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A Critical Review on the Performance of the Solar Stills with Modified Absorber

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The prospect of solar distillation is growing due to the fact that it offers an ecologically sound as well as cost-effective method of supplying drinking water. Solar-powered stills have become the most widely used, needed, and practically feasible methods to harness the power of the sun, and they provide an abundance of potable and agriculturally useful clean water. The purpose of this review is to provide a comprehensive overview of the state of the art in solar still research by compiling investigations that use various methods of modifying the absorber plate of the solar stills to increase their performance. Specifically, a thorough examination of the effect of integrating various biomaterials, such as egg shells, carbonized balsa wood, peanut shells, conch shells, snail shells, and so on., over the absorbing surface of the solar still was carried out. This review article provides value because it gives a framework for systematically evaluating how the application of different biological waste materials over the absorber plate affects the daily production rate of a solar-powered still. The review revealed that there is still enough room to improve the performance of the stills through the modification of the absorber surface with bio-waste materials.

Keywords: solar still, absorbing surface, yield, efficiency, bio-waste material.

1. Introduction

It is essential for humanity to have access to a sufficient amount of fresh water. One hundred years ago, the world's inhabitants were growing at a pace that was double that of the usage of drinking water [1]. There has been an increase in pollution, a drying up of water supplies, or both [2]. Various societal issues may arise as a result of water scarcity, including worsening medical problems, and decreased GDP [3, 4].

One of the most pressing and serious issues stemming from the scarcity of water supplies is the absence of potable water. During 2022, the WHO reported that more than 2.5 billion individuals globally are experiencing a scarcity of potable water [6], specifically in underdeveloped areas of the world [5, 6]. In many nations, the percentage of people without access to clean drinking water is above fifty percent, and in other cases, it's substantially higher than ninety percent. Every year, thousands of innocent individuals pass away because they couldn't get clean water for consumption [7, 8]. According to studies, worldwide population growth has been estimated causing a water deficit of almost sixty percent before 2026 [9]. World Health Organisation estimates indicate that around 2055, over fifty percent of the planet's water needs will be entirely satisfied [10, 11].

Desalting has been a widely deployed technique that purifies saline water by eliminating salt and other impurities, making it drinkable [12]. This method uses a number of thermal, electrical, or transmembrane methods to separate contaminants that dissolve from impure water [13]. In fact, a number of equipment and procedures were initially created for the purpose of transforming briny water into water that could be consumed. These include the processes of reverse osmosis, capacitive deionization, electrodialysis, solar still-based distillation, forward osmosis, humidification-dehumidification, and so on [14, 15], as shown in Figure 1.

