



Research Article

Solar Stills: Review

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ABSTRACT

Solar stills are simple, economical apparatuses that harness solar energy to cleanse water by evaporation and condensation. This research study examines solar stills' principles, types and designs, highlighting their significance in mitigating water shortage, particularly in desert and isolated areas. Critical performance metrics, such as thermal efficiency, water production, and material selection, are examined to ascertain the determinants affecting their efficacy. The analysis further addresses creative improvements, including using phase change materials (PCMs), nanotechnology, and hybrid systems that merge solar stills with other renewable energy sources. Additionally, the article assesses the environmental and economic ramifications of solar stills and traditional water purifying techniques. The results elucidate the obstacles and potential for enhancing solar still designs, rendering them a feasible alternative for sustainable water production amid worldwide water scarcity.

1. INTRODUCTION

Solar stills harness solar energy to produce clean water from saline sources through evaporation and condensation processes. They offer a sustainable and eco-friendly approach to desalination, especially beneficial in sunny, arid regions lacking fresh water sources. The fundamental principle is to heat saline water in a basin using solar radiation, causing it to evaporate and condense on a cooler surface, resulting in purified water. Various solar still designs, ranging from simple single-basin models to advanced multi-effect and tubular configurations, all aimed at increasing water output and thermal efficiency by optimising structural aspects such as the still's shape and materials [1-3].

2. THE CONCEPT OF SOLAR STILL

The purpose of a solar still is to use solar energy to evaporate and condense water from sources such as seawater or contaminated water, separating impurities. The resulting water is clean and potable. This process is cost-effective and environmentally friendly. Solar stills are more effective in regions with direct sunlight and arid landscapes, especially where there is no access to fresh water. Various types of solar stills exist, including single-basin, multi-effect, and tubular designs, which have been refined to improve their productivity and efficiency. For instance, tubular solar stills have demonstrated impressive results [4]. Their unique structure and the use of materials like iron, zinc, and copper in the solar still interfaces have led to higher efficiency and productivity [5].

As the global demand for clean water continues to rise, particularly in regions affected by climate change and population growth, the adoption of solar still technology could become a critical component in sustainable water management strategies. By integrating advanced materials like nano-coated films and phase change materials, solar stills can significantly enhance their thermal efficiency, potentially making them more competitive with traditional desalination methods. Moreover, decentralising water purification through solar stills could empower remote and underserved communities, reducing their dependence on centralised infrastructure and fossil fuels. As research and development continue, the potential for coupling solar stills with other renewable energy technologies, such as solar photovoltaic systems or wind energy, offers an exciting avenue for further increasing their productivity and reliability.

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3. THE IMPORTANCE OF SOLAR STILLS

The solar still is important because it provides a sustainable and environmentally friendly means of water purification. Conventional desalination techniques are energy-intensive and often utilise nonrenewable energy sources. Solar stills can also be installed in remote locations without access to conventional energy sources or built structures. Therefore, the device solves the challenge of water scarcity in regions that do not have sufficient access to fresh water. The new technologies and designs have significantly improved efficiency and water yield over the years. Innovations such as using phase change material and reflectors in the construction have made solar still more efficient. As a result, the new designs can be adapted for large-scale use [6-7]. Water scarcity is a major challenge in many countries, underscoring the need for sustainable and eco-friendly solutions.

4. HISTORICAL DEVELOPMENT OF SOLAR STILLS

The historical development of solar stills commenced from the passive solar desalination designs available in the 19th century and progressed to the development of innovative designs that improved the existing system. Development shifted from passive to active solar stills in the 20th century with the material advancement and thermodynamic analysis that resulted in the significant system improvement to solar stills productivity and efficiency [8]. These developments included various design modifications, such as multistage design and the inclusion of phase change materials for better water production and thermal efficiency improvement [7]. The ongoing development of new and innovative features in solar stills in the present day is driven by the high demand for fresh water from the salinity treatment. Continuing from these advancements, modern solar stills are now evaluated based on their thermal dynamics and innovative heat transfer mechanisms that optimise freshwater production [9] (Saxena et al. 377-413). These systems harness solar energy more efficiently through enhanced design features, such as reflective surfaces and improved insulation, significantly reducing heat loss and increasing water yield. Innovations in material science have also contributed to the development of more durable and cost-effective materials, facilitating broader implementation in water-scarce regions. Additionally, recent designs incorporate hybrid systems that integrate photovoltaic panels, providing dual benefits of water purification and electricity generation, thus addressing multiple resource needs simultaneously. These technological advancements underscore solar stills' critical role in meeting the global demand for sustainable and clean water solutions, reflecting a continuous evolution driven by environmental necessity and scientific innovation [9].

