

Thermal Performance Improvement of a Triple Basin Solar Still Using Evacuated Tubes, Heat Pipes, and Energy Storage Materials

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Abstract- This study reviews multiple strategies aimed at boosting solar still efficiency, such as the incorporation of evacuated tube collectors (ETCs), optimization of insulation layer thickness, addition of extended surfaces (fins), glass cover cooling modifications, and the use of thermal energy storage materials (ESMs). According to the literature, combining ETCs with solar distillation units can raise productivity by as much as 67%. Insulation materials, particularly carbon-impregnated foam (CIF), have been shown to enhance yield by 38.7%. The inclusion of fins improves heat transfer, leading to a 25% increase in output, while water-based cooling of the glass cover raises efficiency by up to 81%. Furthermore, adjusting water depth and utilizing nanoparticles contribute to additional performance gains. Despite these improvements, challenges related to cost-effectiveness, material longevity, and system scalability persist. This review consolidates key technological advances and outlines future research needs to make solar stills more viable for real-world freshwater production, especially in remote and water-scarce regions.

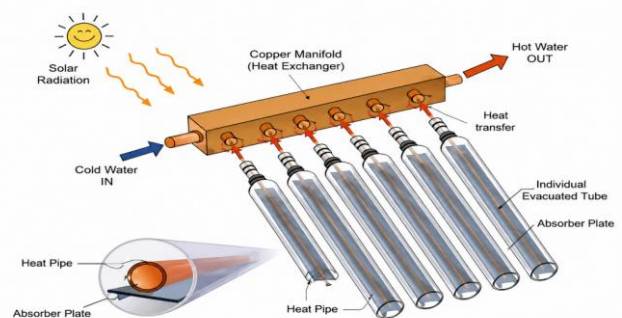
Key Words: Solar Still Efficiency, Evacuated Tube Collectors (ETCs), Glass Cover Cooling, Thermal Energy Storage Materials (ESMs), Solar Desalination

1. INTRODUCTION

Numerous researchers have investigated various approaches to improve the distillate output of solar stills. This section reviews the design and fabrication of solar stills (SS), along with the integration of evacuated tube collectors (ETCs), insulating materials, condensers, and energy storage materials (ESMs) in different SS configurations. The discussion concludes by highlighting existing research gaps and the novelty of the present work. Conventional solar stills typically suffer from low water productivity, which has motivated researchers to explore a wide range of efficiency-enhancing techniques [1–10]. Several design modifications have been proposed and experimentally evaluated, such as the use of evacuated tubes, external water heating arrangements, and multi-basin setups. Drawing from both earlier and recent studies, this section specifically identifies research gaps concerning the application of ETCs, insulation thickness, fins, and various absorber materials in solar still systems [11–20].

2. RESEARCH WORKS ON SOLAR STILL WITH EVACUATED TUBES

Many studies have employed evacuated tubes within solar stills to increase the distillate yield. The evacuated tube absorbs solar radiation throughout the course of a complete day due to its tubular and self-tracking construction. One inner tube and another outer tube were stacked on top of one another in an evacuated tube. The outside tube is still clear, allowing sunlight to travel through it. Shown in the figure 1.



Panchal et al. (20) researched the concluded the result by taking readings to calculate the effect of coupling of evacuated glass tube collector to the lower basin of the solar still and the effect of black granite gravel on the distillation output of solar still.

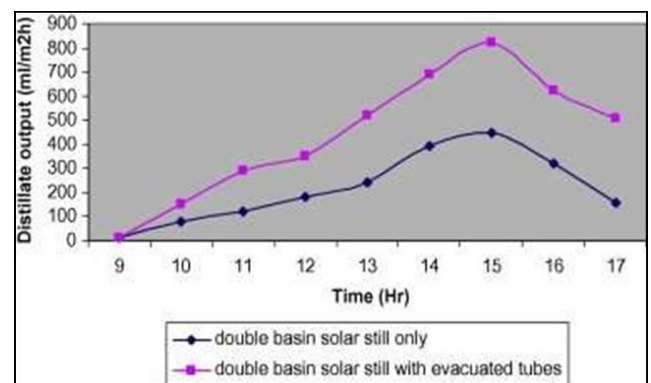


Figure 2: Effect of coupling evacuated tubes on double basin solar still distillate output (20)