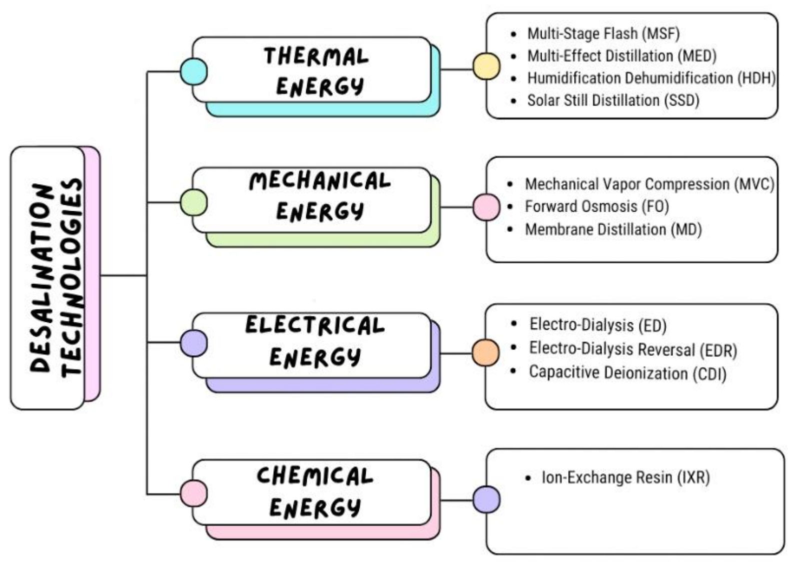

Figure 1. Approaches of water distillation

When it came to desalting, heating technologies were the first to be employed for producing clean water. Thermal energy approaches are based on the principle of changing phases. Evaporation of saline water is the initial phase in producing vapour, which turns into condensation to get purified water. The heat needed for this process may be provided through the use of fuels and other energy sources. The majority of those strategies have been employed in nations that rely on coal and oil for their energy requirements. Yet, contaminants in the air are a result of burning petroleum and petroleum products [16]. Even so, these reserves are out of reach for numerous countries. To address this issue, we can utilize renewable energy sources such as solar power to evaporate the brine through a heating method. It is fresh, affordable, as well as environmentally friendly. Many places that lack accessibility to clean freshwater have been equipped to create potable water using solar stills in the past decade. These locations often have accessible salt water but no fresh water [17]. The basic principle of the solar distilling process is to boil briny water using solar energy, and then recover the water that has evaporated as clean water by placing it in an area for cooling [18, 19]. These technological advancements have a lengthy history of usage. They will also be perfect for the situation right now.

Owing to their many exceptional features, such as being sustainable, inexpensive, simple, low-maintenance, and having architectural versatility, solar stills are better suited for distributed water for domestic usage in distant as well as underdeveloped locations [20, 21]. But their efficiency and production rate are not impressive, which hinders their wider spectrum of application. The performance of such stills depends on different parameters, such as the material properties of the absorber, solar irradiation levels, saline water characteristics, design aspects of the still, and so on [22]. Figure 2 shows the major influences on the performance of the solar stills. By introducing suitable methods, materials, or modifications, which can potentially influence the process parameters, it may result in positive improvements in the solar still performance.

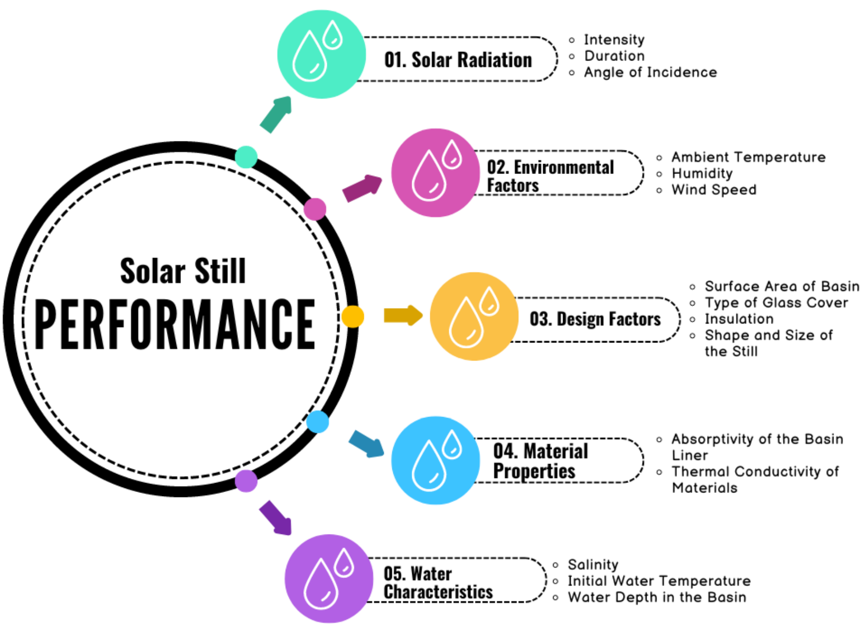

Figure 2. Factors affecting performance of the solar stills

This review paper is aimed at presenting the existing state of the art on enhancing the effectiveness of solar-based stills, which are essentially focused on modifications to the absorbing material/surface of the stills.

