Research Journal of Engineering Technology and Medical Sciences (ISSN: 2582-6212), Volume 06, Issue 03, September-2023
Available at www.rjetm.in/

Enhancing Solar Pond Design for Improved Thermal Storage: A Review

[1]Dhiraj Kumar, [2]Dr Rashmi Dwivedi

[1]Department of Mechanical Engineering, Sri Satya Sai University of Technology and Medical Sciences Sehore (M.P.) India,
[2]Department of Mechanical Engineering, Sri Satya Sai University of Technology and Medical Sciences Sehore (M.P.) India,
Email [1]dhirajpoddar88@gmail.com, [2] rashmidwivedi29@gmail.com

* Corresponding Author: Dhiraj Kumar

Abstract: *This review paper explores the collaborative potential of heat transfer fluid technologies with solar pond systems, highlighting how this partnership could significantly boost the efficiency and sustainability of renewable energy approaches. It identifies solar ponds as key in harnessing and storing solar energy through a process of water stratification, and discusses the pivotal role of thermal storage in enhancing energy efficiency, ensuring grid stability, and facilitating the integration of renewable energy sources. The paper examines a range of factors that influence the effectiveness of thermal storage, such as the choice of storage mediums and the intricacies of system design. Through an extensive literature review, it unveils various innovative strategies for heat extraction and system integration within solar ponds, particularly emphasizing the role of phase change materials and nano-additives in elevating performance levels. Ultimately, the paper highlights the revolutionary potential of integrating state-of-the-art heat transfer fluids with solar pond technology to improve renewable energy generation, advocating for further research and innovation in this promising sector.*

Keywords: *Heat transfer fluid technologies, Solar pond systems, Renewable energy efficiency and sustainability, Water stratification, Thermal storage, Energy efficiency.*

I. INTRODUCTION TO SOLAR PONDS

Water and energy are intricately interconnected; water is essential for the transportation and utilization of energy in various forms, while energy is crucial for the extraction, treatment, and distribution of water, as well as its purification post-consumption. The global demand for freshwater and energy is projected to continue increasing in response to growing populations, expanding economies, shifting lifestyles, and evolving consumption patterns. Historically, human societies have depended on rivers, lakes, and groundwater for their freshwater needs in residential, agricultural, and industrial sectors. However, rapid industrial growth and population increase have led to a surge in demand for freshwater, both for personal use and agricultural production to ensure adequate food supply. Additionally, the pollution of water bodies due to industrial waste and significant volumes of sewage discharge poses a critical challenge [1]. The concept of the solar pond was initially identified by von Kalecsinsky at Medve Lake in Transylvania in the early 1900s, where temperatures as high as 70°C were measured at a depth of 1.32 meters by summer's end. By spring's start, temperatures dropped to around 26°C, with a 26% NaCl concentration noted at the lake's bottom. This discovery led to the identification of similar solar ponds worldwide, including locations like Orovilve in Washington, Vanda in Antarctica, and Eilat in Israel. Solar ponds are designed to capture and store solar energy efficiently. As solar energy warms the water, the heated, less dense water rises to the surface, cooling and releasing heat to the atmosphere through convection or evaporation. Conversely, denser, cooler water sinks, creating a cycle that naturally mixes and dissipates heat unless specific measures are taken to retain it, thereby harnessing the stored thermal energy for various uses [2].

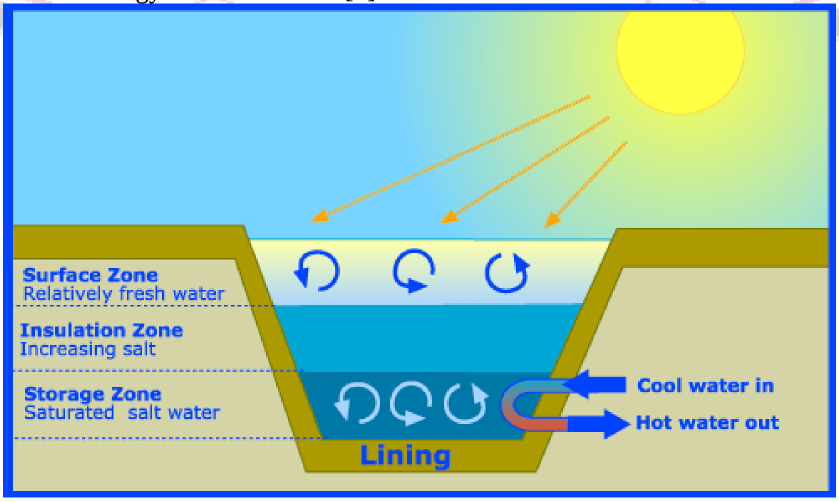

Fig. 1 Concept of Photovoltaic/Solar Pond (PVT/SP)

