Babylonian Journal of Mechanical Engineering
Vol.2024, **pp**. 115–121
DOI: https://doi.org/10.58496/BJME/2024/014; ISSN: 3006-5410
https://mesopotamian.press/journals/index.php/BJME

Research Article

Tubular Solar Stills: Review

Duaa Mraiza [1], Farqad T. Najim [2,*]

[1] *School of Engineering and Natural Sciences, Altinbas University, Istanbul-Turkey*
[2] *Electrical Engineering Department, College of Engineering, Al-Iraqia University, Baghdad, Iraq.*

ARTICLE INFO

Article History
Received 01 Sep 2024
Revised: 29 Sep 2024
Accepted 28 Oct 2024
Published 30 Nov 2024

Keywords
Solar still
Tubular still
Multi-effect still
Hybrid-still

ABSTRACT

This study discusses tubular solar still concepts, designs, and performance improvement for sustainable water purification. A greener alternative to traditional methods, tubular solar stills use sun energy for evaporation and condensation. Advances in phase transition materials, reflectors, and nanotechnology improve heat efficiency and water output. The research shows their adaptability and ability to sustainably address global water scarcity in remote and disaster-affected areas. This study examines tubular solar still concepts, designs, and performance optimization for sustainable water purification. Tubular solar stills use sun energy for evaporation and condensation, a greener option. New technologies including phase change materials, reflectors, and nanotechnology boost heat efficiency and water production. Applications from distant to disaster-stricken locations show their versatility and capacity to sustainably manage global water constraint.

1. INTRODUCTION

Tubular solar stills lie at the heart of new advancements for water purification systems. Tubular solar stills are systems that use the heat from solar energy to distill water. By providing a viable alternative method to purify water that is more eco-friendly than common techniques used today, this review will look at the different tubular solar stills and the enhancement techniques presented to increase the performance of a tubular solar still. To achieve this, the review will present the different kinds of tubular solar stills and the characteristics that make it unique and how each of them operates. The review will also focus on the enhancement techniques available to increase the efficiency of tubular solar stills in solar distillation and how each enhances performance [1-2].

2.THE CONCEPT OF SOLAR STILL

A tubular solar still is a device that utilizes solar energy to purify water via evaporation and condensation processes. The still comprises a cylindrical, transparent casing encasing a black basin that captures sunlight as shown in figure (1), so warming the water. Heating water causes evaporation, resulting in the concentration of salts, minerals, and contaminants. The water vapor subsequently condenses on the colder inner surface of the transparent cover, resulting in droplets that flow into a collecting tube, yielding clean, distilled water [3].
The tubular configuration optimizes solar energy absorption during the day, hence enhancing efficiency. This environmentally beneficial technology functions independently of external energy sources, rendering it both economical and sustainable. Tubular solar stills are optimal for desalinating salty water, supplying potable water in dry areas, and generating clean water for industrial or laboratory applications. Their simplicity and dependence on renewable energy render them a viable solution for water purification in distant and resource-constrained regions.

*Corresponding author. farqad_alani@yahoo.com

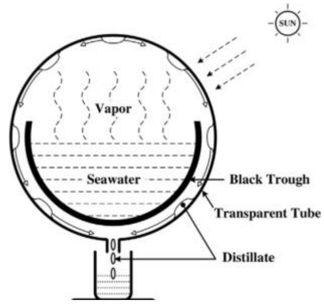

Fig.1. A tubular solar still

3.TYPES OF TUBULAR SOLAR STILLS

The designs and mechanism of tubular solar stills can be distinguished based on their operational process and application needs. The basic tubular solar still is the most basic and elementary type that works under the principle of solar distillation. In this still design, the radiation of the sun heats water present in the tube. The water evaporates from the surface and later condenses to be extracted as boiled or purified water. The cylindrical shape of the tubular solar still design is advantageous in this concern and allows exterior integration with solar concentrators [4] . Solar concentrators aid significantly to enhance the absorption rates of the solar energy. The basic tubular solar still is also widely selected as it is easier to design and builds with lesser complexity and efforts. Moreover, it requires minimal maintenance and care in its operational and implementation processes for the regions where sunlight is abundantly available. The basic tubular solar still is low on complexity but also forms the base of other types or designs of the tubular solar still for enhanced efforts and efficiency.