2. Overview of a solar still

One of the simplest types of solar still that are being studied over a long time was a normal single-sloped solar still (NSSS) as illustrated in Figure 3 [23]. It primarily consists of a reservoir named basin to store the saline/untreated water, a transparent sloped glass top, an absorbing surface at the bottom of the basin, a water collecting arrangement, and insulations to prevent heat losses to the surrounding. The saline/untreated water in the bottom reservoir has been heated by rays from the sun that gets by means of the transparent concealment, which speeds up the vaporization process [24]. Black-coloured painting on the bottom surface of the basin is a common practice in such NSSS for increased solar heat absorption. Insulation surrounds the boundary walls and base to mitigate heat losses to the environment [25]. Diffused water vapor from the reservoir rises inside the transparent covering, where it forms condensates. Subsequently, gravitational force causes the condensates on the transparent surface to fall to the water collecting arrangement [23]. In this way, its operation is mainly depending on the available radiation from the sun.

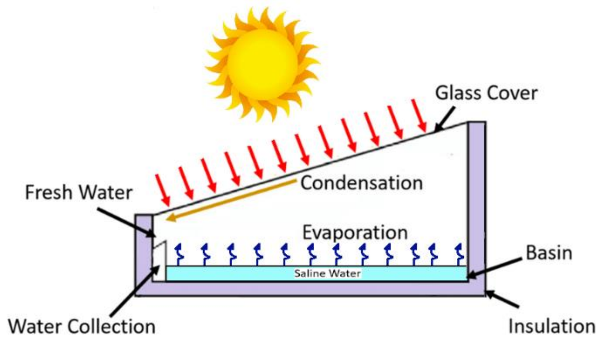

Figure 3. A normal solar still [23]

3. Importance of the absorber in a solar still

Among the different parts of a solar still, the absorbing surface, or absorber, plays a crucial role in its performance. Usually, the absorbing medium or the absorbing surface is a dark-colored layer that is positioned within the base of the still, as shown in Fig. 3. Its main function is to capture incoming heat rays from the sun and transfer them into the saline water that is stored in it. This transferred heat diffuses within the stored saline water, increasing its temperature and promoting vaporization. Subsequently, the process of vaporizing water is accelerated when the saline water's temperature is raised by the diffused heat energy from the absorbing surface. The efficient capture of heat energy by the absorbing surface causes a greater production of water vapor from the impure water [26].

If the substance used for the absorbing surface is of excellent consistency, it will maximize the reception of the radiated heat from the sun that is transformed into heat while minimizing the amount that escapes by any other means, such as reflection [27]. Because of this, the solar-powered system can still extract greater quantities of fresh water within the same amount of time. The rapid transmission of radiant energy into raw water by substances having excellent thermal conductivity makes them ideal absorbing surfaces since the resulting heat propagates uniformly throughout the layer of saline water. The process of evaporation occurs more uniformly because of this equally distributed heat. It is equally crucial that the absorbing element be long-lasting and durable [28]. For the solar still to work for many years to come, it needs an absorbing plate that can endure high and low temperatures without cracking down.

4. Influence of design alterations in the absorber on the performance of the solar still

The modifications in the absorber surface, through the incorporation of the fins, the application of nano-coatings, varying the designs, and so on [29], can positively improve the solar reception, and by the way, they can contribute to the enhancement of the performance of the solar stills. Kumar et al. [30] experimented on a solar still by incorporating a nano-paint over the absorbing surface. The nano-paint was prepared by dispersing a highly conductive nanoparticles within the black paint. The results revealed that the nano-paint enhanced the efficiency of the still to a greater extent (Figure 4).

Matrawy et al. [31] investigated the efficacy of the still in creating a black-coated wavy absorption area using a capillary-activated medium that is permeable. Given that the perforated surface of the suggested solar still reaches an elevated temperature under identical working circumstances as a NSSS, the result is an increase in output of around 35%. Findings showed that over 76% of the total output came from the ridge's permeable layer. Through suspending several permeable absorbers fabricated from black jute cloth, Srivastava and Agrawal [32] enhanced the yield of the NSSS. Observations revealed a 70% increase in the production of the absorbing surface-modified NSSS on cloudless days, and a 36% improvement on cloudy days. The absorbing surface exhibits high sensitivity to variations in solar thermal concentration (Figure 5).