5. BASIC PRINCIPLES OF SOLAR STILLS

Solar energy principles still involve solar energy, which converts saline/impure water to pure potable water by evaporation and condensation, as shown in figure (1). When the solar radiation heats the basin water quickly and evaporates, this vapour condenses at low-temperature surfaces, such as glass or plastic, and this vapour can be collected as pure water. The process can be made more efficient by advanced materials and technologies, e.g. various nano-coated films, ultrasonic atomisers, etc., for enhanced evaporation and condensation rates [10]. Design is also crucial; tubular solar still provides better evaporation surfaces and thermal performance [11]. These advanced designs and materials integrated solar stills aim for better productivity and efficiency for portable water purification, especially in regions with scarce fresh water.

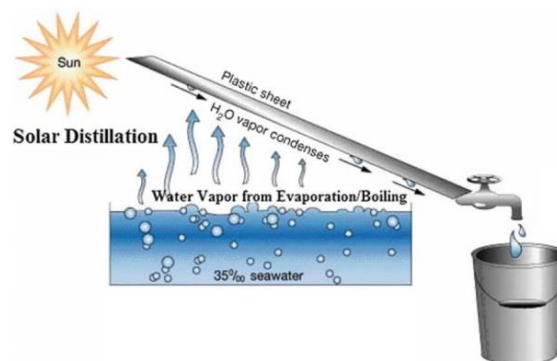


Fig. 1. Working principle of solar still.

6. TYPES OF SOLAR STILLS

Different types of solar stills are being designed with different mechanisms to optimise the amount of water distilled in each cycle depending on the usage required. The most popular systems include the single basin still, which lacks complicated structures. The multi-effect solar still system implements more than one step in the distillation and condensation reactions [12]. The tubular still is designed in a tubular fashion to increase its area exposure to sunlight, which enhances its thermal efficiency and productivity. The angled solar still system increases the efficiency of the water-grabbing process as it utilises gravity to help the condensed water flow down. All of these solar stills provide a specific advantage that distinguishes them from others depending on the surrounding environment and the required specifications.

6.1 Single-Basin Solar Stills

Single basin solar stills are the most common type of solar still design, which is also very basic and reliable for small-scale water purification. This type of stills contains a shallow basin filled with saline or contaminated water; the basin is then covered by a transparent material such as glass, which allows sunlight to enter the basin. The evaporation process takes place, and the resulting vapour condenses at the underside of the cover and is then collected as fresh water. The single basin stills are believed to be less efficient compared to the multi-stage designs; the single basin still lacks the proper evaporation surface and has a poor ability to retain heat [12]. Despite this claim, the design is still valued for being cheap and easy to build; the solar single basins will work best for communities that have trouble getting clean water supply, specifically those that live in remote and impoverished areas.

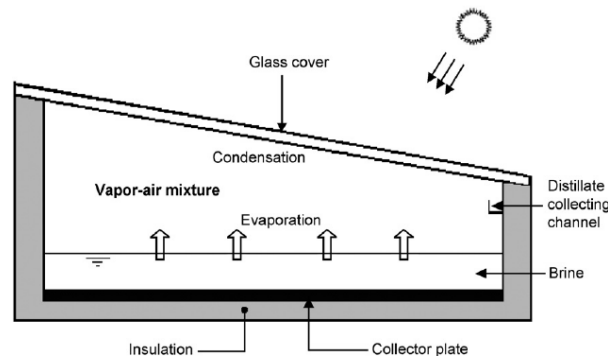


Fig. 2. Single-basin solar still.

