Review of Enhancements in Absorber Plate Geometry for Solar Desalination: Key Insights and Prospects

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Abstract - *Amidst the current global water scarcity crisis, solar desalination stands as a promising solution. It addresses the abundant but saline water reserves, though challenges persist, particularly the low productivity of solar stills. The critical factor lies in the interaction between the absorber plate and saline water, making absorber plate geometry modifications pivotal for enhanced productivity. This article explores the impact of integrating fins, employing baffles, and using corrugated or stepped absorber plates. It delves into the influence of geometric parameters, such as fins, baffles, steps, and corrugations, and their effects on thermal resistance, heat distribution, and preheating time. Notably, fins excel when considering the same mass of saline water, whereas corrugations prove superior for consistent water depth. The article culminates with a tabular summary of the latest findings in absorber plate geometry modifications and a discussion on comparative studies, key discoveries, and future research prospects.*

Key Words: **Solar Desalination, Absorber Plate Geometry, Productivity Enhancement, Flat Plate Collector**

1.INTRODUCTION

In a world where sustainable energy solutions have become imperative, solar water heaters with flat plate collectors have emerged as a notable innovation. This technology harnesses the abundant and renewable energy from the sun to provide cost-effective and eco-friendly heating solutions for a variety of domestic and industrial applications. The concept of utilizing solar energy for heating water is not only environmentally responsible but also economically sound, offering a significant reduction in energy bills and carbon emissions.

At the heart of this technology is the flat plate collector, a fundamental component that absorbs sunlight and converts it into usable thermal energy. Unlike more complex solar systems, the flat plate collector is celebrated for its simplicity, durability, and efficiency. Its versatility allows it to be integrated into a wide range of settings, from residential rooftops to commercial and industrial facilities, making it a practical choice for many.

This introduction sets the stage for a comprehensive exploration of solar water heaters with flat plate collectors, delving into their principles of operation, advantages, applications, and ongoing innovations. By harnessing the power of the sun, this technology not only contributes to a greener and more sustainable future but also offers tangible benefits to individuals and communities looking to reduce their carbon footprint and energy expenses. In the sections that follow, we will embark on a journey to uncover the intricacies of this transformative technology and its role in shaping a cleaner and more energy-efficient world.

As the world grapples with the dual challenges of rising energy costs and environmental concerns, the utilization of solar energy in everyday life has become a compelling solution. Among the various solar technologies, solar water heaters equipped with flat plate collectors have gained prominence for their effectiveness in harnessing the sun's energy for residential and commercial heating needs. This introduction offers a glimpse into the world of solar water heaters, focusing on the pivotal role played by flat plate collectors in this sustainable energy revolution.

Solar water heaters are a testament to the fusion of cutting-edge technology with the Earth's oldest and most abundant energy source—the sun. These systems are designed to capture, convert, and store solar radiation as thermal energy, primarily for the purpose of heating water. In doing so, they alleviate the dependence on fossil fuels and electricity for water heating, reducing both energy bills and carbon footprints.

At the heart of these systems are flat plate collectors, which act as the workhorses responsible for capturing sunlight and transforming it into usable heat. These collectors are typically mounted on rooftops or other suitable locations, positioned to maximize sun exposure. What sets flat plate collectors apart is their straightforward yet ingenious design: a dark-colored, heat-absorbing plate covered with a transparent cover that traps heat while allowing sunlight to pass through. This seemingly simple arrangement conceals a remarkable ability to raise water temperatures efficiently and consistently.

In the pages that follow, we will embark on a comprehensive exploration of solar water heaters featuring flat plate collectors. We will delve into their underlying principles, advantages, and versatility across various applications.

Moreover, we will discuss how these systems contribute to energy sustainability, reduce greenhouse gas emissions, and ultimately enhance our quality of life. As we journey deeper into the world of solar water heaters, it becomes evident that they represent more than just an alternative energy source; they symbolize a sustainable path forward in our quest for a cleaner and greener future.

