Co-published by
Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Committee on Thermodynamics and Combustion
Polish Academy of Sciences

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http://www.imp.gda.pl/archives-of-thermodynamics/

Enhancing Solar Still Productivity through Fin, Solar Collector and Wick Modifications: A Comprehensive Review

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Received: 09.06.2025; revised: 23.04.2026; accepted: 10.08.2026

Abstract

Solar distillation has emerged as a vital technique for providing fresh water to communities at an economic level. Among various systems, the solar still has been recognised as a promising technology due to its simple design, low maintenance requirements and environmental benefits, particularly in reducing carbon footprint and supporting sustainable development goals. However, the yield of a solar still is highly dependent on solar intensity, which drops significantly at night, thereby limiting its overall efficiency. So, this review article explores a wide range of low-cost modifications for improving the evaporation rate and freshwater yield. The article covers the fabrication process of the solar still and discusses various design modifications. These modifications include the effects of fin geometry and placement. Furthermore, the article examines the integration of external attachments such as flat plate collectors (FPC) and evacuated tube collectors (ETC) to enhance heat transfer. The influence of wick materials, their types and placement within the solar still are also analysed. Lastly, the article provides a key recommendation highlighting the potential future research for the development of high-performance solar stills.

Keywords: Solar still; Yield improvement; Evaporation rate; Fins; Solar collector; Wicks

Vol. 47(2026), No. 3, 147–156; doi: 10.24425/ather.2026.7514

Cite this manuscript as: Negi, A., Ranakoti, L., Sharma, K.K., Mandal, A., Sharma, M., Kumar, D., Khare, J.M., Sharma, S., Bhandari, P., & Singh, S. (2026). Enhancing Solar Still Productivity through Fin, Solar Collector and Wick Modifications: A Comprehensive Review, *Archives of Thermodynamics*, 47(3), 147–156.

1. Introduction

Fresh water is a fundamental necessity for all living beings to sustain their day-to-day routines. This concept is undeniably acceptable around the globe, but the efforts to adequately address this challenge remain insufficient. Fresh water supply to every household is now become a challenge due to continuous increasing population and limited water resources. It was estimated that freshwater demand may rise by 55% by the end of 2050 [1]. This challenge intensifies further due to rapid industrialisation and its consequences, that is pollution of the available water resources. Therefore, exponential rise in freshwater demand has been observed in the last few decades. Considering developing countries, in particular arid and remote areas, there is a large shortage of electricity, and conventional methods to treat impure water

are not feasible for producing fresh water [2]. Major sources of fresh water in such regions are canals, groundwater, lakes, water streams, etc., which are either insufficient in amount or not adequately clean [3]. These concerns underscore the dire need for a sustainable technique for water treatment, which is efficient, reliable and pocket friendly.

It has been estimated that freshwater availability is limited (less than 3%) and distributed unevenly throughout the globe [4]. Despite that, saline water is plenty in nature and covers 97% area of the total water bodies [5]. However saline water cannot be considered for drinking due to the high content of total dissolved solids (TDS), salt, and bad pH [6]. Various water treatment methods can be employed to treat saline water efficiently, and later they can be employed for betterment of the society. These water filtration techniques include reverse osmosis (RO), electrodialysis (ED), multistage flash distillation (MFD), nanofiltration membrane (nFM), solar distillation using a solar still,

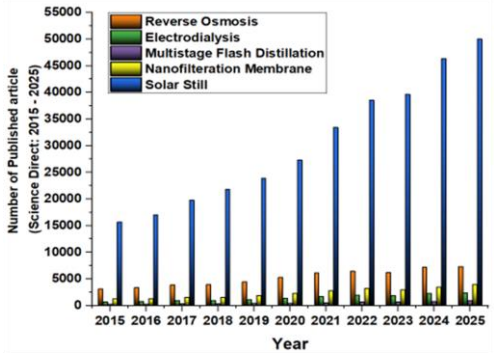


Fig. 1. Number of published articles in ScienceDirect from 2015 to 2025 (source: ScienceDirect).

and so on [7–11]. Nonetheless, the dilemma arises regarding which technique to use due to their respective advantages and disadvantages.

