Solar Stills in the Modern Era: Addressing Global Water Scarcity with Renewable Energy

[1]Rahul, [2]Dr Rashmi Dwivedi
Department of Mechanical Engineering, Sri Satya Sai University of Technology and Medical Sciences
Department of Mechanical Engineering, Sri Satya Sai University of Technology and Medical Sciences
Email-: [1]rahulcipet95@gmail.com, [2]rashmidwivedi29@gmail.com

* Corresponding Author: Rahul

Abstract: *This paper reviews advancements in solar still technologies, a renewable energy solution addressing the global challenge of freshwater scarcity and conventional energy limitations. Solar stills, utilizing basic principles of evaporation and condensation under solar radiation, are explored in various configurations: single effect passive, multi-effect passive, single effect active, and multi-effect active stills. Each type presents unique design attributes and efficiency considerations. The paper delves into the role of temperature differentials in improving distillate production and investigates design enhancements like condensers, fans, and reflectors. It also examines the classification of solar stills based on their operational modes, contrasting active systems that incorporate external heat sources with passive systems relying solely on solar energy. The study underscores the importance of solar stills in providing potable water, particularly in arid regions and areas with limited freshwater sources.*

Keywords: *Solar Still, Desalination, Renewable Energy, Water Scarcity, Sustainable Development, Solar Distillation, Passive Solar Stills, Active Solar Stills, Water Purification, Thermal Efficiency.*

I. INTRODUCTION

Utilizing renewable energy for desalination presents a dual solution to the challenges of freshwater scarcity and conventional energy limitations. The solar still, a centuries-old technique, offers a simple yet effective method for desalination. Its design is straightforward, typically involving a basin with a black-painted interior to maximize solar heat absorption, covered by a transparent lid. The process works by evaporating saline or brackish water in the basin under solar radiation, with the vapor then condensing on the lid and being collected as fresh water through channels. Despite the simplicity of conventional basin-type solar stills, their main drawback is low efficiency, attributed to heat loss and difficulty in elevating water temperature for evaporation. To address this, extensive research has been conducted exploring various design modifications, including different shapes, basin materials, water depths, and heat absorbers, as well as integration with solar heaters, collectors, and concentrators. This work reviews various designs of solar stills, particularly focusing on inclined solar stills and their enhanced distillation productivity.

Water is vital for human survival, supporting crucial activities such as agriculture, irrigation, and domestic use. However, fresh water availability is a growing concern worldwide. Approximately 97% of Earth's water is saline, and only a fraction of 1% is accessible freshwater. Increasing population, industrial pollution, and varying rainfall patterns, especially in arid and desert regions, exacerbate the depletion of existing freshwater sources. Desalination stands as a critical solution for obtaining potable water from saline sources.

Water's importance extends beyond its physical presence; it is integral to economic development and national welfare. The constant freshwater supply faces challenges due to population growth, industrialization, and environmental changes. Health issues often stem from the lack of access to clean water. Industrial and urban expansion have led to increased water pollution, affecting water quality in rural and agricultural areas. Women globally spend an estimated 200 million hours daily collecting water, often from polluted and distant sources. This highlights the urgent need for effective desalination solutions to secure clean drinking water for all.

II. TYPES OF SOLAR STILLS

A. Single effect passive solar stills

Single effect passive solar stills, the traditional form of solar distillation units, are characterized by their simplicity and ease of construction, featuring a single glazing layer above the water surface. However, these stills often experience significant heat loss due to the latent heat of condensation escaping through the glazing. This presents a substantial opportunity for enhancing the efficiency of these stills by recovering this lost heat. Ongoing research efforts are focused on various design modifications aimed at improving the performance of these solar stills. A schematic representation of a single effect passive solar still [3].

B. Multi effect passive solar stills

Multi-effect solar stills are engineered to maximize the use of dissipated heat. These stills are distinguished by having multiple glazing layers over the water surface, which helps in harnessing the latent heat of condensation to boost the thermal efficiency of the still. Compared to single-effect stills, multi-effect solar stills are more productive as they recycle available energy multiple times. There is a growing body of research focused on enhancing the efficiency of these stills through various design innovations. For better understanding, a schematic representation of a multi-effect passive solar still

C. Single effect active solar stills

The primary limitation of passive solar stills lies in their reliance solely on solar radiation absorbed by the basin water to increase water temperature. To address this challenge, active solar stills have been developed. Similar to single-effect passive stills, single-effect active solar stills feature one glazing layer. However, they are distinct in that they receive additional thermal energy from an external source to boost the water temperature. This elevation in temperature leads to a higher evaporation rate, thereby enhancing the still's efficiency. A schematic illustration of a single-effect active solar still

D. Multi-effect active solar stills

Multi effect active solar stills are developed to further increase the productivity of the solar stills. These types of stills have more than one glazing covers. To achieve the better evaporation rate of water an additional thermal source is provided by an external source. This additional thermal energy source is mostly provided to the bottom most basin of the still as it receives less solar radiation than other upper basins, due to decrease in transitivity by other additional basins. A schematic diagram of multi effect active solar still.Working principle of solar distillation device.