2. LITERATURE REVIEW

Gamal B. Abdelaziz et al. [1], The paper explores five different combinations to enhance the performance of a tubular solar still. These combinations include using a v-corrugated aluminum basin, adding wick material to the basin, incorporating carbon black nanofluid on the wick material, using phase change materials (paraffin wax) under the basin with wicks and carbon black nanofluid, and adding carbon black nanoparticles to paraffin wax under the basin. The results show that the productivity of the tubular solar still is enhanced by 21.4% to 88.84% with these combinations. The best case, which includes the v-corrugated basin, wick, 1.5 wt.% carbon black nanofluid, and carbon black nanoparticles in paraffin wax, improves thermal energy and exergy efficiencies by 82.16% and 221.8% respectively, while saving 22.47% in cost compared to conventional tubular solar stills. **Mohamed Abdelgaied et al. [2],** The study aims to enhance the performance of tubular solar stills by using copper hollow fins and phase change materials (PCM). Experimental scenarios were conducted to investigate the effects of different fin shapes and the addition of PCM, resulting in significant improvements in productivity. **Abdullah et al. [3],** The study aimed to enhance tubular solar still performance by using copper hollow fins and phase change materials (PCM). In one scenario, they compared traditional, square fins, and circular fins tubular solar stills, with circular fins showing a 47.2% productivity boost. In another scenario, adding circular fins and PCM led to a remarkable 90.1% increase in productivity compared to the traditional still. These modifications demonstrated outstanding performance, surpassing previous studies in Egypt. **A.S. Abdullah et. al [4]**, The paper presents a study on a novel single basin solar still called trays solar still (TSS) that has been modified by adding trays on its internal sides to increase the evaporative surface area and exposed area to solar radiation. The water depth over the trays was varied, and internal and external mirrors were used to enhance solar energy input. The results showed that TSS without reflectors had 1.5 times the daily productivity of a conventional solar still (CSS) at certain water levels and tray heights. The use of internal mirrors (TSSIM) increased productivity by 58% compared to CSS, while the use of external bottom and top mirrors (TSSIBM and TSSITM) further improved productivity by 84% and 75% respectively. The highest productivity was achieved when both external mirrors were used with TSSIM (TSSIBTM), resulting in 95% higher productivity than CSS. The thermal efficiency of the different systems was also evaluated. **Mohammed Shadi S. Abujazar et al. [5],** The paper evaluates the efficiency of an inclined copper-stepped solar still through theoretical calculations and experiments, conducted by the Faculty of Engineering and Built Environment, UKM, Bandar Baru Bangi, Selangor. The experimental data was used to validate the theoretical model, and the results showed good agreement between the experimental and theoretical data. The convective, evaporative, and radiative heat transfer coefficients, as well as the water productivity and efficiency, were calculated for each hour. The maximum hourly productivity in the inclined copper-stepped solar still was found to be 474 mL/m2 h (theoretical) and 605 mL/m2 h (experimental). The daily efficiency of the system varied between 28.33% and 29.5% from September to December 2016. **W.M. Alaian et al. [6],** The paper presents an experimental investigation on the performance of a solar still augmented with a pin-finned wick evaporation surface. The study involves two identical solar stills, one with a conventional surface and the other with a pin-finned wick surface. Outdoor experimental tests are conducted to evaluate the effect of the pin-finned wick on the still productivity. The measurements indicate that the use of the pin-finned wick enhances the still productivity, with an increase in distillate of more than 23% compared to the conventional still. The system efficiency recorded when using the pin-finned wick is about 55%. **Chaouki Ali et al. [7]**, The paper presents a theoretical and experimental analysis of a solar still with a pin fins absorber plate, comparing it with a conventional absorber plate under the same climatic conditions. The heat transfer energy balance equations for the various elements of the active solar still are formulated, numerically solved, and validated. **Abdulmohsen Alsaiari et al. [8],** The paper focuses on the synthesis of TiO2/jackfruit peel nanocomposites through green synthesis and their application in a single slope single basin solar still (PSBSS). The nanocomposites were characterized and found to have a porous structure with 85% crystallinity and grain size ranging from 40 to 60 nm. A new hybrid nanofluid (CTS) was created by mixing