For instance, data collected (published articles) for five major water treatment techniques, that is reverse osmosis, electrodialysis, multistage flash distillation, nanofiltration membrane, and solar still taken from ScienceDirect for the years 2015 to 2025, as represented in Fig. 1, suggesting that research and development in the field of solar still is currently leading by a very big margin due to renewable energy input and ease of water purification. Data also signifies a steady rise in research publications for reverse osmosis but still trailing behind solar still by a huge margin. The lower number of publications in the field of electrodialysis, multistage flash distillation and nanofiltration membrane indicates the shift of research and development for water purifying techniques towards sustainable and low-cost freshwater production methods.

Several key components of the solar still and its working principles have been presented in Fig. 2. The solar still system is an airtight chamber, covered with a transparent sheet of glass at the top. The saline or contaminated water is poured through the inlet into the basin of the solar still. The solar radiation is incident through the glass and impinges on the system's basin [12]. The material used for the basin has high radiation absorptivity properties. These materials include different grades and gauges of steel, mild steel (MS), copper, stainless steel (SS), galvanised iron (GI), aluminium, and so on [13]. Good insulation materials, especially foam, thermocol, glass wool, rock wool, and so on, are used to reduce the losses from sides and bottom [14]. The thermal radiation impinges on the basin surface and enhances the temperature of the contaminated water, causing evaporation and leaving behind all the impurities in the basin.

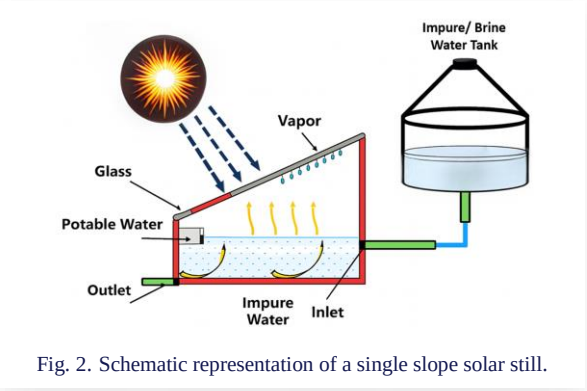


Fig. 2. Schematic representation of a single slope solar still.

The evaporated water gets condensed over the glass surface due to the temperature difference between the basin water and the glass surface. The condensed water droplets are collected in a separate clean container that can be used for domestic purposes [15].

Solar desalination has shown its prominence in getting attention from various scholars due to its ease of working principle, construction, manoeuvrability, maintenance, and so on [16]. Yet, along with several advantages, it has certain disadvantages such as low distillate yield, even zero at night due to the unavailability of solar energy. Earlier studies [17] reported an overall daily distillate yield of less than 3 kg/m^2 a day using a basic design of the solar still, which is quite low. Papers [18–19] have suggested that the yield of the solar still depends on the heat transfer rate (at evaporation and condensation) within the system. A higher evaporation rate results in more vapour generation, while condensation helps turn that vapour back into water droplets.

In addition, Fig. 3 presents a schematic classification of solar stills based on passive and active systems. Passive solar stills rely entirely on sunlight, making them simple, low-cost and suitable for small-scale use [20]. They include conventional designs such as basin-type stills, which vary in shape (single slope, double slope, pyramid) and number of basins, as well as models enhanced with reflectors or condensers [21]. To improve efficiency, modified designs introduce features like wick materials, rotating cylinders, or innovative shapes such as stepped, tubular, or concave forms, all aimed at increasing evaporation and condensation rates. Hybrid solar stills take this a step further by combining the still with technologies like photovoltaic panels, solar ponds, or waste heat sources to boost performance [22].

Active solar stills are designed for higher productivity by incorporating external energy support [23]. They are often integrated with solar collectors, such as flat plate or concentrating collectors, to preheat water, with circulation occurring naturally or through pumps [24]. More advanced systems use components like evacuated tubes, heat pipes, or parabolic collectors to achie-

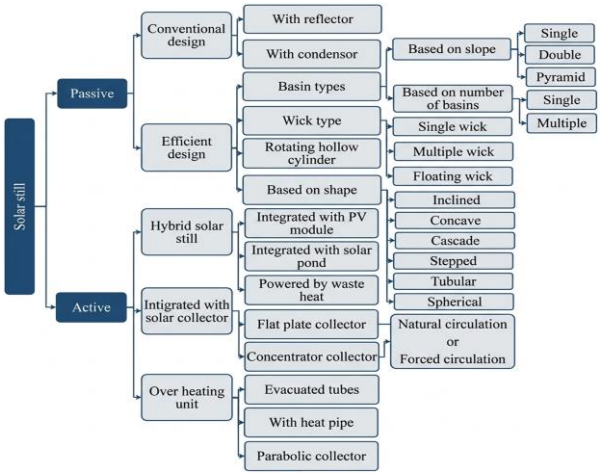


Fig. 3. Yield improvement techniques of the solar still.

ve higher temperatures and faster distillation. Overall, the classification shows how solar still technology evolves from simple, standalone units to more advanced and efficient systems capable of producing greater amounts of fresh water [25].