3.1 The single-effect tubular solar still

The single-effect tubular solar still is also one of the basic distillation system. This system uses a tubular construction; tubular distillation setup is relatively simple to construct and operate. In this type, the setup consists of a cylindrical tube made from glass or other transparent material. The light penetrating through the walls of the tube heats the water. When water temperature increases, evaporation occurs. The vapor then condenses on the cooled surfaces of the tube setup and is collected as clean water. The design involves extreme solar radius absorption. In addition, special materials are used to optimize temperature retention and evaporation [5]. The efficiency may not be the highest compared to other setups, but because of its effectiveness and low-cost design, the distillation method can be used in places without access to complex intermediating technology.

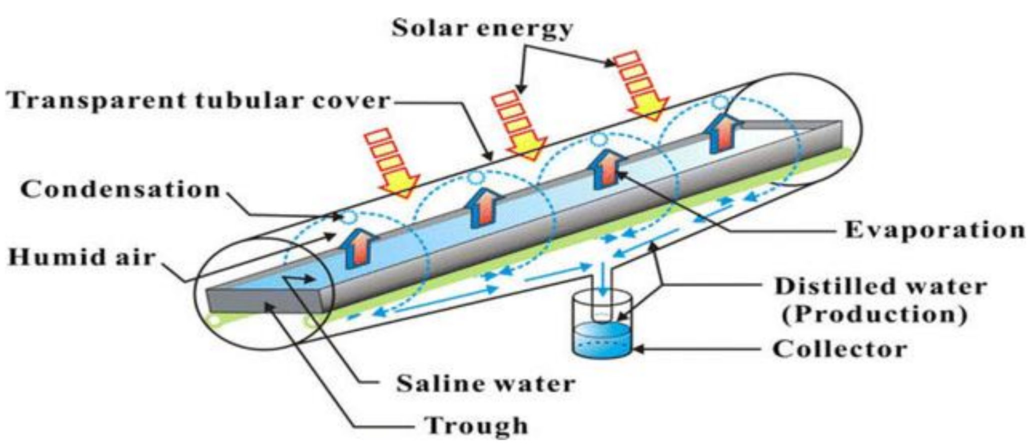

Fig.2. Single-effect tubular solar still

3.2 The Multi-effect tubular solar still

Multi-effect tubular solar still is an advanced version of single-effect tubular solar still in which multiple effects of evaporation and condensation are achieved with the same system. A multi-effect system is more efficient as it reuses the latent heat from one effect to another [5]. Each effect has connected tubes that are preferably structured to recover water from the distillation process with no additional energy requirements. A multi-effect system is especially useful in the scenario where energy and resources are limited due to its efficiency in energy utilization. This provides abundant productivity over a single-effect system at a lower cost per unit of purified water, which is further promising in the drought areas or at a larger scale.