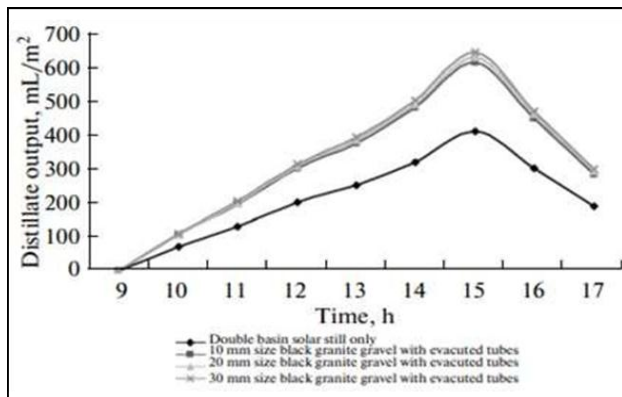


Figure 3: Effect of coupling evacuated tubes with different size black granite gravel on solar still distillate output (20)

In both situations, the effect of black granite gravel was investigated. It was discovered that inserting evacuated tubes raised distillate production by 56 percent and linking evacuated tubes with average 30 mm size black granite pebbles boosted distillate output by 67 percent. The annual production of evacuated tubes will be greater than that of flat plate collectors and parabolic collectors. According to their economic study, the payback period was 195 days.

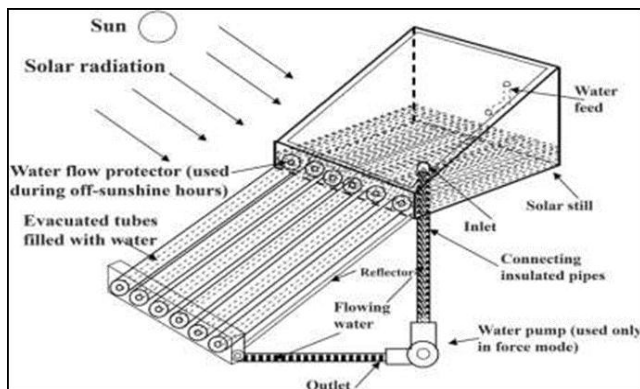


Figure 4: Schematic of setup (21)

The study conducted by Raghvendra et al. (21) The research specifically examined how varying the water depth within the solar still basin influences the distillate energy efficiency, exergy yield and efficiency, of the system. Their objective was to identify the optimal combination of ETC size and water depth in a solar still for best performance. Their system comprises an evacuated tube collector with water and a solar still. The one-slope solar still had an iron stand and a 1m² effective basin area. The still consists of an airtight basin that was typically made of superior insulating material such as cement or concrete, galvanized iron sheet, fibre-reinforced plastic or galvanized reinforced plastic.

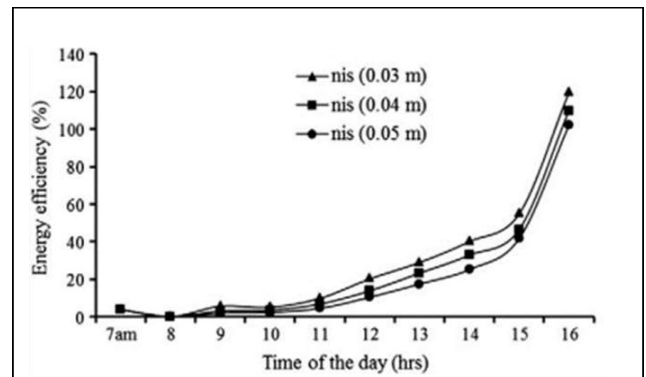


Figure 5: Energy efficiency from different set up (21)



Figure 6: Average total yield from the conventional solar still, solar still with evacuated tubes, and solar still with evacuated tubes and calcium stones between January and June 2019 (22).

The results of the proposed study by Panchal et. al. (22) demonstrated how evacuated tubes coupled with solar power may increase production in which 14 evacuated tubes had been employed at the still's lower side, together with a 1-meter square experiment basin. In the proposed research, calcium stones as sensible heat storage materials have also been used to increase yield. Solar still with evacuated tubes, Conventional solar still, and solar still with evacuated calcium and tubes stones are the three kinds of experimentation that where been carried out.