In addition, the efficiency of a solar still can be enhanced by minimising the losses occurring in a solar still. Major losses that occur in a solar still are due to radiation and convection. Proper care can prevent heat losses from the solar still by applying insulating materials [14]. Several types of insulations have been utilised in solar stills [15,26–28], such as foam, thermocol, saw dust and glass wool, focusing on specific insulating thickness. Without knowing about the thickness of insulation to be applied over the solar still, the effective output will not be achieved. For instance, the thickness of insulation of 60 mm for a single slope solar still (SSSS) operating at a water depth of 40 mm can produce a yield up to 80% as reported by Khalifa et al. [29]. Results have also been reported for insulating thickness of above 60 mm, which certainly performed better in terms of yield but only during the nocturnal period. It was observed that materials such as sawdust (of thermal conductivity 0.08 W/(m·K)), glass wool (0.04 W/(m·K)), and plywood (0.13 W/(m·K)) are commonly used as insulation in solar stills to minimise heat loss to the surroundings. A brief summary of the previously used insulation materials is given in Table 1.

More focus has been given to enhancing the yield of the solar still system during the nocturnal period, and to do so, various developments have been done in the past that could store energy during peak hours and can deliver back to the system during low sunshine hours, i.e. the nocturnal period. Enhancement of yield can also be achieved by modifying the solar still system in which utilisation of flat plate collector, application of tilted khes wicks and incorporation of absorbers are included [15]. The rate of evaporation which eventually determines the yield of the solar still can also be tailored by incorporating phase change materials in the water basin, using fins at the surface, and incorporating nanoparticles with the basin water [30,31]. These modifications in the solar still help in improving the overall surface area and lead to higher yields as compared to the yield of an unmodified solar still. The said modifications of the solar still are cheap and do not require any complex engagements and have proved to be highly promising in enhancing the solar still yield [32]. Therefore, this work primarily focuses on discussing various such modifications and techniques under practice for solar still yield enhancement at a very low cost.

2. Modifications in the solar still

2.1. Yield enhancement using fins

Integration of fins on the basin of the solar still can be seen in Fig. 4. It has been evident from the past literature that the integration of fins improves the heat transfer rate of the system. It increases the surface area, resulting in improved basin water temperature and distillate yield. Notable enhancement in the yield of the solar still of about 3.07 l/m^2 can be obtained by integrating fins at the surface, incorporating a phase change material, applying wicks and utilising a condenser. These changes applied all together in a single slope solar still (SSSS) were reported to have a yield 39.47% higher than that for a conventional conical solar still (CSS) without any modification [33]. The complete setup along with the yield obtained by the systems can be seen in Fig. 5.

Additionally, it has been concluded that the integration of fins increases the greenhouse effect within the solar still as reported by Rabhi et al. [34]. As per the study, apart from improving the heat transfer rate, fins are also used to evenly distribute water within the basin of the solar still [35]. The materials used to fabricate the fins are crucial, as the heat transfer properties of the system depend on them [36]. Contrary to this, Sebaii et al. [37] reported no significant improvement in varying fin materials. During the study, different fin materials such as aluminium, glass, stainless steel, brass, copper, iron and mica were used in solar stills. Figure 6 presents the complete 2D model of the setup along with the dimensions of the fins. As discussed previously, various factors such as the type of fins and geometry

Table 1. Summary of the relevant studies on insulation materials.