Solar energy presents itself as a promising solution to address the escalating energy demands while mitigating the environmental impacts associated with fossil fuel consumption. The urgency to transition towards cleaner and more sustainable energy sources has become increasingly apparent, particularly in light of heightened environmental concerns. Among renewable energy options, solar energy stands out due to its abundant availability and capacity for conversion into various forms of energy, including thermal energy [3]. In regions characterized by high solar radiation, such as Iraq, leveraging solar pond technology emerges as a viable strategy for harnessing solar radiation and storing it as thermal energy. Solar ponds operate on a simple yet effective principle of absorbing solar radiation and storing it within layers of water. This stored thermal energy can subsequently be utilized for various applications, ranging from residential heating to industrial processes [4]. Assessing the thermal efficiency of a solar pond involves calculating the ratio of useful energy, represented by the thermal energy stored within the pond's storage layer over a specified timeframe, to the incident solar radiation, multiplied by the total area of the solar pond. By optimizing solar pond design and operational parameters, such as layer thickness and heat transfer fluid selection, significant improvements in thermal efficiency can be achieved, making solar pond technology a promising avenue for sustainable energy production in regions with abundant solar resources like Iraq [5].

Thermal storage performance plays a crucial role in various sectors, especially in energy production and utilization. Here are some key aspects highlighting its importance.

- Energy Efficiency: Efficient thermal storage allows for the capture and retention of excess energy generated during periods of low demand or high renewable energy availability. This stored thermal energy can then be utilized during peak demand periods or when renewable energy sources are unavailable, thereby enhancing overall energy efficiency [6].
- Grid Stability: Thermal storage systems contribute to grid stability by providing a reliable source of dispatchable energy. By storing excess energy during off-peak hours and releasing it during peak demand periods, thermal storage helps balance supply and demand on the grid, reducing the need for expensive peaking power plants and minimizing grid fluctuations [7].
- Renewable Energy Integration: Thermal storage facilitates the integration of intermittent renewable energy sources, such as solar and wind power, into the grid. By storing excess energy generated from renewables during periods of high availability, thermal storage systems help overcome the variability and intermittency inherent in these sources, enabling a smoother and more reliable supply of renewable energy [8].
- Load Shifting: Thermal storage allows for load shifting, enabling energy consumers to optimize their energy usage patterns. By storing thermal energy during periods of low demand or low energy prices and using it during periods of high demand or high prices, consumers can reduce their energy costs and alleviate strain on the grid.
- Energy Resilience: Thermal storage enhances energy resilience by providing backup power during emergencies or grid outages. Standalone thermal storage systems or integrated systems with renewable energy sources can serve as reliable sources of off-grid power, ensuring continuity of essential services and operations in critical facilities such as hospitals, data centers, and remote communities.
- Environmental Benefits: By enabling the efficient utilization of renewable energy and reducing reliance on fossil fuels, thermal storage contributes to environmental sustainability and helps mitigate climate change [9]. It supports the transition to a low-carbon energy system by reducing greenhouse gas emissions and dependence on polluting energy sources.

To sum up, thermal storage performance is essential for enhancing energy efficiency, grid stability, renewable energy integration, load shifting, energy resilience, and environmental sustainability. As the demand for clean, reliable, and flexible energy solutions continues to grow, the importance of optimizing thermal storage technologies becomes increasingly apparent [10].

