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Research Article

Manufacturing Of A Solar Desalination System

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Abstract: Distillation is a sophisticated process that transforms readily available water into clean, potable water by eliminating contaminants and pollutants. Among the diverse array of water distillation technologies, solar distillation distinguishes itself due to its cost-effectiveness in both production and operation. Leveraging solar energy as its primary resource, this method emerges as a sustainable and eco-friendly alternative to conventional techniques. This paper provides an overview of the principal classifications of solar water distillation processes, accompanied by a detailed exploration of the mechanisms underlying desalination within these categories. The central focus of this study is the development of a systematically engineered solar water distillation system for the purification of contaminated water. The solar distillation process begins with the evaporation of water, followed by condensation on a cooler surface, where the purified water is subsequently collected in a designated container. This arrangement, known as a basin-type distillation system, served as the foundation for constructing a prototype solar distillation device. The prototype demonstrated the capability to produce approximately 1.05 liters of purified water per day from an initial volume of 5 liters of non-potable water. The system's operational efficiency was evaluated at 45%, highlighting its potential as a viable solution for sustainable water purification.

Keywords: Solar Energy, Distillation, Solar Distiller, Pure Water, Basin Evaporation and Condensation.

1. Introduction

Solar energy is among the most economical and abundantly available energy sources, offering a myriad of applications, one of which is water purification. The concept of solar water distillation, remarkably, dates back to Aristotle in the 4th century BCE, underscoring its enduring relevance. [1-3]. Projections indicate a significant decline in the availability of potable water within the next 20 to 25 years, necessitating innovative purification methods to ensure safe consumption. Currently, approximately 99% of the Earth's water is either in solid form or heavily contaminated, leaving only a minimal fraction in a liquid state suitable for drinking. This alarming reality highlights the urgency of advancing water purification technologies [4-6]. The challenge of securing clean water using existing energy resources is a shared global objective. Solar energy offers a promising solution, enabling the removal of a wide spectrum of contaminants in a single, efficient step. This approach is distinguished by its simplicity, cost-effectiveness, and environmental sustainability. [7-10]

The principles of solar water distillation are rooted in two fundamental processes: evaporation and condensation. These mechanisms enable the conversion of saline or brackish water into fresh water, suitable for a range of domestic applications such as drinking, cooking, and washing. Compared to conventional desalination methods, solar water distillation boasts superior energy efficiency and economic feasibility. The process is executed within a solar distiller, also known as a solar still, which integrates all essential components for distillation. [11-13] Solar distillers are categorized into various types, such as single-slope or basin stills, and can be further classified as passive or active systems based on their operational mechanisms. [14-16] This versatility highlights the adaptability of solar water distillation in addressing the growing global demand for clean water.

This section presents a comprehensive review of the existing literature on the manufacturing processes of solar desalination systems. A recent study [17] indicated an innovative solar desalination system that combines a high-temperature tubular solar still, heated by a parabolic concentrator equipped with solar tracking capabilities, with a low-temperature inclined solar still. Experimental findings demonstrate the system's high performance, achieving a daily freshwater yield of 7.82 liters and a thermal efficiency of 35.6%. Additionally, the system delivers a remarkably low production cost of $0.012 per liter. This cost-effective solution is capable of meeting the daily freshwater requirements of an individual, making it particularly suitable for low-demand applications in isolated or small communities. These promising results pave the way for future advancements in solar desalination technology and provide a foundation for further research and development. In [18], the study presented a comprehensive state-of-the-art review of solar still technologies, focusing on a techno-economic analysis to evaluate efficiency, productivity, and cost-effectiveness. Among the designs reviewed, the low concentrating photovoltaic/thermal (PV/T) solar still is highlighted as the most economical solution, offering affordability without compromising functionality. Cascade solar stills integrated with flat plate collectors are identified as the most productive, delivering enhanced water yields through improved thermal performance. Meanwhile, tubular solar stills with parabolic concentrators are deemed the optimal design, achieving an ideal balance of high efficiency, practicality, and scalability for diverse applications.

This paper [19] explores the field of solar distillation, emphasizing its current global status and future prospects. It encompasses an analysis of water sources, demand, and the availability of potable water, along with purification methods, providing both a historical context and state-of-the-art advancements. Distillation units are classified based on an extensive literature survey, and the fundamental heat and mass transfer relationships that underpin the development and testing of various solar still designs are discussed. The review also examines the status of solar distillation technology in India, focusing on the economic viability and long-term performance of single and double slope fiber-reinforced plastic units. Finally, recommendations for future research and development in solar distillation are presented to guide advancements in this critical area of sustainable water purification.

By synthesizing findings from various studies, this section identifies trends, gaps, and opportunities in the field, offering a foundation for future research in solar desalination system manufacturing. The critical analysis provides a nuanced understanding of the state-of-the-art advancements and their implications for addressing global water scarcity.