Publication	Insulation material	Thickness of insulation (mm)	Modifications	Enhancement (%)
Agarwal et al. [68]	rockwool	4	copper tubes and copper cylinders filled with PCM	92.02
Ramzy et al. [69]	steel wool pads	–	internal reflectors and woven wire mesh	22.1
Karthikeyen et al. [70]	thermocol	–	nanomaterial with colour die	66.7
Negi et al. [64]	foam	30	blackened inclined wick	14.9
Omara et al. [71]	saw dust	40	fins	40

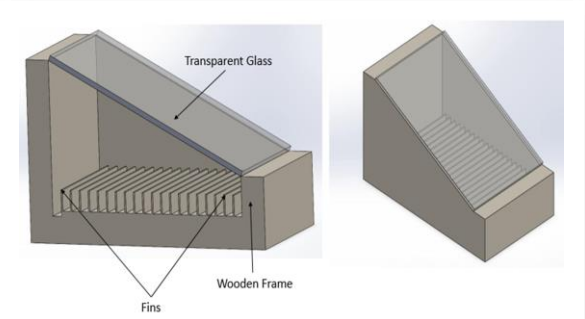


Fig. 4. Fins integrated solar still.

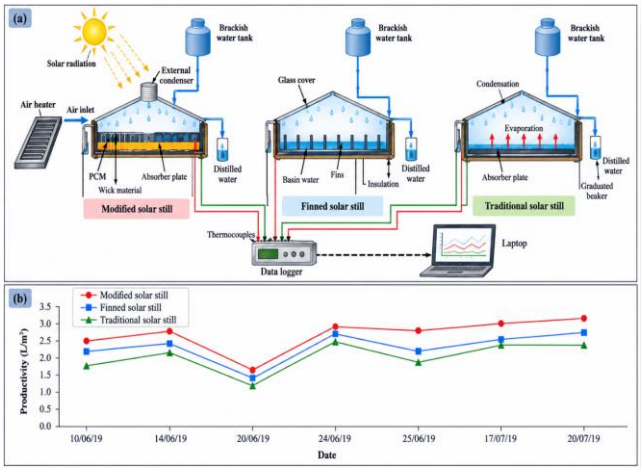


Fig. 5. Schematic diagram of the experimental setup (a), and yield obtained from the respective solar still (b) (drawn based on [33]).

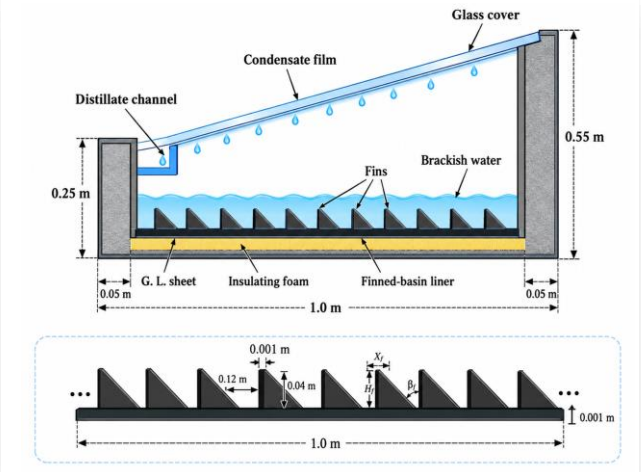


Fig. 6. Experimental setup modified with fins (drawn based on [37]).

are the influencing parameters that directly improve the efficacy of the solar still. In a recent study, Panchal et al. [38] experimented with vertical and inclined fins incorporated in a solar still. The inclined fins were tilted at a 30° angle. It was observed that the distillate yield of inclined fins was slightly higher compared to vertical fins. The yield was improved by 26.77 % and 24.19 % for an inclined and vertical fins-based solar still compared to CSS. Also, Rajaseenivasana et al. [39] tested circular and square-shaped fins with varying water depth (1–3 cm) in SSSS. It has been reported that square-shaped fins in a solar still have higher distillate yield compared to circular fins. Based on the study, it was concluded that increasing the fin's height has a great impact on the rate of heat transfer, as reported in the literature. Apart from this, it has been observed that increasing fin quantity and width can significantly reduce the overall distillate yield [40]. This was observed due to higher heat loss from the side and bottom of the still. To reduce these losses, an acrylic material-based casing was used with aluminium fins. These modifications decrease the heat losses and improve the overall temperature of the basin water and hence contribute to overall improved water yield [41]. Modi et al. [42] experimented on a solar still with and without hollow circular fins. It was reported that the evaporative area of the still was significantly improved compared to the still without fins. Furthermore, it has been observed that the number of fins also influences the distillate yield of the system. Islam et al. [43] reported significant improvement in the distillate yield using 14 fins and 4kg of fly ash. Apart from this, Panchal et al. [44] studied the effect of porosity on SSSS. The obtained results show a 42.3% improvement in distillate yield with porous fins compared to CSS.