II. FACTORS INFLUENCING THERMAL STORAGE EFFICIENCY

Several factors influence the efficiency of thermal storage systems, affecting their ability to capture, store, and release thermal energy effectively [11]. Understanding these factors is crucial for optimizing the performance of thermal storage technologies. Here are some key factors influencing thermal storage efficiency:

The efficiency of thermal storage systems is influenced by several key factors. Firstly, the choice of thermal storage medium plays a crucial role, with options including water, molten salts, phase change materials (PCMs), and thermal oils. Each medium possesses unique properties such as specific heat capacity and thermal conductivity, impacting energy storage and release characteristics [12]. Additionally, storage temperature significantly affects efficiency, as higher temperatures may lead to greater energy losses due to heat leakage and radiation, while lower temperatures can limit the efficiency of certain storage materials. Effective thermal insulation is essential for minimizing heat losses and maximizing efficiency, achieved through techniques such as foam insulation, vacuum panels, and reflective coatings. Furthermore, the charging and discharging rates of thermal energy influence efficiency, with slower rates often allowing for more efficient energy transfer and storage [13]. The design of the thermal storage system, including its size, shape, and configuration, also plays a critical role, affecting energy storage and release rates, as well as overall system performance. Operating conditions, such as ambient temperature, humidity, and solar irradiance, can impact thermal storage efficiency, necessitating adaptive control strategies for optimization. Finally, the frequency and magnitude of thermal cycling, or the repeated heating and cooling of the storage medium, can affect system longevity and efficiency, with potential impacts on material degradation and overall reliability [14]. The integration of thermal storage systems with renewable energy sources, such as solar thermal collectors or concentrated solar power plants, can enhance efficiency and overall system performance. Coordinated operation and control strategies enable optimized energy capture, storage, and utilization. Multiple factors influence the efficiency of thermal storage systems, spanning from the choice of storage medium to system design, operating conditions, and integration with energy systems. By carefully considering and addressing these factors, it is possible to optimize thermal storage efficiency and unlock the full potential of these technologies for sustainable energy storage and utilization.

III. LITERATURE REVIEW

A. Alcaraz, et al. (2016) [15] assessed heat extraction methods in a salinity-gradient solar pond (SGSP) using an experimental setup established in Barcelona, Spain, in 2009. The research focused on comparing the efficiency of lateral wall and traditional bottom-placed heat exchangers within a cylindrical solar pond measuring 3 meters in height and 8 meters in diameter. Experiments conducted across different seasons—winter, summer, and autumn—investigated temperature variations during heat extraction. Findings revealed that using the lateral heat exchanger alone significantly improved the pond's heat extraction efficiency compared to the bottom heat exchanger or a combination of both.

Farayi Musharavati et al. (2022) [16] introduces a cutting-edge hybrid system integrating a salinity gradient solar pond (SGSP) with a proton exchange membrane fuel cell (PEMFC) and a thermoelectric generator (TEG) to enhance low-temperature heat source performance and achieve complete waste energy recovery. The study evaluates the system's energy, exergy, and economic performance, comparing it with variants lacking TEG and PEMFC to highlight the added value of these components. Through parametric analysis and simulation, the integrated system showcased a net output of 2288.8 kW, with efficiencies of 11.26% for energy and 13.17% for exergy, alongside a cost rate of 394 $/h. Notably, the SGSP was responsible for the majority of exergy degradation and incurred the highest investment cost. Optimal system performance was sought through multi-criteria optimization and decision analysis, resulting in significant improvements in output and efficiencies at a minimal cost increase. This study emphasizes the effectiveness of combining SGSP, PEMFC, and TEG in an optimized energy system for enhanced performance and cost-effectiveness.

Solar energy, celebrated for its role in combating climate change and offering sustainable solutions, utilizes solar ponds among various techniques for harnessing and storing thermal energy. Challenges like heat loss, evaporation, and inefficient heat transfer have limited solar pond effectiveness. To address these issues, **N. Poyyamozhi, et al. (2023) [17]** has focused on integrating phase change materials (PCMs) and nano-additives, enhancing thermal storage and heat transfer capabilities. PCMs allow solar ponds to store significant heat during the day and release it at night, while nano-additives like carbon nanotubes (CNTs) and $AgTiO_2$ nanoparticles improve the thermal conductivity of the pond's fluid. Experimental studies have demonstrated that incorporating PCMs and nano-additives can significantly raise the lower convective zone's (LCZ) temperature, proving the effectiveness of these enhancements in boosting solar pond performance.