6.2 Multi-Basin Solar Stills

Multi-basin solar stills are an improved version of solar desalination technology where the stills have multiple stages of evaporation and condensation. These stills include a sequence of basins that are connected and are functioning at different thermal levels to improve the evaporation process, as shown in figure (3). The heat and evaporation process increases the total freshwater output compared to conventional solar stills with single basin units [13]. The multi-basin design increases the yield and, therefore, enhances the energy efficiency of the solar stills by conserving and reusing the heat within the system. As a result, multi-basin solar stills are more beneficial in water-scarce regions as they are economical, sustainable, and scalable.

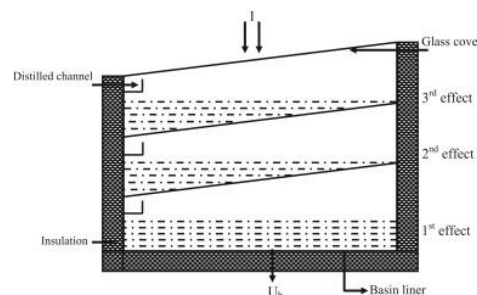


Fig. 3. Multi-basin solar still

6.3 Wicked Solar Stills

Wicked solar stills employ capillary wicks to efficiently transport water from the basin to the evaporation surface, enhancing evaporation rates as shown in figure (4). This design reduces thermal resistance, leading to higher temperatures and faster evaporation. Additionally, wicks ensure uniform water distribution, preventing localised boiling and dry spots, and can help minimise heat loss. These advantages contribute to improved overall efficiency and productivity compared to traditional solar stills [10].



Fig. 4. Wicked Solar still

6.4 Hybrid Solar Stills

Hybrid solar stills use the principle of the traditional method of solar desalination. Still, they are combined with other renewable energy technologies to boost efficiency and water output. In most cases, hybrid solar stills use photovoltaic (PV) panels (as shown in figure (5)) or wind turbines as additional energy for the system to compensate for the energy losses in integrating solar energy and water desalination system, thus being able to produce more from a solar still [8]. The performance and productivity of hybrid solar stills are maximised even on a non-sunny day as they use different sources of renewable energy, making them more reliable for desalination installations in areas with fluctuating weather. Along with improved materials and innovations in the design of solar stills, such as the application of phase change materials and reflectors, the water yield and thermal performance of hybrid solar stills are significantly improved [7]. Hybrid solar stills combine different sources of energy and innovations that drive the performance of solar stills. Hybrid solar stills further improve the adaptability of desalination systems to respond to the increasing demand for clean drinking water worldwide.

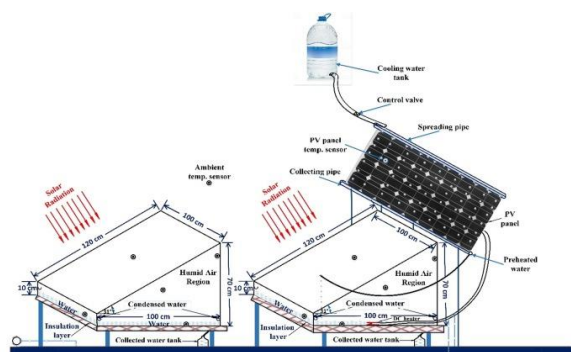


Fig. 5. Hybrid solar still

6.5 Active Solar Stills

Active solar stills build on the solar desalination principle; additional external energy sources are integrated into the unit to enhance the system's efficiency and productivity. Active solar stills use mechanical components, such as pumps, rotating drums and fans, to circulate water and move heat throughout the absorbent, as shown in figure (6). This mechanism results in a higher evaporation rate of saltwater within the active still than in passive designs [8]. However, an active solar still is made to perform well even without an ideal weather condition. Unlike the previous stills that only use the sun as an energy source, this new technology can supplement its processes using photovoltaic panels or wind turbines. Active solar stills allow water to be produced even in unfavourable sunlight. Active solar stills combine renewable energy sources and technologically advanced materials to innovate sustainable clean water technologies. In a world where clean water demand

continues to grow, this new technology will be a viable alternative to conventional methods, especially in places where access to clean water is affected by the weather.