Few studies have incorporated both fins and energy storage materials simultaneously with the solar distillation setup. Simultaneously using these modifications increases the yield of the modified system and significantly lowers the cost per litre of obtained water (CPL). In a similar fashion, Kumar et al. [45] modified a conventional solar still with aluminium, galvanised iron (GI) based fins and paraffin wax. Among fin materials, aluminium was superior due to its thermo-physical properties. The authors report a 36% improvement in the overall distillate yield for CSS, when compared to the conventional solar still. In another study, the authors studied the effect of fins above and beneath the absorber plate with paraffin wax. It has been evident from the study that the placement of the fins above the absorber plate increases the surface area of the system, while extending fins beneath the plate increases the heat storage capacity of the system. This modification increases the distillate yield of CSS by 55.59%. Also, these modifications lower CPL of the obtained distillate [46]. In another study, Abdullah et al. [47] modified the shape of the basin. Additionally, fins were covered with jute cloth to increase the capillary action. The CuO-based nPCM was used to store energy for improved distillate yield for a longer period. Apart from this, three heaters were provided to heat the basin water up to its evaporation temperature. These modifications improve the distillate yield by 196% as compared to a reference CSS, as reported by the author.

2.2. Yield enhancement using solar collectors

Solar collectors or solar water heating devices utilise solar energy to convert radiation into useful heat, particularly for water heating applications. These solar collectors are coupled with solar stills to enhance the overall efficiency of the system by improving the evaporation rate. The collectors enhance the inlet

basin water temperature, thereby reducing the amount of energy required for water evaporation. Various collector designs are capable of providing a wide range of operating temperatures. The classification of the solar water heating systems can be seen in Fig. 7. Among these, a flat plate collector (FPC) and an evacuated tube solar collector (ETSC) are frequently used in the solar still. Flat plate collectors (FPCs) typically operate within the range of 20–80°C, whereas evacuated tube solar collectors (ETSCs) operate effectively at higher temperatures, between 50–200°C [48].

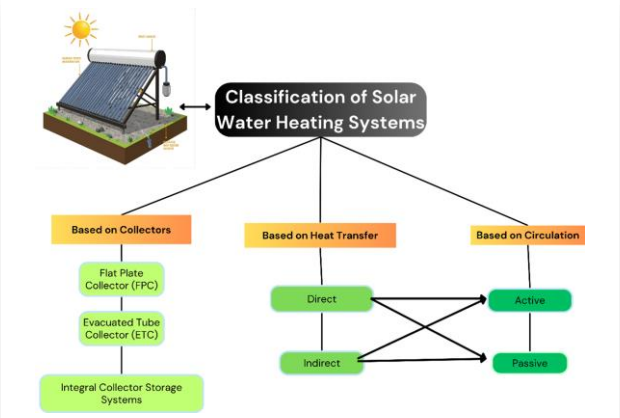


Fig. 7. Classification of solar water heating systems.

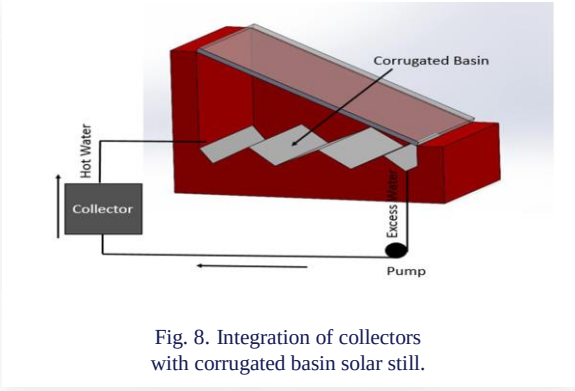


Fig. 8. Integration of collectors with corrugated basin solar still.

Among these, FPCs are the most commonly used due to their simple construction, low maintenance requirements and cost-effectiveness, yet they generally offer lower efficiency and outlet temperatures compared to other collector types. A scheme of utilisation of collectors in the solar still can be seen in Fig. 8.