In real-world applications, a simple solar still with a single basin typically produces a limited quantity of distilled water daily. **Yuvaperiyasamy, M., et al. (2023) [18]** examined various configurations, including fin-type solar ponds and solar stills, as well as integrated systems combining both, in Pongalur, near Tirupur. The research developed several models: a single basin solar still, versions with added fins, and combinations with finned ponds, aiming to boost the thermal efficiency and water distillation rates. The introduction of fins into the system significantly improved heat transfer efficiency, leading to an increase in daily water output. Experimental results revealed that the addition of fins to the solar still setups resulted in water collection increases of 46% to 52%, depending on the specific configuration. This enhancement underscores the fins' role in facilitating more efficient heat transfer from the basin to the water, thereby optimizing the distillation process.

The proposed energy system by **Farbod Esmaeilion et al. (2023) [19]**, featuring a salinity-gradient solar pond (SGSP), showcases significant potential for solar energy capture, efficient low-temperature heat storage, and improved performance over time. This system integrates various components, including a flat plate collector, a single-stage absorption chiller, a thermoelectric generator, a desalination unit, a sodium hypochlorite production plant, and a wind turbine farm, offering a versatile solution for residential energy needs such as electricity, cooling, and fresh water production. Theoretical analysis highlights the system's year-round multidimensional advantages, including thermodynamic, economic, and environmental benefits. Comparative assessments reveal energy and exergy efficiencies of 27.3% and 19%, respectively, alongside a notable capacity to meet substantial cooling demands, generate electricity, produce hydrogen and freshwater, and create sodium hypochlorite. The system also promises a payback period of 3.2 years and a favorable environmental impact score, indicating its economic viability and sustainability.

For over a century, solar stills have been utilized to desalinate saltwater, producing potable water, albeit with limited efficiency and high costs. **Kumara, M. M., et al. (2023) [20]** introduces an enhanced design involving a double basin solar still, augmented with exterior reflectors, a lower basin equipped with a flat plate collector (FPC), and a mini solar pond. Conducted at Francis Xavier Engineering College in Tirunelveli, Tamil Nadu, India, the experiment ran daily from 9:00 to 19:00 for 20 days. This study aimed to assess the impact of these modifications on the still's efficiency. The double basin setup included an innovative structure where the upper basin contained a 5-step tray for increased stability and heat storage, using materials like granite. Remarkably, the introduction of external reflectors and the integration with FPC and a mini solar pond significantly boosted distilled water production from the baseline, highlighting a notable increase in yield by 127.5%. This suggests that such modifications greatly enhance the practicality and output of solar distillation processes.

IV. FLUID & SOLAR SYNERGY

Solar ponds represent a unique and innovative application of heat transfer fluid technology within the renewable energy sector. These systems are a type of thermal solar power plant where a large body of water is used to collect and store solar energy. The fundamental principle behind solar ponds leverages the natural tendency of water to stratify into layers of different temperatures, a concept that directly relates to the advancements and innovations in heat transfer fluids [21].

The connection between solar ponds and the recent innovations in heat transfer fluids, such as those designed for high-temperature operation and enhanced thermal conductivity, is profound. Solar ponds can efficiently absorb and store solar radiation due to the water's thermal mass and the selective use of salts to create a density gradient that prevents convection in the lower layers. This process allows the bottom layer of the pond to reach temperatures up to 90°C or higher, making it a practical and sustainable source of heat energy for various applications, including electricity generation, industrial process heat, and space heating [22].

The innovative heat transfer fluids, such as those discussed earlier like eutectic mixtures of biphenyl-diphenyl oxide or ferrofluids with enhanced thermal properties, can complement solar pond technology by potentially increasing the efficiency of heat extraction from the pond. For instance, the high-temperature operation capabilities of some modern heat transfer fluids could enable more effective transfer of thermal energy from the hot bottom layer of a solar pond to a heat exchanger or an external process [23]. Similarly, the predictive management of these fluids ensures their longevity and optimal performance, a principle that could be applied to maintain the efficiency of the heat transfer systems associated with solar ponds.