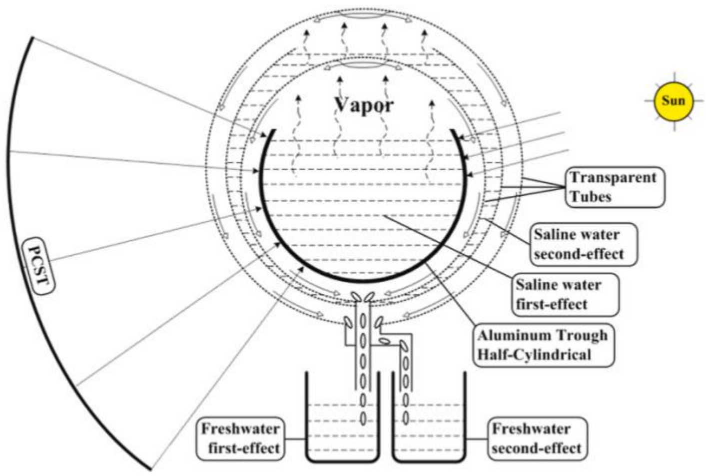

Fig.2. Multi-effect tubular solar still

3.3 The hybrid tubular solar still

The hybrid tubular solar still is a concept that is differentiated for coupling solar distillation with other energy systems, increasing the versatility and efficiency of the system. The hybrid still utilizes unique combinations of solar and other auxiliary energies such as geothermal or waste heat, which fundamentally improve the work of air and solar radiation on physical mechanisms, which can retain the still during low solar insolation [6] . By combining multiple sources of energy into a single hybrid still, the amount of produced water can be significantly increased. It is especially relevant in regions with problematic direct sunlight or nighttime use. The inclusion of hybrid energy mechanisms accumulates not only a more reliable thermal performance but also reduces dependence on traditional energy sources. This directly indicates more promising hybrid solutions for obtaining clean water. The hybrid tubular solar still represents an invention through the introduction of hybrid solutions, as it creates the reliability and economic efficiency of distillation technologies that make adequate work with low solar insolation, which has an impact on even greater acute problems related to water scarcity. On the other hand, the compact tubular solar still was identified as a portable type of still to solve the problems of water purification in substandard areas that cannot be accessed.

4. SIMILARITY AND DIFFERENCES

The similarities and differences between the tubular solar stills will have their own features and variants according to environmental and operational needs. The single-effect tubular solar still is relatively simple and less complicated in design, this concept allows them to become more cost-effective and simpler. Therefore, they are preferable in areas where technological know-how is not complicated . For the multi-effect , since latent heat is reused in the still, they are more thermally efficient and have more output as a result. This is more suited for areas that have a scarcity of water [5]. The hybrid tubular solar still allows us to have more additional sources of energy – such as geothermal or waste heat, so even when solar energy is inconsistent, we can still operate the still [6]. The compact tubular solar still has it's focus on portability and efficiency, hence are perfect for remote areas that have little infrastructure, but are still effective in purifying water for use [7].

5. ENHANCMENT METHOD FOR TUBULAR SOLAR STILLS

Furthermore, the efficiency of tubular solar still can further be enhanced by employing some enhancement techniques while establishing its thermal efficiency and distillation output. One such technique is the introduction of heat storage materials that can efficiently hold heat during no sunshine hours and retain the evaporation rate[8]. Reflectors can be used for greater energy concentration and heat gain. Phase change materials can also ease the temperature fluctuations by absorbing and releasing heat during the phase transitions. It is also helpful in heat retention [5]. This proved to be a good technique to further improve the efficiency of the tubular solar still. In addition, the recent developments in technology, even the use of nanofluids could help in further increase the thermal conductivity of the water that increases the heat energy gain and evaporation rate [9].

5.1 Heat Storage

Heat storage plays a critical role in the efficiency enhancement of tubular solar still in which phase change materials or composites are used to store the heat and maintain a stable temperature for the tubular solar still. A stable temperature directly impacts its distillation output because heat is absorbed and released for moisture evaporation when the solar input is weak, and sustains for a longer period compared to conventional solar stills [8]. Implementation of heat storage materials in tubular solar still schemes have significantly improved their efficiencies, enabling a more stable and even distillation impact influenced by varying meteorological conditions.

5.2 Reflectors

Reflectors are crucial to increase the efficiency of tubular solar stills. They can maximize the solar energy that is incident in the surface of solar stills, improving the thermal gain. Reflectors, usually a higher reflective material like aluminum or silver-coated surface, are placed onto the tubes for directing solar radiation that is falling directly on the water inside them. Increasing solar energy input also increases temperature and evaporation from the still to produce fresh water. It is suggested in the literature that a fuller configuration can be developed and used if reflectors are placed to maximize incident light [10]. Studies have also shown that a parabolic reflector can also be used maximally for concentrating energy in the supported solar stills. Such reflector systems can add to already increased energy supply and can also help in maintaining the distillation rates considerably in relatively sunny and relatively cloudy areas.

5.3 Phase Change Materials

The implementation of phase change materials (PCMs) improves the thermal efficiency of the tubular solar still as they provide thermal stability to the system by storing and releasing latent heat during the phase change process [10]. The integration of these PCMs in the tubular solar still also allows the system to gather and absorb excessive heat during the peak of sunlight and also when the insolation drops [5]. The abstraction of additional heat will provide a longer operating period for the still while improving thermal efficiency as a result. Further, the use of latent heat materials can effectively function regardless of the amount of direct solar radiation in the system while the still is in operation, thereby ensuring a reliable output of water vapour even with changing climatic conditions.