The mass flow rate of the water, intensity of the solar radiation, and properties of the absorber material are the crucial factors that improve the brine water temperature. In this regard, Negi et al. [15] observed a maximum yield of 3.99 kg/m^2·a day from a tilted wick solar still fabricated from stainless steel material integrated with flat plate collectors at an optimal flow rate of 0.041 kg/s. Furthermore, Raju et al. [49] reported a 41% increase in distillate yield when a solar still was coupled with a single FPC compared to a conventional still. Furthermore, connecting three FPCs in series with the still enhanced the yield by up to 89%. Similarly, Badran et al. [50] demonstrated that integrating an FPC with a solar still increased its productivity by approximately 36% relative to CSS. Furthermore, according to Sabiha et al. [51], FPCs exhibit two major drawbacks, i.e. a significant convective heat loss through the glass cover from the absorber plate and the absence of a sun-tracking mechanism, which restricts their ability to consistently capture the maximum solar radiation throughout the day.

According to [52], evacuated tube solar collectors (ETSCs) exhibit significantly higher efficiencies than flat plate collectors (FPCs). ETSCs are capable of capturing both direct and diffuse solar radiation. In addition to their superior thermal performance, they offer advantages such as convenient installation and ease of transportation. Applications that demand higher operating temperatures, such as seawater desalination, air conditioning, space heating, refrigeration, and various industrial heating processes, benefit more from ETSCs than from FPCs [53]. Moreover, ETSCs are suitable for other high-temperature applications, including instantaneous gas heaters, boost element-integrated single solar tank systems, and boost tank-incorporated solar preheaters [54].

Mangal et al. [55] reported that FPCs achieve their peak energy output primarily at midday when the sun's rays are perpendicular to the collector surface. In contrast, the cylindrical design of ETSCs enables passive solar tracking throughout the day, allowing the incident sunlight to strike the tubes at an approximately 90° angle, thus maintaining continuous high absorption. Additionally, ETSCs are less affected by low ambient temperatures and wind, owing to the vacuum layer between the inner and outer tubes. This vacuum effectively minimises convective and conductive heat losses by eliminating air within the evacuated tube. Furthermore, Ayompe et al. [56] conducted an investigation to compare the performance of an FPC and a heat pipe evacuated tube solar collector (ETSC) for domestic water heating. Under similar climatic conditions, FPC and ETSC achieved 46.1% and 60.7% efficiencies, respectively, while the corresponding system efficiencies were 37.9% and 50.3%.

The integration of evacuated tube collectors with solar stills offers a highly effective method for improving heat transfer and increasing distillate yield. For instance, Panchal et al. [57] experimented by modifying a double slope solar still (DSSS) with fins and ETSC. Incorporating both fins and ETSC increases the system's yield by 25% when compared to DSSS with ETSC alone. In the other study, Mevada et al. [58] modified CSS with ETSC, zig-zag condensers and fins. The authors reported a 73.45% improvement in distillate yield with the above-mentioned modifications compared to CSS. Apart from this, carbon credit values of the modified solar still (MSS) and CSS were reported to be 5.8$ and 2.9$ per year, respectively. The complete pictorial view of the experimental setup modified with a zig-zag shaped condenser can be seen in Fig. 9.

2.3. Yield enhancement integrating wicks

Wicks such as jute, cotton, khes (porous cotton) cloth are being used to improve the efficacy of the system. Along with this, it has been reported that wicks are low-cost modifications that are used to improve the evaporation area and capillary action of the system. These modifications are simple in construction, and they are incorporated in the design of the still, as shown in Fig. 10.