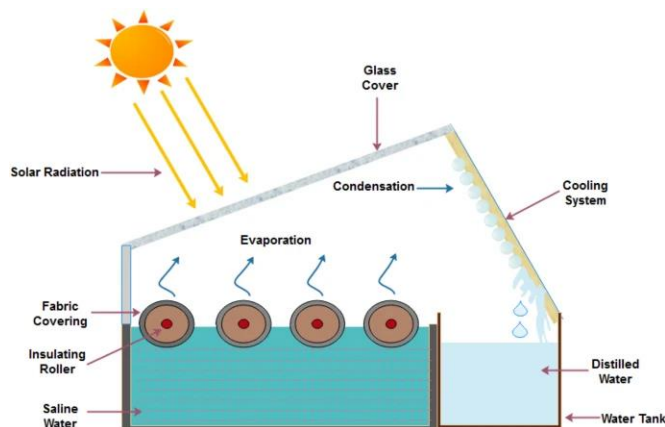


Fig. 6. Active solar still

6.6 Passive Solar Stills

Passive solar stills use only solar energy for desalination and do not include other devices or machinery components. Passive solar stills are based on the principle of natural evaporation and condensation, in which the water is evaporated by the thermal energy of the solar radiation and subsequently condensed on some cooler surface. Passive solar stills can provide a good degree of water purification, and several design modifications, like multistage and using phase change materials, can further improve the performance [12], as shown in figure (7). Passive solar stills are a good alternative in high solar insolation areas with limited technological support. Passive solar stills can be built from locally available materials and need low maintenance. Passive solar stills can be very useful in communities where an accessible solution for clean water resources is needed.

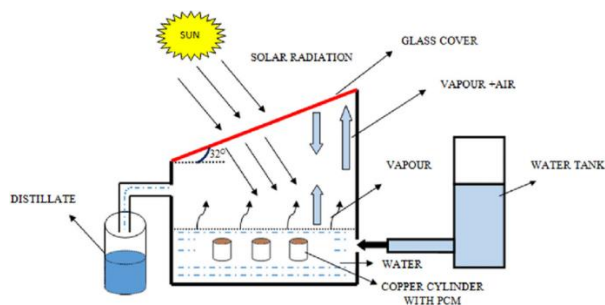


Fig. 7. Passive solar still

7. SOLAR STILL DESIGN CONSIDERATIONS

Important design considerations for solar stills will optimise the design for high efficiency and maximum yield. The material of the solar still, which affects thermal absorption and evaporation ratio, is one such consideration. Incorporating phase change materials and nanoparticles can help improve heat storage and further increase the solar still's operation efficiency [7]. Similar to material design, the structural design of the still, for example, the use of reflector and angle of inclination, are also important factors to account for in increasing the yield. The coupling with other renewable energy technologies, such as photovoltaic panels, can also offer additional energy to ensure continuous operation of the solar still in times of extreme climatic variation [8].

8. FACTORS AFFECTING THE PERFORMANCE

Solar stills' productivity is affected by different parameters, which are mainly related to materials and designs. Using phase change materials and nanoparticles in the design would enhance thermal energy absorption and retention, which results in more water productivity. The inclination angle and the use of reflectors also result in more solar radiation on the still

surface, which results in more evaporation. The environmental parameters such as sunlight radiation and ambient temperature highly affect solar still productivity. Finally, combining some advanced technologies such as photovoltaic panels or wind turbines provides additional energy for operation and an efficient water product even in non-ideal weather conditions [14].

9. Materials Used In Solar Stills

The materials used for the construction of solar panels still have a considerable impact on their efficiency and overall water production yield. For instance, including modern materials like phase change materials and nanoparticles in the construction of solar stills can help in their thermal absorption and retention, which can significantly enhance the solar still performance [7]. Other relevant studies indicate that using metals, namely iron, zinc, and copper, in the construction of solar stills can help in improving thermal conductivity, hence enhancing evaporation and solar still productivity [5]. Lastly, covering the solar stills with transparent materials, such as glass and some plastic types, is paramount as it enhances solar penetration while providing a surface for condensation. Hence, the integration of modern materials can be fundamental in enhancing the design of more effective and efficient solar stills for water purification in extreme environmental conditions.