III. WORKING OF A CONVENTIONAL SOLAR STILL WITH CONDENSER

The efficiency of a solar still is significantly influenced by the temperature difference between its evaporative and condensing surfaces. Research has shown that a greater temperature differential between the water and the glass cover leads to a higher yield of distilled water. To achieve and maintain this optimal temperature difference, various enhancements like condensers, fans, reflectors, thermal storage materials, and cooling of the glass cover have been employed. In solar stills integrated with condensers, the basic structure mirrors that of conventional stills but with an added external or internal condensation unit, as depicted in Fig. 2. Effective condensation conditions accelerate the evaporation rate of the saline water in the still. In solar stills with external condensers, the temperatures of both the glass and basin water tend to be lower than those in conventional designs. As a result, integrating an external condenser, especially when coupled with a fan, significantly increases the temperature differential between the glass cover and the basin water compared to conventional solar stills [4].

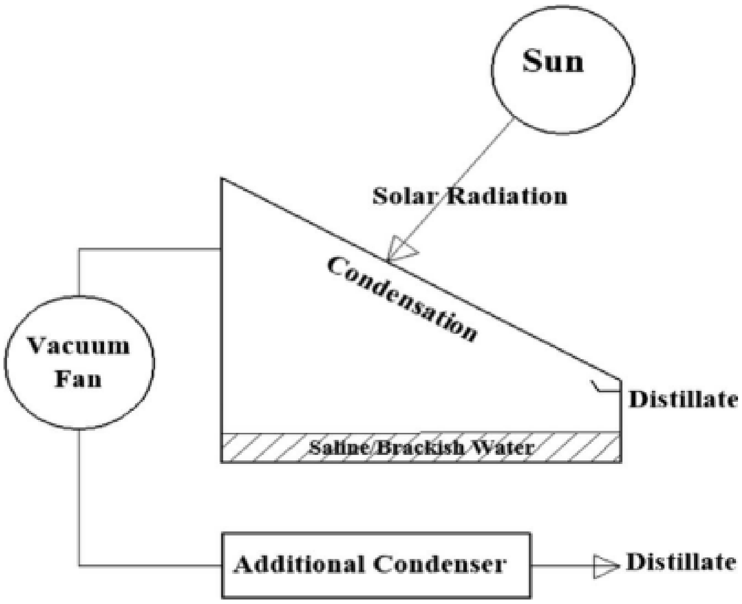

Fig. 1 Solar still with condenser

The enhanced performance of solar stills with external condensers is primarily due to the low-powered fan used to vent water vapor from the still to the external condenser (condensation unit). Additionally, the fan removes non-condensable gases from the basin to the condenser. This effectively minimizes the impact of these gases, which otherwise hinder the condensation rate. The fan also facilitates air circulation within the solar still, leading to less heating of the glass cover and thus preserving a substantial temperature difference between the glass and the water in the basin. This significant temperature disparity accelerates both evaporation and condensation processes, resulting in higher production rates in the modified still compared to the conventional one.

IV. LITERATURE REVIEW

Kadhum, J. A. [5] addressed the global challenge of limited access to safe drinking water, emphasizing the importance of solar distillation systems in producing clean water for various applications. The study involved developing and testing two types of solar distillers. The first, a conventional tub design, produced 3 liters per square meter daily in summer. The second, a more efficient Type II design with optimized solar exposure, achieved a 22% increase in daily water production, showing promise for global clean water needs.

Alkan, C., et al. [6] explored dicarboxylic acid esters as potential materials for Thermal Energy Storage (TES). They assessed esters derived from adipic, succinic, and oxalic acids combined with 1-hexadecanol using analytical techniques like FTIR and NMR spectroscopy. The esters exhibited distinct melting and crystallization points, suggesting their suitability for TES systems. The study analyzed their thermophysical properties, thermal stability, and performance after 1000 heating and cooling cycles, indicating their potential in TES applications.