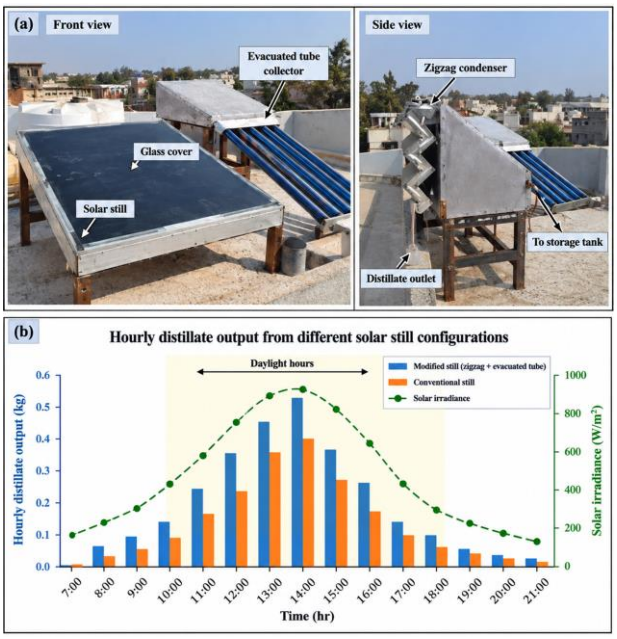


Fig. 9. Experimental setup of a solar still modified with a zigzag condenser and evacuated tube collector (a), and variation of hourly distillate output with time along with solar irradiance (b) (drawn based on [58]).



Fig. 10. Modified solar still with inclined wick.

Researchers have made significant efforts to enhance the productivity of solar stills through both experimental investigations and numerical simulations. For instance, Namshad et al. (2013) [59] examined the performance of flat and rippled wick inverted V-type solar stills (SS) operating under a drip regime in Kerala, considering various climatic conditions. Utilising wicks inside the solar still results in a higher increase in temperature, which in a higher distillate yield. Observations suggested that an increase in rippled angle may lead to a decrease in the productivity [60].

In a recent review, Jobrane et al. [61] analysed various internal and external enhancement techniques applied to wick-type solar stills designed for potable water production. Similarly, Manikandan et al. [62] reviewed the developments and performance improvements of several wick-type solar still configurations.

Furthermore, it was evident that integrating tilted wicks (khes material) inside the basin at the angle of 30º (as presented in Fig. 11) improves the distillate yield by 37.17% compared to CSS [63]. This enhancement in yield was obtained by the extra exposed area of the wick. Apart from this, it has been observed that incorporating these modifications can help mitigate the carbon footprint. With a similar objective, CSS was modified with a black painted basin and tilted wick at various inclinations. It has been reported that a blackened basin with a tilted wick mitigates 2.01 ton of CO_2 per year, which is higher compared to CSS [64]. Other wicks such as an inclined wick, a vertical rotating wick, a floating wick, multiple wicks, a moving wick, and black painted wick are also integrated with the system. For instance, integrating a movable wick can significantly improve the distillate yield of CSS, as reported by Lee et al. [65]. It has been reported that the yield obtained by the system increased by 7% compared to the reference solar still. Similarly, integrating a convex-shaped absorber and jute cloth as a wick, and nanocomposites can lead to an improvement in the distillate yield of a tubular solar still (TSS) by 114.2% [66]. Tanaka et al. [67] investigated and validated the result for improved yield using a tilted wick in a vertical multi-effect solar still. Few studies suggest that applying both wick and fins simultaneously leads to a significant improvement in distillate yield compared to CSS.

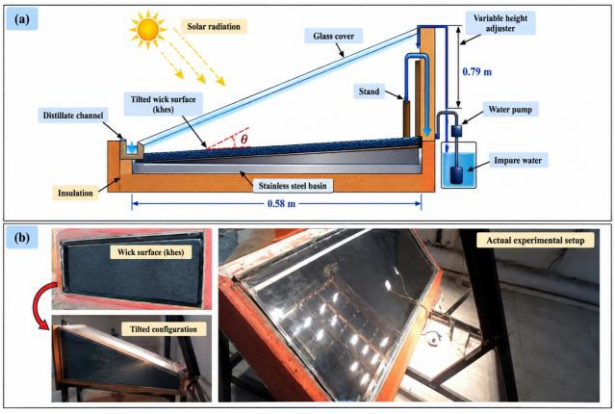


Fig. 11. Schematic diagram of the modified solar still (a), and photograph of the actual experimental setup (b) (drawn based on [64]).

3. Discussion and challenges

The importance of using solar stills can be observed in several arid and coastal areas where the intensity of the solar radiation is high and the quality of water to be purified is poor. Solar stills also hold an edge over other purifying techniques when the cost is considered a critical factor. On the contrary, solar stills exhibit low yield mostly due to the unavailability of sunlight and therefore remain non-operational during the night time.

Several design alterations have been proposed in the literature to enhance the evaporation rate and consequently its yield. These modifications include utilisation of nanofluids, thermal energy storage materials (sensible and latent), preheating the basin water and integration of external attachments, including FPCs and ETCs. Furthermore, the importance of insulation plays a crucial role in minimising heat loss from sides and bottoms. As far as the thickness of the insulating material is concerned, it has been found that 60 mm thickness of styrofoam material can significantly reduce heat losses. This ensures im-

proved basin water temperatures, leading to a higher rate of evaporation.