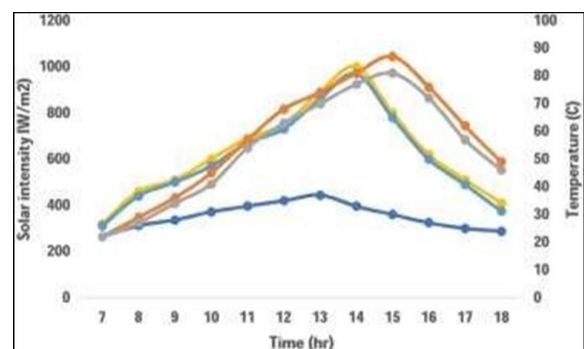


Figure 7: Hourly fluctuations of temperature in solar still with evacuated tubes and calcium stones (22)

Calcium stones are good storage materials because they may increase production at night and store heat in form of hot water. In comparison to the Conventional solar still during the trial days, the percentage increase in yield attained by solar still with evacuated tube and calcium's stones and Solar still with evacuated tube was determined to be 113.53 percent and 104.67 percent, respectively.

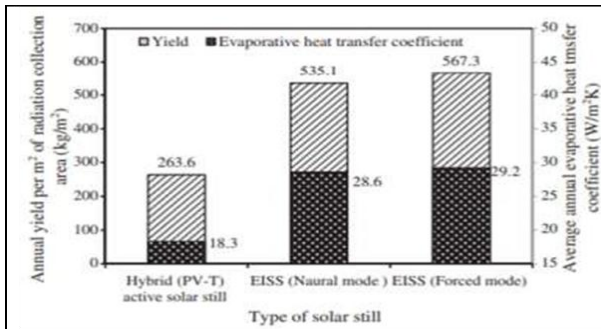


Figure 8: Annual comparative performance of three solar still designs (24)

Bhargava's (25) studied intends to enhance the single-slope solar still's (SS) freshwater production by integrating an evacuated tube collector (ETC). Utilizing a heat exchanger (HE), an internal reflector (IR), and an exterior condenser improves the performance of this ETC linked yet much more.

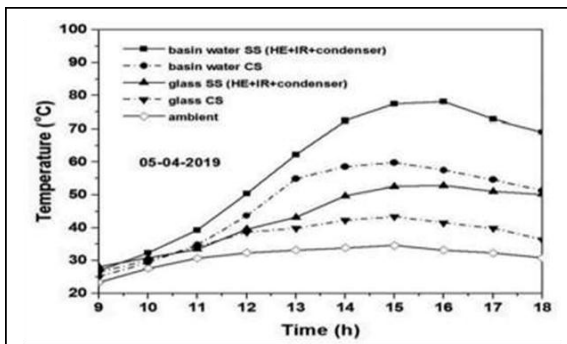


Figure 9: Different hourly temperature variations for SS (heat exchanger + internal reflector) and CS. (25)

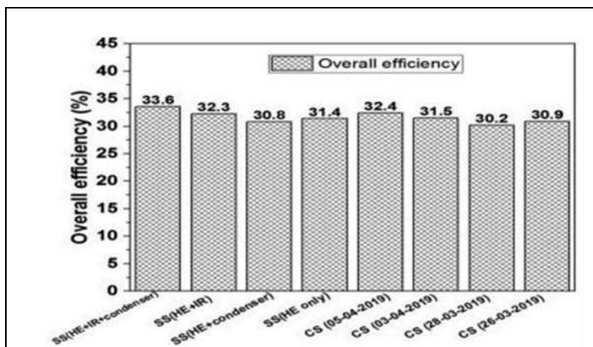


Figure 10: Overall efficiency of all four modified designs and conventional still on different testing days (25)

To conduct the research, two similarly sized solar stills were constructed. According to the findings of the experiments, SS (heat exchanger +IR+ condenser) has a maximum production of 2259 ml and an efficiency of 33.4 percent. Using a HE and an IR in a solar still significantly influenced production, according to the data, whereas an external condenser had less impact on still performance. The outcomes also showed that all four modified designs' improvements over traditional still in terms of total efficiency were modest.