Pawar, V. R., & Sobhansarbandi, S. [7] focused on enhancing the efficiency of solar water heating systems using evacuated tube collectors (ETCs) and phase change materials (PCMs). They used CFD modeling and real-world data to study the impact of integrating Tritriacontane paraffin PCM into HPETCs, finding substantial improvements in thermal distribution and efficiency.

Sharon et al. [8] conducted an extensive analysis to identify potential sites for solar desalination along India's coast, based on thermodynamic and enviro-economic evaluations. Experiments in Chennai showed the system's efficiency with highly saline water. The study highlighted the system's energy efficiency, cost-effectiveness, and significant reduction in greenhouse gas emissions.

Rashidi, S., et al. [9] provided a comprehensive review of nanofluids in thermal energy systems, focusing on their impact on condensation and evaporation processes. The study highlighted the advantages and challenges of using nanofluids and recommended future research directions, particularly concerning nanoparticle deposition and suspension.

Y. Tanoto et al. [10] assessed the integration of variable renewable energy into the Java-Bali grid's dynamic operating reserves. Using the National Electricity Market Optimizer, they analyzed scenarios with and without wind and solar resources, finding that VRE integration can reduce costs and enhance grid reserves.

Al-Yasiri, Q., et al. [11] reviewed the use of nanofluids in Flat Plate Solar Collectors (FPSCs) to improve thermal performance. The study focused on parameters like particle size and concentration, identifying challenges and emphasizing the potential of nanofluids to increase the energetic and exergetic efficiency of FPSCs.

Jose, J., et al. [12] combined experimental and computational methods to study the integration of a serpentine copper tube heat exchanger and nanofluids in solar photovoltaic thermal collectors. They examined different coolants and found that Al2O3 nanofluids significantly increased thermal efficiency, confirming these results with CFD analysis.

Frolova, L. A., et al. [13] explored replacing Pb2+ ions in MAPbI3 with various elements, finding that Hg substitution notably improved solar cell performance. This discovery opens new possibilities for compositional engineering in lead halide materials for photovoltaic applications.

Urieta-Mora, et al. [14] reviewed the role of chemistry in developing new hole transporting materials (HTMs) for perovskite solar cells. They highlighted the contributions of organic synthesis in creating innovative HTMs that enhance device stability and meet market demands.

Y. Luo et al. [15] designed a dual-polarized patch antenna integrated with solar cells, operating in dual compressed high-order modes for sustainable communication solutions. The antenna combined enhanced signal gain with solar energy harvesting, demonstrating significant potential for 5G applications.

Maddah, H. A. [16] used decision trees to evaluate the performance of Dye-Sensitized Solar Cells (DSSCs) with natural photosensitizers. The study identified key predictors for high Power Conversion Efficiencies and confirmed the potential of natural sensitizers in DSSCs through statistical analysis.

Al-Hayeka, I., & Badran, O. O. [17] compared two solar still designs, finding the asymmetric greenhouse-type still more efficient than the symmetric version. The study emphasized the importance of water surface temperature and identified ways to enhance still productivity, such as reducing water depth and adding dye.

V. WORKING PRINCIPLE OF SOLAR STILLS

Solar distillation is the process which basically uses the heat of the sun directly for obtaining useful water from the salty brackish or sea water. The equipment or the device used is known as solar still. The solar still consists of a shallow basin blackened from the inside to absorb high amount of incident rays and is covered with a transparent glass cover. Fig. 2 presents a schematic diagram and components of a traditional solar still built from a single basin contain saline water and covered by an inclined single glass cover. To reduce heat losses to surrounding the basin was insulated with glass-wood, fiberglass, and wood. The working of solar stills is very simple. A sun's rays that are incident on the glass cover of a still allow the water (to be distilled) to heat up present in the basin causing the process of vaporization. When the rate of vapor production increases, it condenses on the inner surface of the glass casing and consequently condensed water vapor on the inner surface of the glass lid slowly flows through the collecting channel and is assembled into a storage bottle. During this process, salts and microorganisms are left in salt water.