5.4 Nanofluids

The rise of nanofluids as heat absorption enhancement technique in tubular solar stills shows significant impact on systems performance. By mixing nanoparticles with working fluids, the fluid showed greater impact on thermal conductivity increase and heat absorption rate. With this, the solar energy can be absorbed rapidly and water temperature can rise quicker than conventional fluids [11]. With the rising temperature, the thermal performance also improves which speed up the process of evaporating the water thus improving the distillation rate. Studies have also shown that nanofluids behaves depending on the use of nanoparticles and its concentration that can be optimized for specific applications [12].

5.5 PV-Panels

PV panels when coupled with tubular solar stills are a great way to increase efficiency. The energy from the sun can be converted to electrical energy which is used to either directly heat the feed or used to run other off systems. This integration allows the still to better handle fluctuations in solar insolation. Stills can run even when there is little solar energy available to generate electricity. Electricity to maintain desired temperatures. The ability for photovoltaic panels to generate electricity while providing heating means photovoltaic panels coupled tubular solar stills for more than producing clean water. This technology provides a sustainable clean water and renewable energy source in areas where electricity grid is nonexistent. Coupled tubular-still and photovoltaic solar panels systems document overall efficiency increases were substantial [13]. The combined system outputted more water while its environmental footprint decreased overall. There was a reduction in reliance of nonrenewable energy resulting in improved environmental efficiency. This ambitious step in solar distillation technology is in line with world prospects for abundant sustainable energy and water sources.

5.6 Advanced Martials

The use of advanced materials such as graphene is gaining a lot of attention to further improve the efficiency of tubular solar stills. Graphene can help with its excellent thermal conductivity and light absorption properties. Graphene's high thermal conductivity allows it to promoted better heat transfers in solar stills . The integration of graphene-based materials can increase the thermal efficiency of tubular solar stills, thus increasing the rate of evaporation and water output. As shown in the studies, graphene can help the solar still maintain the ideal temperature for its operation because of its ability to quickly transfer heat in the system [14]. The development of advanced materials that can be incorporated in tubular solar stills can further increase its overall performance and application in different systems while promoting cleaner and greener solutions for water purification.

The enhancement techniques examined in the case of tubular solar stills present both advantages and shortcomings vis-a-vis water desalination efficiency. The heat storage materials used, thereby serving to mitigate temperature variations and prolong the duration of operation, may lead to supplementary material expenses and demand meticulous calibration to prevent heat breach [8]. The reflectors provide the unique ability to markedly increase the absorption of solar energy, yet they rely on precise orientation and are weather-dependent, thus limiting their use in inconsistently sunlit locales. The phase change materials apply as a sustainable approach to developing thermal behaviour; yet their implementation is elaborate, demanding detailed attention in selecting conforming materials suitable for the type of still utilized. The nanofluids provide a means to improve heat transfer; however, further investigations would be required to address existing obstacles concerning stability in terms of nanoparticles as well as eventual environmental effect.