10. ADVANTAGES OF SOLAR STILL

A solar still has various benefits especially in parts of the world, where fresh natural resources are scarce. It is a cleaner and more sustainable approach to water distillation, as it employs solar energy instead of the traditional desalination plants that make use of fossil fuels and other non-renewable energy [5]. Solar stills are ideal in off-grid locations as they require little or no maintenance while being a source of clean drinking water for society. Due to integrating the innovative materials and design flexibility that boost the performance of solar distillers, their efficiency has also been improved [7]. Solar stills can be regarded as a water-stressed solution to the increasing requirement for potable water across the globe.

11. LIMITATIONS OF SOLAR STILL

There are certain limitations that solar stills have despite its benefits. To begin with, one of the disadvantages would be its low water yield compared to traditional desalination. This could limit the application of solar stills in small-scale areas with low water demand. Another disadvantage would be its performance, which relies greatly on environmental conditions, particularly solar radiation and ambient temperature. This could pose a challenge for areas in producing a constant flow of water from solar stills [12]. In addition, the material cost and construction materials for sophisticated designs – where phase change materials or nanoparticles are used – could also be a limitation due to high costs [7].

12. APPLICATIONS OF SOLAR STILL

There are many applications of solar stills, especially in areas where there is limited access to clean water. Solar stills are used for desalination in coastal areas where there is a shortage of clean drinking water for the population; the community simply depends on seawater. Solar stills also help convert salt water into drinking water and provide a sustainable alternative for communities lacking conventional infrastructure for water purification. Another use of solar still is in agriculture, where it serves as irrigation water in dry-land agriculture and in drought-affected areas where there is insufficient rainfall. Solar stills also find application in emergencies and disaster relief, especially in cases where there are shortages of clean drinking water, and rapid deployment of water purification is needed as this machine serves as an immediate source of portable drinking water [4]. Their versatility and minimum maintenance requirements allow them to be used in various applications, from solving a long-term problem of water scarcity to providing immediate solutions to the current situation where there is no source of drinking water in the environment.

13. INNOVATIONS IN SOLAR STILL TECHNOLOGY

Technology regarding solar stills has recently achieved breakthrough innovations, improving the efficiency as well as the productivity of these water desalination devices. For instance, the use of reflectors and phase change materials configured with nanoparticles has recently been explored to support maximum thermal absorption and retention with positive implications on the water yield of solar stills [7]. Similarly, tubular solar stills have also proposed newcomer designs that improve the thermal performance of solar stills by having a greater surface area for solar absorption [4]. The use of advanced materials has also recently been studied, such as nano-coated films that improve different solar still characteristics and mechanisms, ensuring enhanced evaporation and condensation rates for effective water recovery even at low solar intensities. Overall, these recent advancements have made solar stills more desirable to implement as a global solution to water crises.

14. FUTURE PROSPECTS FOR SOLAR STILLS

Research efforts are continuously being made to improve solar still efficiency and scalability, given the positive outlook of solar stills. Recent innovations integrating reflectors, phase change materials and nanoparticles on stills are said to improve thermal absorption and output drastically and, therefore, increase its scalability for mass use. Hybrid solar systems using solar stills are being studied to combine reliable energy sources for continued production of potable drinking water in varying weather and climate [7]. Solar still can provide an efficient and green means of water disinfection in the future due to its scalability and low environmental impact as water demand increases and environmental issues take place.

15. CONCLUSION

Solar stills are one of the most sustainable innovations designed to provide a water purification method in an environmentally sustainable manner. They harness the natural cycles of evaporation and condensation to obtain a water supply, and they are also able to desalinate seawater. Solar stills offer an innovative, unique solution to water scarcity in areas that do not have access to the conventional water supply and a lack of conventional infrastructure. As such, they are an environmentally viable option to produce potable water from water sources despite their challenges and limitations. Solar stills can vary from the mono basic concept of evaporation and condensation to a more complex system such as the hybrid, tubular or multi-basin solar still systems. These unique designs enhance the evaporation and condensation process of seawater or contaminated water to produce purified or potable water. Solar still systems do not yield as high a productivity rate compared to conventional methods of obtaining water, but due to constant technological innovations, solar still systems can potentially become a viable method of producing potable water as the demand for clean and potable water continues to increase globally.

Conflicts of Interest

The author's paper explicitly states that there are no conflicts of interest to be disclosed.

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