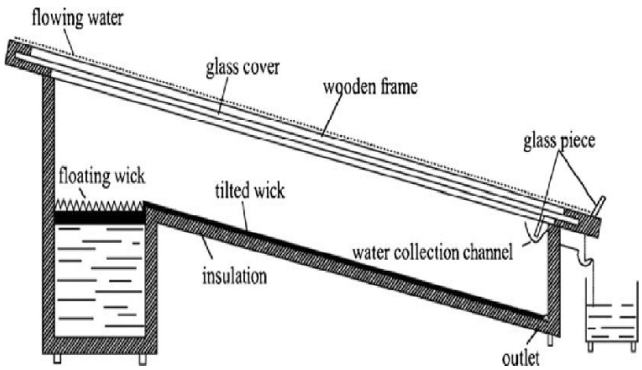

Fig. 6. Schematic diagram of Wick type solar still.

16.2% and 45.9% for wick, sponge, and fins accordingly [42]. A study on different types of the fin and its effect on the passive solar still was investigated and found a 50% increment in distillate output [43]. Experiments on three different types of passive solar stills such as conventional, finned and corrugated studied in climate conditions of Egypt. The primary aim is to determine the best configuration of passive solar still and found that, fin type passive solar still is best as compared with remaining two passive solar stills [44]. Fig. 8 shows the schematic of passive solar still with fins. The effect of fin depth and size was also investigated, and their effects on passive solar still have been studied. From the series of experimental investigations, it has been found that the fin depth and size of the fin enhances the performance of passive solar still [45].

3.5. Sensible heat storage materials in the passive solar still

Rays from sun are never found constant; they always remain intermittent. Also, it is not used during off-sunshine hours or night hours. Hence, to use solar energy during off-sunshine hours or night hours storage is mandatory [11].

Different sensible heat storage materials such as black rubber mat, black ink and black dyes inside the passive solar still have been investigated. They concluded that black rubber mat enhances the potable water production by 38% [46]. Different sizes of black rubber (2, 6 and 10 mm) thickness and black gravel materials (7–12, 12–20 and 20–30 mm) size used as sensible heat storage materials have been used inside passive solar still to assess its effect on potable water production [36]. Black granite gravel is also used inside passive solar still as sensible heat storage material and received 3.9-L distillate output [47]. Different size of charcoal particles has also been used in passive solar still to store excess of solar energy and increase distillate output [48,49]. Fig. 9 represents sensible heat storage materials added in the passive solar still.

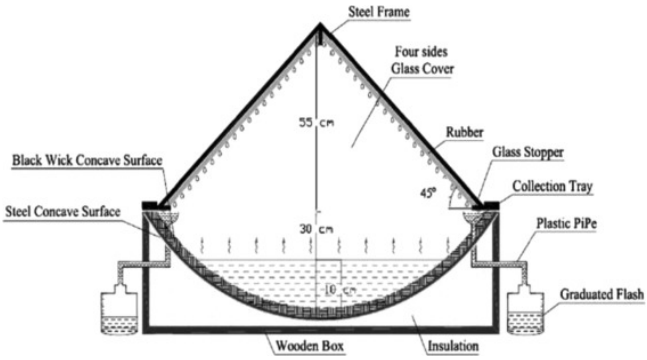

Fig. 7. Schematic diagram of concave wick type solar still.

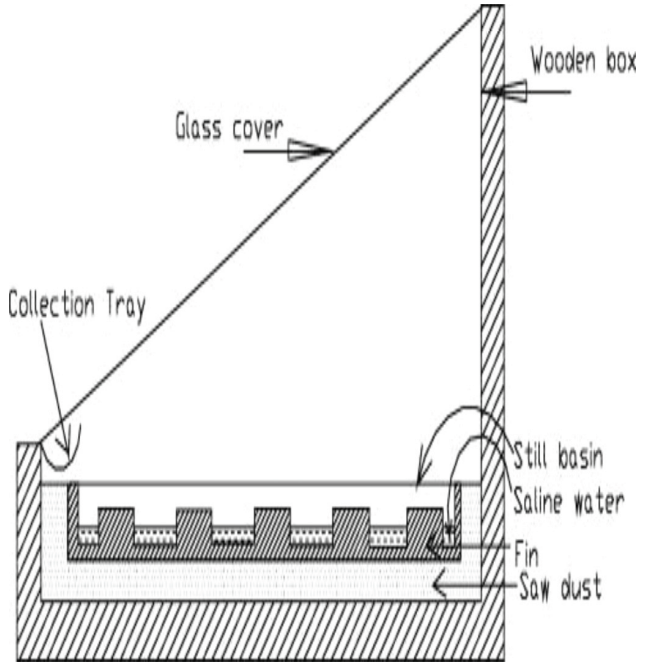

Fig. 8. Schematic diagram of passive solar still with fins.