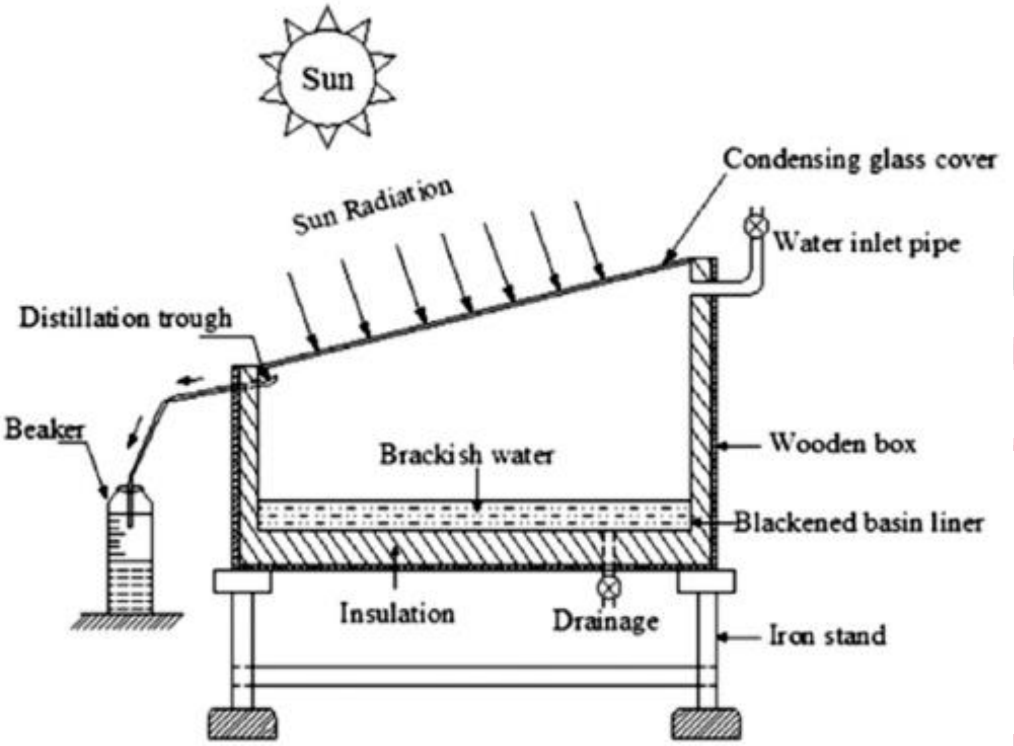

Fig. 2 A traditional single basin solar still

The useful fresh water gets collected in the measuring flask through the outlet present on the side of the still leaving behind all the impurities and the salt content. Incoming radiation from the sun is one of the most substantial input variables in solar distillation. There are different types of energy balance and energy losses in the single basin solar still.

VI. CLASSIFICATION OF SOLAR STILLS

The simple solar still is the oldest and most basic, low-tech desalination system currently in use. Many improvements have been suggested over the years to improve its efficiency. Different kinds and designs of solar stills have been available in today's worldwide including basin and wick stills. Then, water vapor from the hot saline water is condensed for the production of distilled water. A conventional solar still has one basin with no heat recovery from the transparent cover which results in a low efficiency. Nonetheless, various basins may be piled to improve heat. Various solar stills were developed and estimated for comparison with conventionally stills. On the basis of operation mode that introduced to the traditional solar stills, solar stills can be classified mainly on passive and active stills [18].