Furthermore, improving the surface area is highly recommended while enhancing the evaporation rate. This can be achieved by integrating the fins and wicks alone or simultaneously. The material that is utilised for the fabrication of fins and wicks should possess favourable thermo-physical properties, and also a high capillary action. The inclination at which the fins and wicks are placed inside should need a critical assessment. Fins improve the water distribution within the basin. Among various materials studied, aluminium fins exhibit a higher thermal conductivity and performance compared to glass, stainless steel or brass. Research further suggests that inclined fins (around 30°) and square geometries provide higher distillate yields than vertical or circular fins due to improved surface exposure. However, increasing the number or width of fins can lead to higher heat losses through the sidewalls, thereby reducing efficiency. The combination of fins with phase change materials such as paraffin wax or nanoparticle-enhanced PCMs has shown yield improvements ranging from 50% to 190%, while also significantly lowering the cost per litre of produced water.

The use of wick materials such as jute, cotton, and their fabric cloths has been proven to significantly enhance the evaporation rate and overall efficiency of solar stills. These low-cost, easily implemented modifications increase the effective surface area and promote capillary water movement. Among different configurations, tilted wicks (inclined according to the location latitude) have demonstrated yield improvements of up to 37% over conventional stills. Additional performance gains have been reported for blackened basins, movable wicks and multilayer wick systems, which also contribute to carbon footprint reduction. Furthermore, hybrid setups combining wicks with fins or nanoparticles suspended absorbers have achieved an improved yield exceeding 100%, highlighting the potential of wick-assisted hybrid stills as a sustainable and economical approach for freshwater production.

Additionally, the integration of evacuated tube collectors with the solar still enables operation of the system at higher temperatures, leading to better heat retention and greater overall productivity. Compared to flat plate collectors, which are inexpensive and easy to construct but limited by higher heat losses and lower temperature ranges (20–80°C), evacuated tube collectors operate efficiently at 50–200°C and benefit from passive solar tracking due to their cylindrical configuration. Studies report yield enhancements of 36–73% when evacuated tube collectors are combined with fins, condensers, or other hybrid design features.

4. Conclusions and recommendation

Solar stills are economical devices that can provide a fresh water supply to the backward arid areas. However, the low distillate yield of the solar still attracts researchers to seek for alternatives in order to improve the solar still yield. The following conclusions can be drawn based on the above discussion:

a) The low yield of conventional solar stills necessitates performance enhancement through effective modifications such as improved insulation, fins, wicks, and solar collector integration.
b) Integration of fins significantly improves heat transfer and evaporation by increasing the effective surface area, resulting in yield enhancement of up to 39.47%, compared to conventional solar stills.
c) Fin geometry and configuration play a critical role; incorporating inclined fins improved the yield of the solar still by approximately 26.66%, whereas vertical fins resulted in an improvement of about 24.19%, while square fins show better performance than circular ones.
d) Integration of solar collectors effectively increases basin water temperature, leading to productivity improvements of 36% to 89% with flat plate collectors (FPCs).
e) Evacuated tube collectors (ETSCs) demonstrate superior performance due to higher operating temperatures (50–200°C) and improved efficiency (up to ~60.7%), compared to FPCs.
f) Hybrid systems combining ETSCs with fins and condensers can enhance the yield by 25% to 73.45%, making them highly effective for large-scale applications.
g) Wick materials significantly enhance evaporation through capillary action, with tilted wick configurations improving the yield by up to 37.17%, compared to conventional systems.

Future research should focus on developing a road map for hybrid solar still systems by integrating multiple modification techniques such as fins, wicks, phase change materials and solar collectors. Furthermore, there is a strong scope for optimisation of key design and operating parameters, including fin geometry, wick inclination, insulation thickness (around 60 mm), and water depth, to achieve maximum efficiency under varying climatic conditions. Additionally, the use of advanced materials such as nanomaterials and nano-enhanced phase change materials can further improve heat transfer and energy storage capabilities. Also, future work should be concentrated on integrating yield improvements with detailed techno-economic analysis of various solar still modifications to identify the most efficient and cost-effective configurations.

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