Moreover, the focus on reducing water consumption and enhancing the environmental sustainability of heat transfer processes finds a parallel in solar pond technology. Solar ponds utilize natural resources (water and solar energy) efficiently and can be integrated into local ecosystems with minimal environmental impact, echoing the sustainability goals of the latest heat transfer fluid innovations [24]. The advancements in heat transfer fluids, from their operation at higher temperatures to the predictive management and emphasis on sustainability, align closely with the principles and goals of solar pond technology. These innovations not only enhance the efficiency and environmental footprint of industrial processes but also offer potential improvements to renewable energy technologies like solar ponds, further bridging the gap between traditional energy sources and sustainable alternatives [25].

These innovations represent a paradigm shift in the utilization and management of heat transfer fluids across various industries. By improving efficiency, reducing environmental impact, and leveraging renewable energy sources, these advancements are setting new standards for industrial operations and energy generation.

V. CONCLUSION

The review paper presents a comprehensive analysis of the integration between heat transfer fluid technology and solar pond applications, emphasizing the potential of this synergy to enhance the efficiency and sustainability of renewable energy solutions. It highlights solar ponds as effective systems for collecting and storing solar energy through water stratification and discusses the role of thermal storage in improving energy efficiency, grid stability, and renewable energy integration. The paper explores various factors affecting thermal storage efficiency, including the choice of storage medium and system design. Through a literature review, it showcases studies on innovative approaches to heat extraction and system integration in solar ponds, underscoring the use of phase change materials and nano-additives to boost performance. Conclusively, the paper underscores the transformative potential of combining advanced heat transfer fluids with solar pond technology to achieve greater renewable energy outcomes, setting a path for future research and development in the field.

REFERENCES

[1] Osamah A.H. AL-Musawi, Anees A. Khadom, Hammed B. Manhood, Mustafa S. Mahdi, Solar pond as a low grade energy source for water desalination and power generation: a short review, Renew. Energy Environ. Sustain. 5 4 (2020), DOI: 10.1051/rees/2019008

[2] Alrowaished Abdulsalam, Azni Idris, Thamer A. Mohamed & Amimul Ahsan (2014): The development and applications of solar pond: a review, Desalination and Water Treatment, DOI: 10.1080/19443994.2013.870710

[3] Abbood, M. H., Alhwayzee, M., & Sultan, M. A. (2021, February). Experimental investigation into the performance of the solar pond in Kerbala. In IOP Conference Series: Materials Science and Engineering (Vol. 1067, No. 1, p. 012098). IOP Publishing.

[4] Dehghan, A. A., Movahedi, A., & Mazidi, M. (2013). Experimental investigation of energy and exergy performance of square and circular solar ponds. *Solar energy*, *97*, 273-284.

[5] Singh Bhathal Singh, B. (2023). Analysis and Optimization of Heat Transport for the Purpose of Maximizing the Potential of Solar Ponds in Sustainable Energy Applications. Intech Open. doi: 10.5772/intechopen.112768

[6] Ines, M., & Jomâa, S. M. (2019). Experiment study of the effect of salt on the stability of solar ponds. *Environmental Progress & Sustainable Energy*, *38*(2), 699-705.

[7] Liu, H., Wu, D., Liu, X., & Xie, M. (2021). Experimental Study on the Temperature and Turbidity Characteristics of a Mini Solar Pond with Three Enhancing Measures. *Heat Transfer Research*, *52*(4).

[8] Abhishek Saxena, Varun Goel, "A Technical Note on Fabrication and Thermal Performance Studies of a Solar Pond Model", Journal of Renewable Energy, vol. 2013, Article ID 475282, 5 pages, 2013. https://doi.org/10.1155/2013/475282

[9] Kabeyi, M. J. B., & Olanrewaju, O. A. (2022). Sustainable energy transition for renewable and low carbon grid electricity generation and supply. *Frontiers in Energy research*, *9*, 1032.

[10] Krishna Kumar Jaiswal, Chandrama Roy Chowdhury, Deepti Yadav, Ravikant Verma, Swapnamoy Dutta, Km Smriti Jaiswal, SangmeshB, Karthik Selva Kumar Karuppasamy, Renewable and sustainable clean energy development and impact on social, economic, and environmental health, Energy Nexus, Volume 7, 2022, 100118, ISSN 2772-4271, https://doi.org/10.1016/j.nexus.2022.100118.