3.6. Unconventional shapes of passive solar still

Generally a simple design such as a square or rectangular basin, glass cover and insulation at bottom and sides is used for passive solar still. But there are some unconventional shapes of passive solar stills. Research has been done by researchers to increase distillate output. Some of them are as given below:

3.6.1. Triangular passive solar still

Triangular passive solar still has a triangle surface rather than square or rectangular surface, and it can take more solar radiations due to its design. The distillate output of solar still depends on solar radiations, hence the distillate output is more for triangular passive solar still than the conventional passive solar still [50]. Fig. 10 expresses the set-up of triangular passive solar still. Use of forced cooling effect on performance analysis of triangular solar still has been performed in climate conditions in Chennai. The primary objective was to reduce the temperature of the inner glass cover for increment in condensation rate [51]. A study on triangular solar still with phase change materials was also carried out and received a 25% enhancement of potable water production [46].

3.6.2. Tubular type passive solar still

Tubular type passive solar still is as simple as the conventional passive solar still. An experiment work on varying

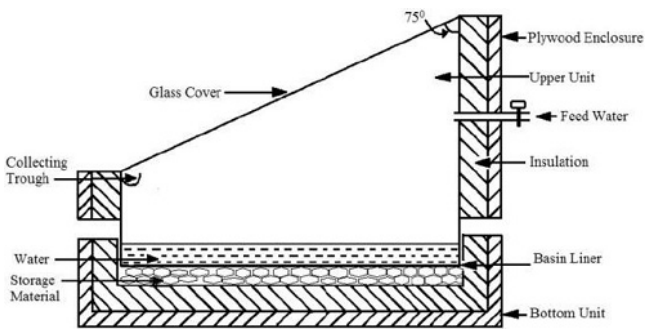

Fig. 9. Schematic diagram of sensible heat storage materials inside passive solar still.

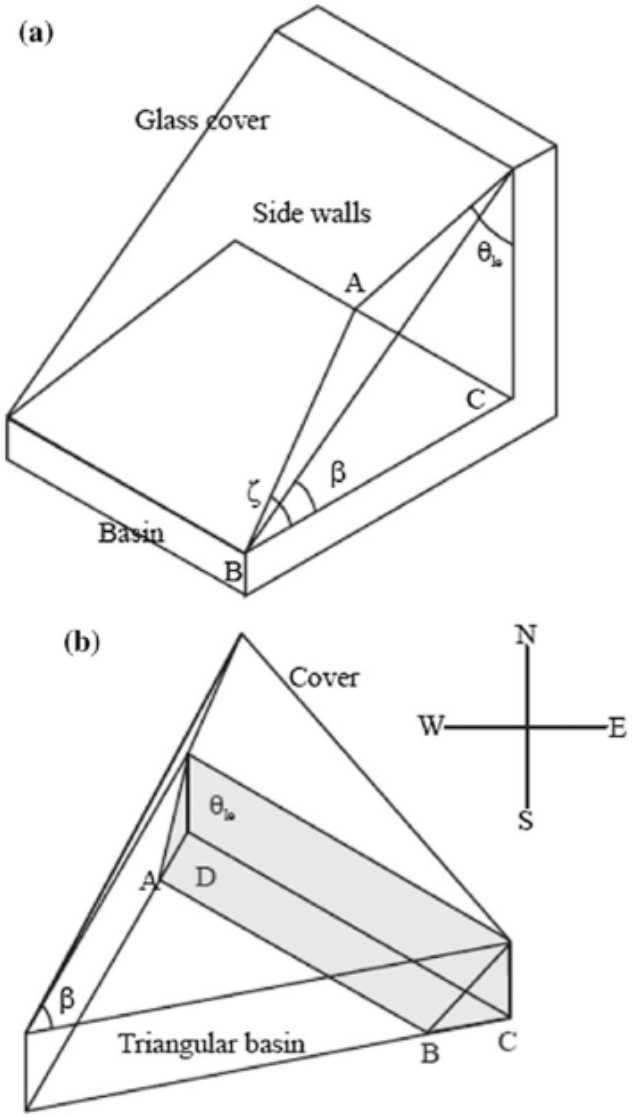

Fig. 10. Experimental set-up of triangular passive solar still.

glass cover has been conducted to see its effect on the condensation process [52] and is shown in Fig. 11. It represents the comparative analysis of different glass covers such as vinyl chloride sheet and polythene film. Results explain that vinyl chloride was found to have impressive performance of distillate output [53].

3.6.3. Hemispherical passive solar still

Fig. 12 shows the hemispherical passive solar still. Due to its hemispherical shape, it can take radiations from any side and hence, no tracking of solar still is required and also it is cheap. The comparative analysis of passive solar still and hemispherical solar still has been carried out with the same water depth and concluded enhancement of 20% [53]. Glass cover cooling is also applied to hemispherical solar still and received an improvement of 15% [54]. Table 1 shows the comparison of various modifications in passive solar still to increase distillate output.