2. Types of Solar Water Distillers

Solar water distillation systems are comprised of solar stills, which facilitate the purification of water through the processes of evaporation and condensation. Broadly, these systems are categorized into two primary types [20-25]:

A. Active Solar Water Distillation

Active solar water distillation systems are characterized by their use of supplementary energy sources to enhance efficiency, in addition to solar radiation. These systems typically involve preheating saline water with an alternative thermal energy source, expediting the evaporation process. Efficiency can be further augmented by utilizing waste heat or discharged hot water from industrial processes, thereby improving the thermal conductivity of the system. Such enhancements make active solar distillation a viable option for applications requiring higher throughput or operational reliability. [5,6]

B. Passive Solar Water Distillation

In contrast, passive solar water distillation systems rely entirely on solar energy for their operation. While their efficiency is generally lower compared to active systems, they can be designed with features that maximize solar exposure. For example, larger surface areas allow for greater sunlight absorption, which increases the surrounding temperature and accelerates water evaporation.

The performance and output of passive solar stills are influenced by a range of factors, including system design, climatic conditions, and operational parameters. Key elements impacting efficiency include water depth, water and top cover temperatures, the thickness and angle of the cover, the collector area, and wind speed. Although passive systems may not match the efficiency of their active counterparts, their simplicity and cost-effectiveness make them suitable for a variety of applications, particularly in resource-constrained settings.

3. Components of the Solar Water Distiller

This section elaborates on the design, fabrication, and assembly of the key components of the solar water distiller. Each component is engineered to optimize the distillation process by enhancing efficiency and ensuring operational reliability [26-31].

A. Glass Box

The primary enclosure of the solar distiller is a glass box designed with a pyramidal top to maximize sunlight exposure. The construction details are as follows:

- *Materials and Dimensions:*

The glass panels used for the box have a thickness of 0.006 cm. The dimensions of the glass box are 140 cm in length, 70 cm in width, and 40 cm in height.

- *Design Features:*

The top section is sealed with two glass panels positioned at a 30-degree angle, forming a pyramid-like structure as shown in Figure 1. This design enhances solar radiation capture and facilitates efficient condensation of water vapor.

B. The Basin

The basin serves as the primary platform for desalination, where saline water is heated and evaporated.

- Construction and Dimensions:
  - Made of glass, the basin measures 140 cm in length and 50 cm in width.
  - Two side streams, each 10 cm wide, rise 10 cm above the main basin body and are designed with a concave profile angled at 5 degrees.
- Functional Design:
  - The side streams collect fresh condensate water, which is directed toward a central drain valve positioned beneath the concave section.
  - The central part of the basin is designated for holding saltwater and is coated in black to maximize the absorption of solar radiation, thus enhancing thermal efficiency.

C. Water Draining Valves

The distiller incorporates four strategically positioned valves to manage water flow effectively:

- Fresh Water Drain Valves:

Two valves are located on the right and left sides of the basin to drain distilled fresh water.

- Salt Water Drain Valve:

A third valve is positioned in the center of the basin for draining the residual salt water post-distillation.

- Water Input Valve:

The fourth valve, installed at the front of the glass box, is designed to introduce saline water into the distiller for processing.

Each valve is precisely positioned to ensure efficient water flow, as illustrated in Figure 2.

D. Painting

- Black Coating:
  - The interior surface of the saltwater basin is coated with black paint, as depicted in Figure 1.
  - This black coating enhances the absorption of solar radiation, thereby increasing the thermal efficiency of the basin and improving the overall production of fresh water.

E. Solar Distiller Table

The solar distiller is supported by a robust iron table, which facilitates both stability and mobility.

- Dimensions and Design:

- The table measures 150 cm in length, 90 cm in width, and 80 cm in height.
- Four wheels are attached to the table for easy relocation of the distiller.

▪ Protective Features:

- A layer of plastic insulation is placed between the table and the distiller to protect against damage during transport.
- Three openings are incorporated into the table's structure to accommodate pipes connected to the drain valves in the basin, ensuring unobstructed water flow.

Figure 1. Solar water distiller.

Figure 2. Draining valves.

The solar water distiller's components are meticulously designed to optimize the distillation process. The glass box maximizes sunlight exposure, the black-coated basin enhances solar radiation absorption, and the strategically placed valves ensure efficient water management. Meanwhile, the iron table provides mobility and structural support, making the distiller a practical and adaptable solution for water purification. Figures accompanying this section provide visual clarity on the structural and functional design of the system.

4. Operation of Solar distiller

Initially, the distiller basin is charged with 5 liters of saline water through the filling valve located at the interface of the solar distiller, as depicted in Figure 1. Subsequently, the water temperature progressively rises due to the absorption of solar radiation by the distiller's structure. This thermal energy transfer increases the humidity within the confined airspace between the water surface and the glass cover of the distiller. As a result, the heated water undergoes evaporation, generating water vapor that condenses upon contact with the cooler inner surface of the glass cover [32-35]. The condensed water droplets then flow downward along the inclined glass surface toward collection channels situated at either end of the distiller basin. Finally, the purified water is directed through drain valves strategically positioned beneath the sloped section at the center of the ducts, as illustrated in Figure 3. This systematic process ensures efficient separation and collection of potable water.