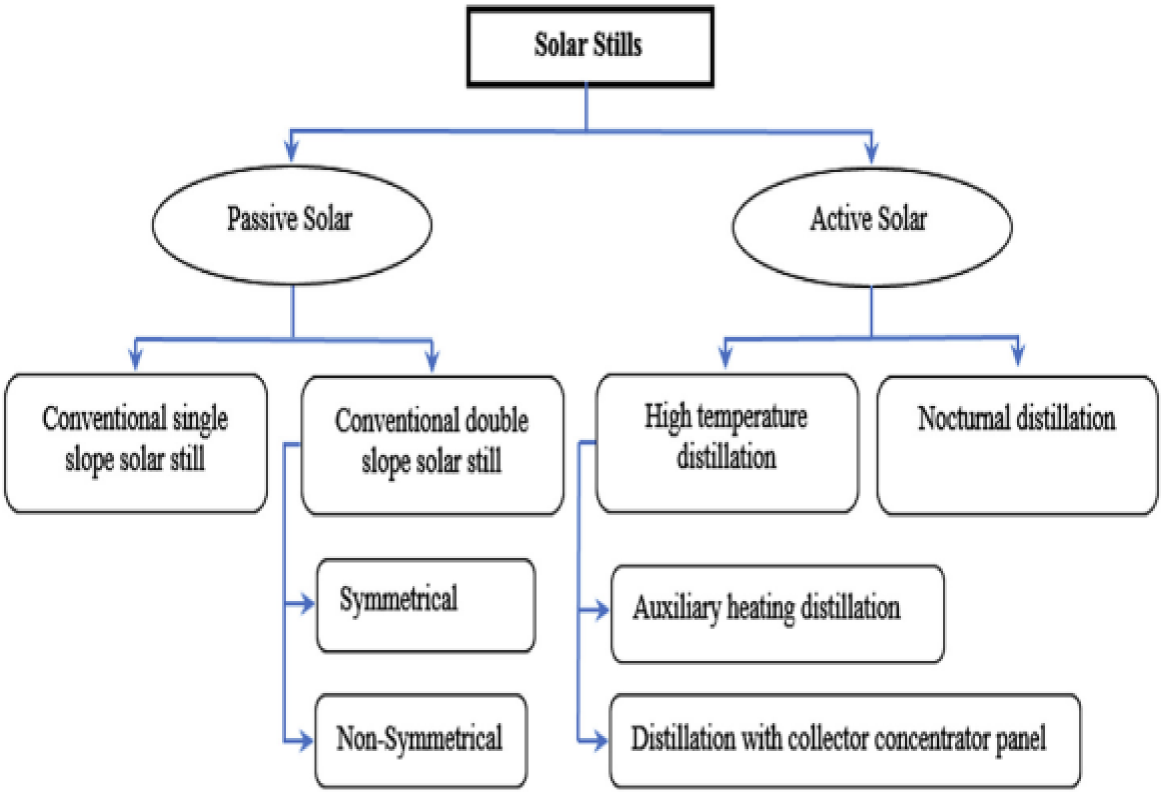

Fig. 3 Classification of solar distillation systems

A. Active solar stills

In the active solar stills, an external heat energy source is added to a basin by external mode to aid heat addition to the salty or brackish water for faster evaporation. The components of the external source may include solar collector, condenser, cooler, or other devices are added to boost the performance. They typically require fans, pumps, or other powered devices for its working. The daily output of inactive stills improved by aggregating the temperature variance between the evaporation and the condensation surfaces. The temperature of evaporation surface can be amplified by feeding the warm air energy into the basin by using some peripheral sources, such stills with external sources are known to be as the active solar stills. Active structures use one or more propels to flow water and/or heating fluid present in the system. Though being more costly than passive system these structures are more efficient comparatively. Such type of system requires high operating and maintenance cost and also high initial investment cost. The basic advantage of using active system is that such system can provide distillate during no sunbeam hours by the usage of energy storage mediums, and other such advantages can also be achieved by enhancing the design of the still or by using some external sources like fins can be used so as to increase the exposure area, by using some sensible heat storage medium, etc. Some of the examples of active still as solar still using flat plate collector, parallel plate collector, solar pond, hybrid PV/T system, and pre-heated water solar still.

B. Passive solar stills

Passive stills use only the solar energy falling into the basin. Thus unlike active solar stills, there is no such external mode is used. To boost the performance some changes were made in the basin design of single slope solar still. Modification of solar still can be done to improve production of still. These are inexpensive to mount and require no maintenance, can be installed easily. The basic disadvantage of this type is the faced in such type of system is of lower yield of the quintessence output.

VII. CONCLUSION

The review highlights significant strides in solar still technology, offering practical solutions to freshwater scarcity through sustainable desalination methods. From traditional single-effect passive stills to more complex multi-effect active designs, each configuration provides unique advantages in optimizing distillate production. Key to these advancements is the management of temperature differentials and integration of elements like condensers and external heat sources. These innovations not only enhance the efficiency of solar stills but also broaden their applicability in various environmental conditions. As global demand for freshwater continues to rise, solar stills stand out as an eco-friendly, energy-efficient, and cost-effective option, marking a significant step towards sustainable water resource management.

REFERENCES

[1] Kaviti, A. K., Yadav, A., & Shukla, A. (2016). Inclined solar still designs: A review. *Renewable and Sustainable Energy Reviews*, *54*, 429-451. https://doi.org/10.1016/j.rser.2015.10.027

[2] Kumar, P. V., Kumar, A., Prakash, O., & Kaviti, A. K. (2015). Solar stills system design: A review. *Renewable and sustainable energy reviews*, *51*, 153-181.