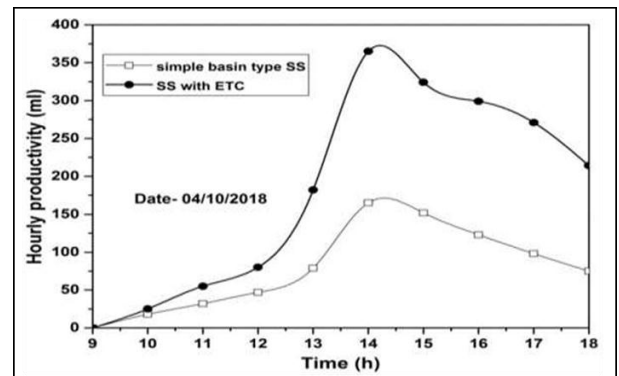


Figure 11: Differences in hourly output between solar stills with and without evacuated tubes (26)

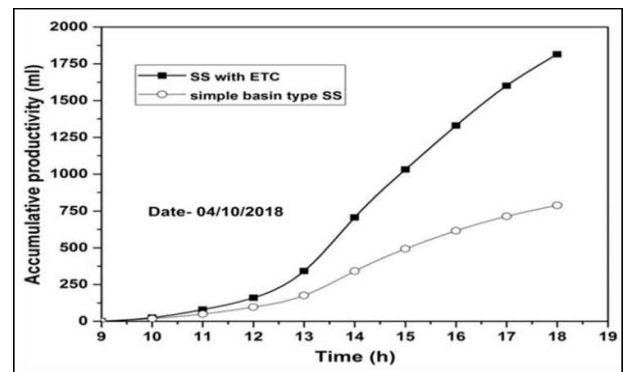


Figure 12: Differences in total output between solar stills with and without evacuated tubes (26)

The impact of evaporative cooling and shading of the glass cover on the performance of an active solar still was thoroughly examined. All experiment were conducted with a consistent water depth of 4.00 cm. The results showed a significant improvement in freshwater output, reaching a maximum of 2114 ml/day under the condition where 12.0% of the glass cover was both cooled and shaded. Compared to a setup without any shading or cooling, this configuration led to a 16.40% increase in distilled water production and a 3.80% improvement in overall efficiency. However, when shading and cooling were applied to more than half of the glass surface, a decline in the still's performance was observed.

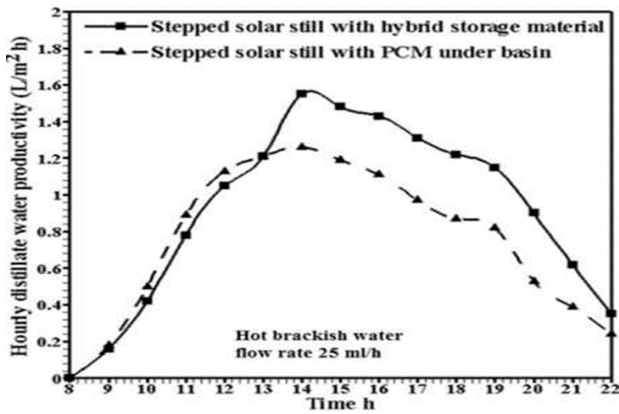


Figure 13: Comparison between the hourly productivity for the first and second case of stepped solar still (27)

According to these findings, the second scenario is more effective than the first. The difference between the first and second cases in terms of the daily production improvement ranged from 20.64 to 21.05 percent. Additionally, the daily efficiency improvement ranged from 21.48 to 21.64 percent for the second example compared to the first one.

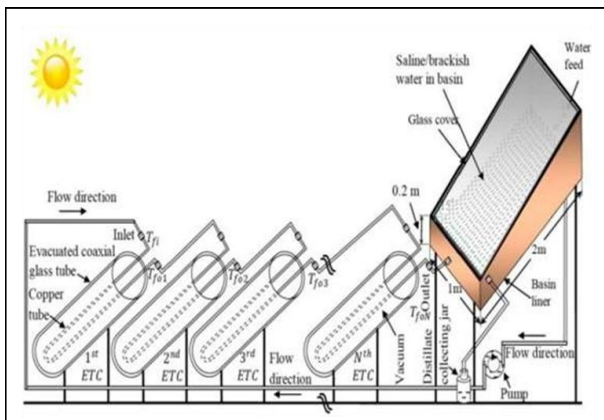


Figure 14: Schematic of solar still with ETC (28)

3. RESEARCH WORKS ON SOLAR STILL WITH WATER HEATING TECHNIQUES

To enhance the evaporation rate, increase water production, and reduce heat losses, Sharshir et al. [29] investigated a novel technique using three different types of hybrid heat localization materials floating on the water surface in solar stills (SSs). To compare the performance of two identical SSs with and without HSHLM, two identical SSs were created, built, and studied.