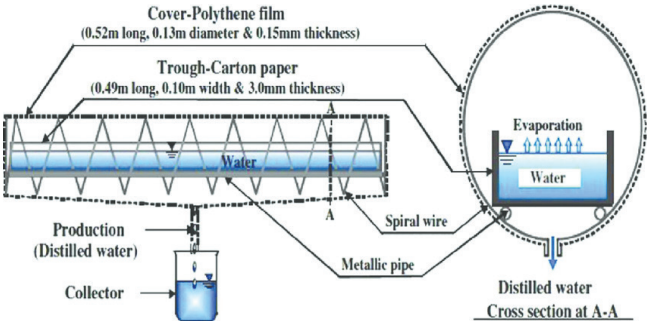

Fig. 11. Schematic diagram of tubular type passive solar still.

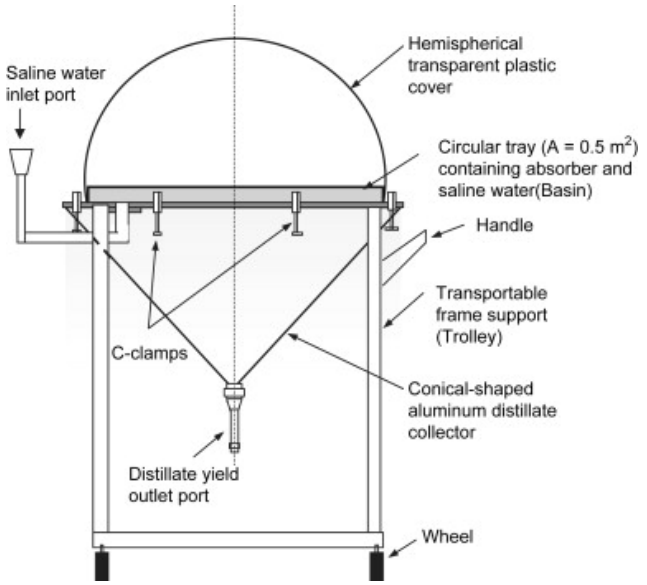

Fig. 12. Schematic diagram of hemispherical passive solar still.

4. Conclusion

Following points are concluded from review paper.

- The inclination of the glass cover of passive solar still should be equal to the latitude of the place and facing should be the south direction.
- Lower water depth inside passive solar still increases the distillate output due to lower volumetric heat capacity.
- Higher water temperature and lower inner glass cover temperature are responsible for increment in distillate output of passive solar still.
- Floating plates increase the distillate output of passive solar still by increasing the surface area of water.
- Attachment of reflector is a simple way to increase potable water production of passive solar still. Also, internal and external reflectors can be used to increase distillate output.
- Stepped type passive solar still increases the distillate output due to use of latent heat of condensation.
- Fins increase the distillate output of passive solar still by an augmentation in the surface area of water and even distribution of water in the basin.

Table 1
Comparison of various modifications in passive solar still to increase distillate output

S No.	Modifications in passive solar still	Percentage increment in distillate output	Main advantage found in passive solar still	Author	Year
1.	Stepped basin	20	Increase in evaporation rate.	Omara et al. [31]	2013
2.	Enhanced productivity	22	Used tap and sea water also dairy effluent to check the efficiency	Panchal and Shah [24]	2013
3.	Fins	45.5	Enhancement of heat transfer from basin to water	Velmurugan et al. [39]	2009
4.	Black granite gravel	20	Reduced side and bottom loss	Shakthivel and Shanmugasundaram [47]	2008
5.	Sensible heat storage	68	Sponge is a better sensible heat storage material than pebble	Velmurugan et al. [40]	2008
6.	Tubular solar still	25	Polythene sheets gave higher performance than vinyl chloride as cover material	Ahsan and Fukuhara [52]	2009
7.	Hemispherical	8%	Transportable hemispherical solar still	Ismail [53]	2009
8.	Aluminium and galvanised iron-type solar still	15	Galvanised iron type solar still gives higher output because of higher thermal conductivity	Panchal and Shah [18]	2011
9.	Single basin	20	Floating cum tilted-wick type	Aruna and Janarthanan [35]	2014
10.	Energy absorbing materials	68	Charcoal, black rubber mat, black ink and black dye	Panchal and Patel [15]	2016
11.	Still with wick material	42	Efficiency increases with wick material compared with conventional solar still	Kassem [37]	2016

- To store the excess of solar energy, sensible heat storage materials should be used in a passive solar still.
- Unconventional solar still such as a triangular solar still, tubular solar still and hemispherical solar still found higher potable water production.

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