[3] Shahin Shoeibi et al. "Energy matrices, exergoeconomic and enviroeconomic analysis of aircooled and water-cooled solar still: Experimental investigation and numerical simulation" Renewable Energy 171 (2021) 227e244. https://doi.org/10.1016/j.renene.2021.02.081.

[4] Kabeel, A. E., Omara, Z. M., Essa, F. A., & Abdullah, A. S. (2016). Solar still with condenser–A detailed review. *Renewable and Sustainable Energy Reviews*, *59*(C), 839-857.

[5] Kadhum, J. A. (2018). Exploitation of solar energy in the process of purification of the land surface water. International Journal of Computation and Applied Sciences IJOCAAS, 5(1), 356-360.

[6] Alkan, C., Gökşen Tosun, N., & Kaplan, Ö. (2023). Synthesis and Characterization of Dicarboxylic Acid Esters of 1-Hexadecanol for a Thermal Energy Storage Application Range of 50–55° C. Energy Technology, 11(8), 2300104.https://doi.org/10.1002/ente.202300104

[7] Pawar, V. R., & Sobhansarbandi, S. (2019, November). Computational fluid dynamics modeling of a heat pipe evacuated tube solar collector integrated with phase change material. In ASME International Mechanical Engineering Congress and Exposition (Vol. 59438, p. V006T06A087). American Society of Mechanical Engineers.https://doi.org/10.1115/IMECE2019-10252

[8] Sharon, H., Reddy, K. S., Krithika, D., & Philip, L. (2020). Viability assessment of solar distillation for desalination in coastal locations of Indian sub-continent–thermodynamic, condensate quality and enviro-economic aspects. Solar Energy, 197, 84-98.

[9] Rashidi, S., Mahian, O. & Languri, E.M. Applications of nanofluids in condensing and evaporating systems. J Therm Anal Calorim 131, 2027–2039 (2018). https://doi.org/10.1007/s10973-017-6773-7

[10] Y. Tanoto, A. Bruce, I. MacGill and N. Haghdadi, "Impact of High Variable Renewable Penetrations on Dynamic Operating Reserves in Future Indonesian Electricity Industry Scenarios," 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Genova, Italy, 2019, pp. 1-6, doi: 10.1109/EEEIC.2019.8783461.

[11] Al-Yasiri, Q., Szabó, M., & Arıcı, M. (2021). Single and hybrid nanofluids to enhance performance of flat plate solar collectors: application and obstacles. Periodica Polytechnica Mechanical Engineering, 65(1), 86-102.https://doi.org/10.3311/PPme.17312

[12] Jose, J., Shrivastava, A., Soni, P. K., Hemalatha, N., Alshahrani, S., Saleel, C. A., ... & Alarifi, I. M. (2023). An analysis of the effects of nanofluid-based serpentine tube cooling enhancement in solar photovoltaic cells for green cities. Journal of Nanomaterials, 2023.

[13] Frolova, L. A., Anokhin, D. V., Gerasimov, K. L., Dremova, N. N., & Troshin, P. A. (2016). Exploring the effects of the Pb2+ substitution in MAPbI3 on the photovoltaic performance of the hybrid perovskite solar cells. The journal of physical chemistry letters, 7(21), 4353-4357.DOI: 10.1021/acs.jpclett.6b02122

[14] Urieta-Mora, J., García-Benito, I., Molina-Ontoria, A., & Martín, N. (2018). Hole transporting materials for perovskite solar cells: a chemical approach. Chemical Society Reviews, 47(23), 8541-8571.

[15] Y. Luo, J. Lai, N. Yan, W. An and K. Ma, "Codesign of Single-Layer Dual-Polarized Dual Compressed High-Order Modes Differentially Fed Patch Antenna and Solar Cells for Green Communication," in IEEE Transactions on Antennas and Propagation, vol. 70, no. 3, pp. 2289-2294, March 2022, doi: 10.1109/TAP.2021.3111194.

[16] Maddah, H. A. (2022). Decision trees based performance analysis for influence of sensitizers characteristics in dye-sensitized solar cells. Journal of Advances in Information Technology Vol, 13(3).

[17] Al-Hayeka, I., & Badran, O. O. (2014). The effect of using different designs of solar stills on water distillation. Desalination, 169(2), 121-127.https://doi.org/10.1016/j.desal.2004.08.013

[18] Kabeel, A. E., Harby, K., Abdelgaied, M., & Eisa, A. (2020). A comprehensive review of tubular solar still designs, performance, and economic analysis. *Journal of cleaner production*, *246*, 119030.