[11] Salim Barbhuiya, Bibhuti Bhusan Das, Maria Idrees, Thermal energy storage in concrete: A comprehensive review on fundamentals, technology and sustainability, Journal of Building Engineering, Volume 82, 2024, 108302, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2023.108302.

[12] Huili Zhang, Jan Baeyens, Gustavo Cáceres, Jan Degrève, Yongqin Lv, Thermal energy storage: Recent developments and practical aspects, Progress in Energy and Combustion Science, Volume 53, 2016, Pages 1-40, ISSN 0360-1285, https://doi.org/10.1016/j.pecs.2015.10.003.

[13] Hussam Jouhara, Alina Żabnieńska-Góra, Navid Khordehgah, Darem Ahmad, Tom Lipinski, Latent thermal energy storage technologies and applications: A review, International Journal of Thermofluids, Volumes 5–6, 2020, 100039, ISSN 2666-2027, https://doi.org/10.1016/j.ijft.2020.100039.

[14] Sarbu, I., & Sebarchievici, C. (2018). A comprehensive review of thermal energy storage. Sustainability, 10(1), 191.

[15] A. Alcaraz, C. Valderrama, J.L. Cortina, A. Akbarzadeh, A. Farran, Enhancing the efficiency of solar pond heat extraction by using both lateral and bottom heat exchangers, Solar Energy, Volume 134, 2016, Pages 82-94, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2016.04.025.

[16] Farayi Musharavati, Shoaib Khanmohammadi, J. Nondy, T.K. Gogoi, Proposal of a new low-temperature thermodynamic cycle: 3E analysis and optimization of a solar pond integrated with fuel cell and thermoelectric generator, Journal of Cleaner Production, Volume 331, 2022, 129908, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2021.129908.

[17] N. Poyyamozhi, C. Bibin, S. Senthil Kumar, P. Renugadevi, Energy storage investigation of solar pond integrated with PCM and nanoparticles during winter season in Chennai, Journal of Energy Storage, Volume 73, Part A, 2023, 108704, ISSN 2352-152X, shttps://doi.org/10.1016/j.est.2023.108704.

[18] Yuvaperiyasamy, M., Senthilkumar, N., & Deepanraj, B. (2023). Experimental and theoretical analysis of solar still with solar pond for enhancing the performance of sea water desalination. *Water Reuse*, *13*(4), 620-633.

[19] Farbod Esmaeilion, M. Soltani, Siamak Hoseinzadeh, Ali Sohani, Jatin Nathwani, Benefits of an innovative polygeneration system integrated with salinity gradient solar pond and desalination unit, Desalination, Volume 564, 2023, 116803, ISSN 0011-9164, https://doi.org/10.1016/j.desal.2023.116803.

[20] Kumara, M. M., Rajesha, S., & Gnanarajb, S. J. P. (2023). Experimental investigation of double basin solar still integrated with solar flat plate collector and solar pond with modified design. DESALINATION AND WATER TREATMENT, 290, 26-35.

[21] Abhishek Saxena, Erdem Cuce, Desh Bandhu Singh, Pinar Mert Cuce, Parul Gupta, Ajay Suryavanshi, Mahmoud Farrokhi, A.A. El-Sebaii, A thermodynamic review on solar ponds, Solar Energy, Volume 242, 2022, Pages 335-363, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2022.07.016.

[22] Muhammad Tawalbeh, Rana Muhammad Nauman Javed, Amani Al-Othman, Fares Almomani, Salinity gradient solar ponds hybrid systems for power generation and water desalination, Energy Conversion and Management, Volume 289, 2023, 117180, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2023.117180.

[23] Frederick, R. L., & Riobó, C. (2016). Heat exchangers for solar pond applications. WIT Transactions on Engineering Sciences, 106, 151-161.

[24] Akbarzadeh, A., Andrews, J., & Golding, P. (2009). Solar ponds. *Solar Energy Conversion And Photoenergy System-Volume I*, *8*, 242.

[25] Choudhary, P., & Srivastava, R. K. (2019). Sustainability perspectives-a review for solar photovoltaic trends and growth opportunities. *Journal of Cleaner Production*, *227*, 589-612.