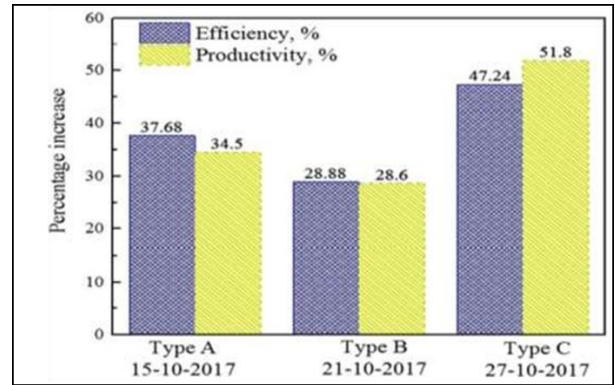


Figure 15: Here’s a refined sentence presenting the percentage increase in productivity and efficiency for the modified solar stills (SSs) using the three different HSHLM types compared to the conventional SS: (29)

Results revealed that while nanofluid significantly influences systems from an energy standpoint, altitude impacts systems most from an energetic one. The Tochal-located filled with nanofluid achieved the maximum instantaneous energy and exergy efficiency by 55.98% and 9.27%, respectively. To make healthier water, use silver nanoparticles for dual purposes and expose the distilled water to sunshine for solar water disinfection.

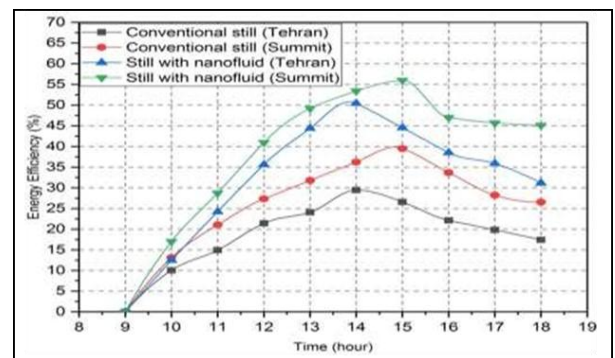


Figure 16: Hourly energy efficiency for solar stills with and without Nano fluid (30)

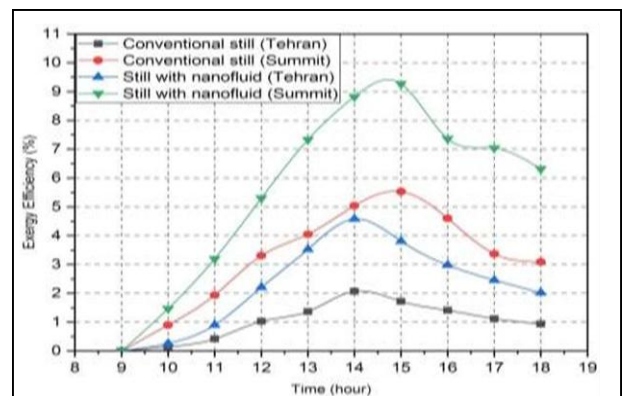


Figure 17: Hourly exergy efficiency for solar stills with and without Nano fluid (30)

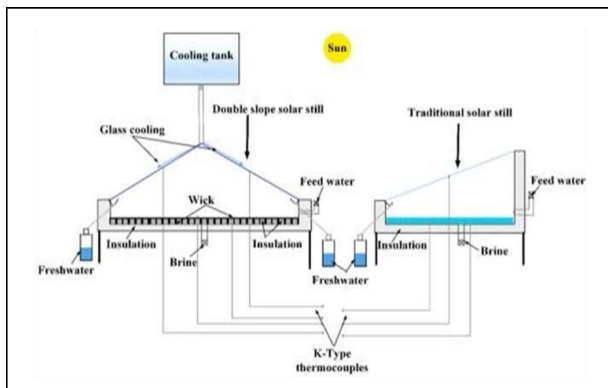


Figure 18: Layout of experimental test-rig with detailed thermocouple positions (32)