6. CASE STUDIES

The case studies available emerge as a significant resource to showcase the feasibility and benefits of tubular solar stills in different locations. One case study provided highlighted the use of tubular solar stills in arid areas, where the solar still system helps provide potable water for use in addressing the limited water supply concerns (Alatawi et al., 2022). Another example of a case study available depicted the use of a solar still system in devastated areas, proving their ability to be installed and used quickly for water supply in emergencies [5]. A further example highlights the integration of tubular solar still concepts in agricultural practices, again proving a means to remain sustainable where water may be a limited concern . With such studies highlighting the benefit of tubular solar still systems in alternative locations, the versatility of the concepts available would support the extended use of the solar still systems. In addition, the tubular solar stills were found to be a viable method for purifying water in arid regions. One of the case studies used solar stills to purify brackish water to determine its effectiveness in producing potable water. The authors confirmed that the tubular solar stills significantly enhanced water supply in remote areas, taking advantage of the abundant solar energy [4]. It was recommended that these systems could be easily scaled since they can be adjusted according to the water demand and the solar energy received . Notably, the adaptability of the tubular solar stills to the existing location makes them a good alternative source of water supply for remote areas and regions with limited resources. These tubular solar stills significantly contributed to the urgent need of producing drinking water in post-disaster settings. The study focused on a disaster area where tsunamis had destroyed existing water systems. The region where they used the tubular solar still system experienced conventional water loss due to the tsunami, making the installation of a tubular-shaped plant useful. Tubular shape makes the installation and functioning easy and use the solar energy to produce drinking water from existing contaminated sources . The researchers embedded improvements of working solar stills with other energy sources, portable generators, and other supportive systems to perform in post-disaster settings even when sunlight is low [5]. Therefore, use of tubular solar stills in the vulnerable state enables the production of drinking water and confirms the alternative system as a sustainable solution, emphasizing the urgent need of resilience against climate change and disasters. The applications of tubular solar stills as described in the case studies mentioned illustrate their potential contribution towards sustainable water resource usage in agriculture. One study discussed the use of tubular solar stills for irrigation [15]. Using the energy from the sun, specially-designed tubular solar still units were able to retrieve fresh water from saline or brackish water. The retrieved fresh water is fit for crop growth and irrigation [4]. Not only does this promote plant growth due to its sustenance, but also conserves soil health by removing the effects of salt deposits on soil which greatly influence agricultural output. What is more notable about this is the modular design of the solar still units due to which it is scalable. This means that as the crop growth seasons go along and whilst there is need for more water, more solar still units can be accommodated. This implies that tubular solar stills can seamlessly fit into the irrigation practices of many farmers and water supplies can be obtained more sustainably through solar energy. The analysis of the conducted case studies of the tubular solar stills presents a number of crucial results and techniques concerning the application of these desalination systems. It is found that the modular design of tubular solar stills allows developing the solution to water deficiency problem in various areas. In this regard, the equipped stills are applicable in open spaces in the hot desert climate, which is characterized by high availability of energy from the sun, and can significantly influence the accessibility of drinking water. In this way, the deployment of modular tubular solar stills in the centers of natural disasters proves a possibility of quick access to a desalination system that ensures water purification. In this case, the construction of standalone solar stills can be launched within a timeframe from hours to days, providing a high level of efficiency and safety during their operation in difficult environmental conditions [5]. Furthermore, the possibility of novel tubular solar stills application in agriculture is highlighted, in which such a system can turn out to be effective in the desalination of saline irrigation water. Thus, tubular solar stills provide a stable access to water for crop irrigation, thus preventing soil salinity and soil degradation [4]. Overall, the case studies demonstrate the successful implementation of tubular solar stills in various circumstances, presenting a wide variety of environment and purposes, which highlight the desalination system as the sustainable technology.

7. SUMMARY

In summary, the future market trends and innovations for tubular solar stills highlight several key opportunities for advancement and development. Continued research and exploration into new materials and nanotechnology are poised to further improve the efficiency and productivity of tubular solar stills, expanding their usefulness and applicability. The potential for the integration of photovoltaic panels into new designs offers additional functionality and versatility, leading to increased adaptation of renewable energy technology in off-grid, rural settings. Furthermore, the market potential for tubular solar stills remains most promising in areas with infamous issues regarding clean water supply, particularly where access to water and energy is limited. Conclusively, future trends indicate that tubular solar stills are set to establish their roles in the existing and emerging global efforts toward advancement in the areas of renewable energy and climate change solutions. Despite the promising performance improvements offered by tubular solar stills, their technology has not yet gained a comprehensive foothold in real-world applications. This can be attributed to the various technical and economic challenges that potential users must confront. On the one hand, the technical hurdles include the difficulties associated with the integration of novel materials and enhancement techniques, including nanofluids and phase change materials which require exacting design specifications and may even lead to the need for additional maintenance. On the other hand, the economic factors that prevent wider uptake are related to the overall production and installation costs that must be fronted even if the net gains over time prove to be sizably beneficial for low-income areas. The fact that sunlight may not be uniformly available across the sites also demands specific adaptation to the various conditions, further increasing installation requirements and total costs. However, with a well-coordinated plan for cost and policy development alternatives, wide dissemination of tubular solar stills technology can help aquatic clean water sources become a reality in low-income regions and through communal partnerships.

8. CONCLUSIONS

To conclude, tubular solar stills are flexible technologies to provide water purification. They can contribute to environmental and resource scarcity issues. Different types of tubular solar stills were presented in this review from single-effect to hybrid models and each type aims its efficiency according to its geographic area. Enhancement techniques like heat storage materials, reflectors, and nanofluids provide remarkable improvements in the overall efficiency of these systems. Each method has its pros and cons but collectively the contribution of each addressed finding can help improve tubular solar stills in the future and contribute to the water security agenda globally. The steps towards improvement and innovation in tubular solar stills technologies will definitely help address water purification challenges and align efforts with sustainable development goals.