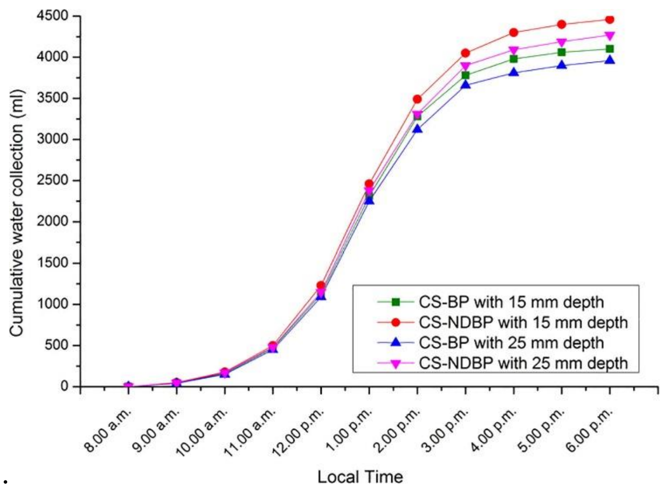

Figure 4. Effect of nano-paint on the yield of the solar still [30].

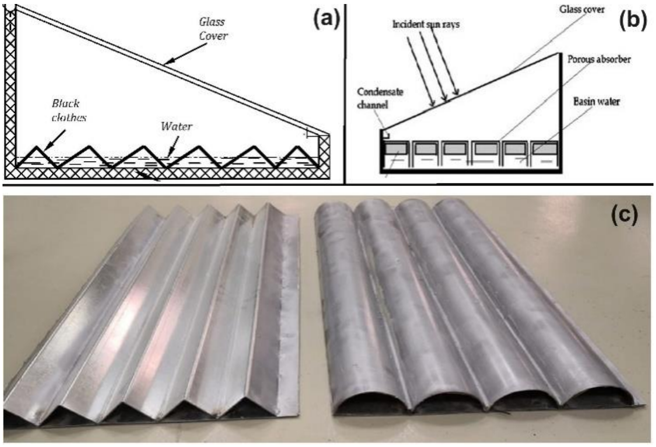

Figure 5. Modifications in absorber (a) Corrugated wick [31] (b) Porous type [32] (c) Wavy and semi-barrel [33].

Younes et al. [33] increased the NSSS's production rate by introducing ridded and barrel-shaped structures over the absorbers. Additionally, spaces under the absorbing surfaces were filled with a nano-CuO-embedded phase-changing substance. The day-wise production of the afore-mentioned stills surged to over hundred percent, compared to the still without any modifications in the absorbing surface. In order to increase the efficacy of an amended pyramidal still, Kabeel and Abdelgaied [34] used a thick graphite-absorbing surface to hasten the process of evaporation. In this study, the modified stills displayed an augmented productivity that ranged around 108% compared to conventional pyramidal stills. The rationale behind the change is that the altered pyramidal still has produced a greater variation in temperature across its reservoir and condensation surface.

5. Influence of embedding biomaterials in the absorber on the performance of the solar still

In recent studies, waste biomaterials have been proposed to be the key materials to enhance the solar thermal absorption of the absorbing surfaces. Dhivagar et al. [35] presented a comprehensive study on the performance of a solar still with snail shells compared to a normal solar still, evaluating various aspects such as productivity, energy and exergy efficiency, economic viability, and environmental impact. They have concluded that the still with snail shell had slightly higher energy efficiency (24.1%) and exergy efficiency (2.8%) compared to the normal still (23% and 2.7%, respectively). Arunkumar et al. [36] proposed a novel solar desalination system using carbonized wood as a thermal absorber to effectively cleanse inorganic biochemical effluent, achieving high potable water productivity and removal efficiency of heavy metal ions and organic contaminants. The research proved that the carbonized wood-integrated solar still exhibited an outstanding 99.77% removal efficiency for given chemical oxygen demand COD in the inorganic chemical wastewater.