5. Results and Discussion

The experimental is performed in six hours a day during one week in spring season and the results were as follows in Table 1.

Table 1. Water temperatures and amount of pure water output

Days	Time experiment period	Water Temperatures (ċ)	Water output (liters)
SAT	9:00 AM To 15:00 PM	50	0.85
SUN	9:00 AM To 15:00 PM	59	1.2
MON	9:00 AM To 15:00 PM	57	1.1
TUS	9:00 AM To 15:00 PM	55	1.1
WEN	9:00 AM To 15:00 PM	60	1.2
TUS	9:00 AM To 15:00 PM	55	1
FRI	9:00 AM To 15:00 PM	52	0.9

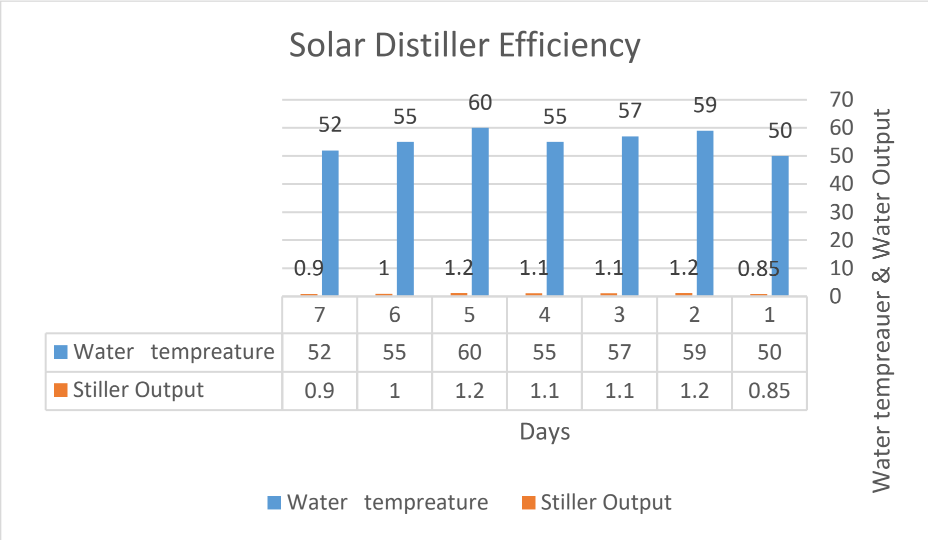

Figure 3. Solar water distiller output.

The daily rate of the amount of pure water produced by the solar distiller is calculated as follows:

$$\text{Average amount of fresh water obtained per day} = \frac{\text{amount of pure water obtained during the period of operation of the solar distiller}}{\text{number of days of operation of the solar distiller}}$$

$$= \frac{0.85+1.2+1.1+1.1+1.2+1+0.9}{7} = 1.05 \text{ Liter/ Day}$$

The efficiency of solar distiller can be calculated by following equation. Note that, (2.33 liters) Standard theoretical amount pure water for simple basin solar distiller.

$$\mu_{solar\ distiller} = \text{(Actual amount of pure water) / (Theoretical amount pure water) * 100}$$

$$= \frac{1.05}{2.33} = 45\%$$

The investigation into the solar distillation process involved the treatment of approximately 5 liters of non-pure water over a duration of 6 hours daily for one week, as detailed in Table (1) The findings are summarized as follows:

- A direct correlation was observed between the temperature of the water in the basin and the volume of distilled water produced. Specifically, the highest temperature recorded was 60 degrees Celsius on Wednesday, resulting in the production of approximately 1.2 liters of pure water. Conversely, on Saturday, the water temperature reached only 50 degrees Celsius during the same operational period, leading to a reduced output of about 0.85 liters of distilled water.
- Figure 3 depicts the varying operational efficiency of the solar distiller throughout the week-long testing period, highlighting the temperature readings and corresponding volumes of pure water produced for each day of operation.
- Upon concluding the practical experiment, the average daily production rate of pure water from the solar distiller was calculated. This was achieved by dividing the total volume of distilled water collected over the week by the number of operational days, yielding an average production rate of approximately 1.05 liters per day.
- The operational efficiency of the solar distiller was assessed by comparing the actual production rate to the theoretical output of a basic solar distiller. This efficiency was determined by calculate the ratio of actual to theoretical production, resulting in an efficiency value of approximately 45%.

6. Conclusion

This study highlights the effectiveness of using a solar still basin as a cost-efficient method for producing potable water. The distillation process demonstrated its capability to effectively purify water, aligning with the experimental objective of extracting clean water from a saline solution. The experiment commenced with an initial volume of 5 liters of saline water, which yielded 1.05 liters of purified water by its conclusion. Conducted during the spring season, the experiment ensured that the collected water met the standards for safe drinking. Based on theoretical calculations, the anticipated yield was 2.33 liters, indicating an actual system efficiency of 45%. This outcome underscores the potential of solar distillation as a viable and sustainable solution for addressing water scarcity challenges.

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