Conflicts Of Interest

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

Funding

The author's paper clearly indicates that the research was conducted without any funding from external sources.

Acknowledgment

The author acknowledges the institution for their commitment to fostering a research-oriented culture and providing a platform for knowledge dissemination.

References

[1] M. J. Al-Dulaimi and K. E. Amori, "A tubular solar still integrated with a heat pipe," Heat Transfer, vol. 52, no. 4, pp. 3353–3371, Feb. 2023, doi: 10.1002/htj.22831.

[2] M. J. Al-Dulaimi and K. E. Amori, "Optical and thermal performance of a parabolic trough collector for different receiver geometries," Arabian J. Sci. Eng., vol. 47, no. 12, pp. 16117–16133, Apr. 27, 2022, doi: 10.1007/s13369-022-06795-5.

[3] K. E. Amori and T. A. Hussien, "Thermo-enviro-economic study of solar concentrated hexagonal covered tubular still using interrupted and tilted receiver," Heat Transfer, Nov. 25, 2024, doi: 10.1002/htj.23231.

[4] I. Alatawi, A. Khaliq, A. M. A. Heniegal, G. B. Abdelaziz, and M. Elashmawy, "Tubular solar stills: Recent developments and future," Solar Energy Mater. Solar Cells, vol. 242, p. 111785, 2022.

[5] S. R. Akkala and A. Kaviti, "Advanced design techniques in passive and active tubular solar stills: a review," Environ. Sci. Pollut. Res., vol. 29, no. 32, pp. 48020–48056, 2022, doi: 10.1007/s11356-022-20664-6.

[6] A. E. Kabeel, K. Harby, M. Abdelgaied, and A. Eisa, "Augmentation of a developed tubular solar still productivity using hybrid storage medium and CPC: an experimental approach," J. Energy Storage, vol. 28, p. 101203, 2020.

[7] A. S. Abdullah, F. A. Essa, H. Panchal, W. H. Alawee, and A. H. Elsheikh, "Enhancing the performance of tubular solar stills for water purification: A comprehensive review and comparative analysis of methodologies and materials," Results Eng., p. 101722, 2023.

[8] A. E. Kabeel, G. B. Abdelaziz, and E. M. El-Said, "Experimental investigation of a solar still with composite material heat storage: energy, exergy and economic analysis," J. Clean. Prod., vol. 231, pp. 21–34, 2019.

[9] G. B. Abdelaziz, A. M. Algazzar, E. M. El-Said, A. M. Elsaid, S. W. Sharshir, A. E. Kabeel, and S. M. El-Behery, "Performance enhancement of tubular solar still using nano-enhanced energy storage material integrated with v-corrugated aluminum basin, wick, and nanofluid," J. Energy Storage, vol. 41, p. 102933, 2021.

[10] F. A. Essa et al., "Experimental enhancement of tubular solar still performance using rotating cylinder, nanoparticles' coating, parabolic solar concentrator, and phase change material," Case Studies Therm. Eng., vol. 29, p. 101705, Jan. 2022, doi: 10.1016/j.csite.2021.101705.

[11] S. W. Sharshir et al., "Augmented performance of tubular solar still integrated with cost-effective nano-based mushrooms," Solar Energy, vol. 228, pp. 27–37, Nov. 2021, doi: 10.1016/j.solener.2021.09.034.

[12] T. Gunay, C. Gumus, and A. Z. Sahin, "The impact of using nanofluid on the performance of solar stills: A comprehensive review," Process Safety Environ. Prot., 2024.

[13] M. Manokar et al., "Integrated PV/T solar still- A mini-review," Desalination, vol. 435, pp. 259–267, Jun. 2018, doi: 10.1016/j.desal.2017.04.022.

[14] F. A. Essa, W. H. Alawee, S. A. Mohammed, H. A. Dhahad, A. S. Abdullah, and Z. M. Omara, "Experimental investigation of convex tubular solar still performance using wick and nanocomposites," Case Studies Therm. Eng., vol. 27, p. 101368, Oct. 2021, doi: 10.1016/j.csite.2021.101368.

[15] T. Arunkumar et al., "A review of efficient high productivity solar stills," Renew. Sustainable Energy Rev., vol. 101, pp. 197–220, Mar. 2019, doi: 10.1016/j.rser.2018.11.013.