In another paper, Dhivagar et al. [37] evaluated the performance of a solar still using conch shells as an energy storage biomaterial and porous media and compared it to an ordinary solar still, analyzing the energy as well as exergy efficiencies, cost of fresh water yield, and CO2 emissions mitigation. It was concluded that the exergy efficiency of the still using conch shell as an energy storing bio-waste material was 1.2%, which was considerably higher than the corresponding exergy efficiency of the normal still. In a different piece of literature, Arunkumar et al. [38] described the development and evaluation of a peanut shell-derived photothermal absorber for use in solar desalination, which demonstrated improved evaporation rate, efficiency, and durability compared to other biomass-derived materials. It was noted that the peanut shell-derived photothermal absorber pointedly increased the evaporation rate and efficiency of the solar desalting arrangement. The peanut shell-derived absorber demonstrated notable durability and salt confrontation (Figure 6).

Sibagariang et al. [39] examined an experimental study on the effect of using oil palm shells as a sensible heat storage material in double slope solar stills to improve freshwater productivity. The results showcased that the use of oil palm shells in solar stills increased the temperature within the still, leading to a 40% upsurge in freshwater productivity compared to ordinary solar stills. Thakur et al. [40] studied the development and characterization of activated carbon nanoparticles synthesized from bio-waste and their application in enhancing the performance of a solar desalination unit by coating the absorber with the activated carbon nanoparticle-containing black paint, which resulted in up to 39.3% intensification in water yield compared to the conventional solar still. It was identified that the activated carbon nanoparticles synthesized from dead Kigelia Africana leaves exhibited high porosity and surface area, which improved the thermal conductivity, solar reception, and surface roughness of the solar absorber coating.

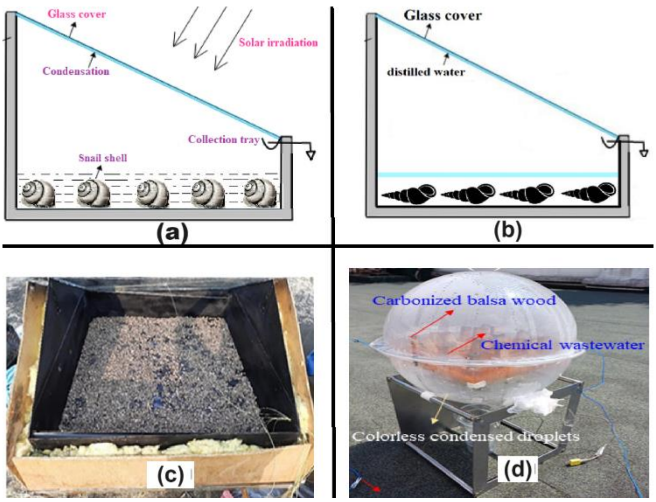

Figure 6. Absorber surface with bio-waste materials (a) Snail shells [35] (b) Conch shells [37] (c) Peanut shells [38] (d) Carbonized balsa wood [36].

6. Conclusions and future direction

Solar still is widely recognized as a feasible option to generate clean water from a saline or impure water source in an economical and eco-friendly manner. However, extensive research is required to improve its performance and overcome its shortfalls, such as lower yields. The absorbing surface of the solar stills is the critical element, and hence, suitable alterations in such components can enhance the performance of the still. This article reviewed the state-of-the-art presented in the earlier literature to enhance the efficacy of the solar stills through modifications to their absorbers. The review confirms the following significant findings:

- The design modification of the absorbing plate, such as fabricating the plate in the form of ridges, corrugations, perforations, ribs, and so on., can enhance the solar reception through augmented surface area.
- The dispersion of highly conductive nano-sized particles within the coating material can also improve the dark coating over the absorbing surface. Such nanoparticles aid in enhancing the heat transfer characteristics of the plate surface.
- Very importantly, the utilization of bio-waste materials is an eco-friendly and viable solution to augment the thermal absorption properties of the absorbing surface. Snail shells, oil palm shells, peanut shells, Kigelia Africana leaves, and carbonized balsa wood are the few bio-waste materials reported in the earlier literature. It shows the potential of such waste materials to improve the performance of solar stills.

Since the impregnation of suitable bio-waste materials is identified to have a greater potential for modifying the absorbers thermal properties in a positive manner, a few other bio-waste materials can be experimented in the future to explore the opportunities of enhancing the thermal behaviour of the solar still's absorbing surface.

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