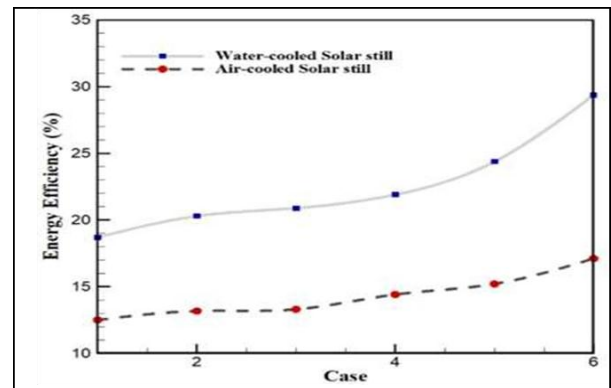


Figure 21: Hourly variation of energy efficiency in different cases of the water-cooled and air-cooled solar still

Experimental research on graphite and copper oxide micro-flakes with various concentrations, basin water depths, and film cooling flow rates was done to enhance the performance of solar stills by Sharshir et al. (31). The concentrations of micro flakes range from 0.125 percent to 2 percent. At the same time, the depths of the basin's nanofluids range from 0.25 to 5 cm. While the flow rates for cooling glass range from 1 to 12 kg/h.

Three different combinations of materials were used by Khaled Elmaadawy et al. (32) in the still basin to increase evaporation: heat localization (wick), sensible storage (gravel), and nanoparticles/fluid (carbon black/water). These changes were made to boost thermal conductivity, concentrate the heat on the water's surface, and expand the wet area exposed to solar radiation.

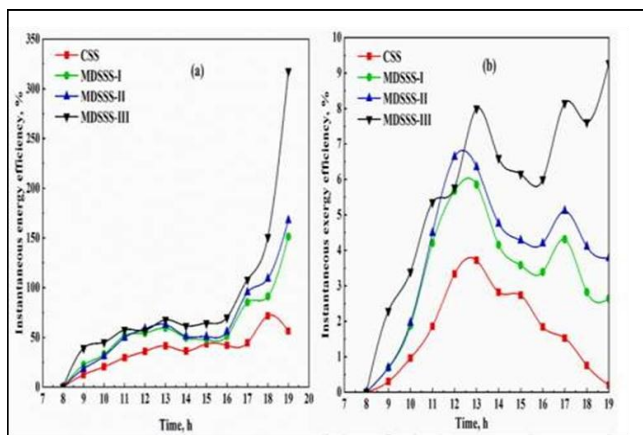


Figure 19: Instantaneous thermal performance (a) energy, and (b) exergy (32)

4. CONCLUSIONS

Solar stills offer an eco-friendly pathway for producing fresh water, yet their limited output remains a major drawback. This study reviews multiple strategies aimed at boosting solar still efficiency, such as the incorporation of evacuated tube collectors (ETCs), optimization of insulation layer thickness, addition of extended surfaces (fins), glass cover cooling modifications, and the use of thermal energy storage materials (ESMs). According to the literature, combining ETCs with solar distillation units can raise productivity by as much as 67%. Insulation materials, particularly carbon-impregnated foam (CIF), have been shown to enhance yield by 38.7%. The inclusion of fins improves heat transfer, leading to a 25% increase in output, while water-based cooling of the glass cover raises efficiency by up to 81%. Furthermore, adjusting water depth and utilizing nanoparticles contribute to additional performance gains. Despite these improvements, challenges related to cost-effectiveness, material longevity, and system scalability persist. This review consolidates key technological advances and outlines future research needs to make solar stills more viable for real-world freshwater production, especially in remote and water-scarce regions.

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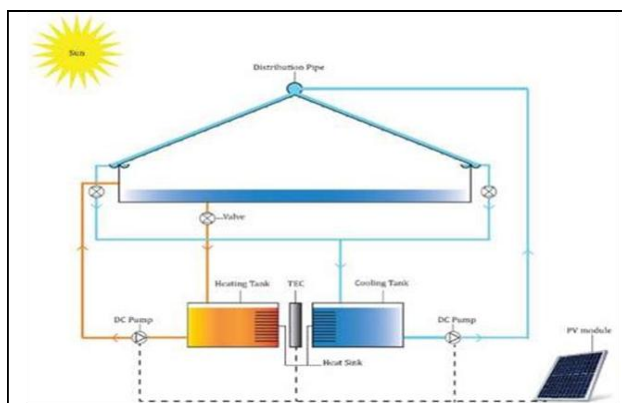


Figure 20: Schematic of water-cooled solar still (33)

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BIOGRAPHIES



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