the nanocomposite with cobalt (II) chloride, thiourea, and silicon dioxide. The PSBSS with the nanocomposites and nanofluids showed higher productivity (8.7919 L/m2day) compared to the conventional solar still (CSS) with nanofluid and saline water in the basin. **D. E. Benhadji Serradj et. al [9]**, Single slope solar stills are a viable solution for freshwater production, and researchers have explored various design modifications to improve their yield. However, the use of passive baffles to enhance natural convection inside the stills has not been well explored in the literature. This study conducted computational fluid dynamics simulations and experimental validation to investigate the effect of vertically mounted passive baffles on natural convection in single slope solar stills. The results showed that baffles can increase the natural convection heat transfer coefficient and improve the still's yield by up to 20%. Short baffles were found to enhance natural convection at low cover angles, while baffles mounted close to the front of the still provided improvements over a wide range of conditions. **J.S. D'Cotha et al. [10**], Solar desalination is an environmentally friendly approach to augment fresh water productivity, and researchers have explored the use of passive stepped solar stills to enhance distillate output. **S.A. El-Agouz et al. [11],** The paper presents a modified stepped solar still with continuous water circulation using a storage tank for sea and salt water, and compares its performance with a conventional solar still under the same climate conditions. The modified stepped still showed higher productivity and daily efficiency, with a maximum efficiency at specific feed water flow rates. The study also investigated the effect of installing a storage tank and cotton black absorber on the distillate productivity, and found that the modified stepped still had a higher productivity than the conventional still, with an increase of approximately 43% and 48% for sea and salt water with black absorber, and 53% and 47% for sea and salt water with cotton absorber. **El-Naggar et al. [12**], In this study, a conventional single basin solar still and a modified unit with a finned-basin liner were constructed and tested in June 2014 under Tanta's typical weather conditions in Egypt. The research involved both experimental and theoretical approaches, with energy balance equations formulated and solved analytically. Computer programs were developed to optimize and predict the thermal performance of these systems, and comparisons were made between experimental and theoretical results, as well as with findings from previous studies. The daily productivities of the conventional and modified stills were measured at 4.235 and 4.802 kg/m^2 per day, respectively, with daily efficiencies of 42.36% and 55.37%. The addition of fins significantly increased the convective heat transfer coefficient by 3.6 times compared to the non-finned case. The agreement between measured and calculated daily productivity was reasonably good. Furthermore, the cost of producing 1 liter of distilled water was determined to be 0.28 Egyptian pounds (LE) **Ahmed El-Sebaii et al.[13],** The study investigates the impact of fin configuration parameters on the efficiency and productivity of a finned plate solar still (FBLS) under Tanta weather conditions in Egypt. The parameters studied include the number of fins (nf), fin height (Hf), and fin thickness (xf). The productivity of the FBLS was found to increase with increasing fin height, but decrease with increasing fin thickness and fin number. The highest daily productivity achieved was 5.377 kg/m2 day when nf, Hf, and xf were 7, 0.04 m, and 0.001 m, respectively. **A.A. El-Sebaii et al. [14]**, The paper presents a mathematical model for a single basin solar still with a v-corrugated basin liner, and investigates its performance using computer simulation. The v-corrugated plate improves the daily productivity and efficiency of the still by approximately 24% compared to a flat basin liner of the same area. **Mohamed Elashmawy et al. [15],** The present study developed a new composite sensible heat storage tube (CSHSTs) to improve the freshwater productivity of a tubular solar still activated by a parabolic concentrator solar tracking system. Results showed enhancements by 24.05% and 20.06% in the freshwater yield and thermal daily efficiency, respectively. The developed device produced 4.9 L/m2day with 13% lower freshwater production cost of $0.0087 per liter. The developed device showed higher performance compared to the previous studies in the literature. **Ammar H. Elsheikh et al. [16],** The paper presents a new design of a vertical water distillation tower based on solar stills, with improved water yield and thermal, exergic, and economic features. The authors developed a hybrid model using the random vector functional link (RVFL) neural network integrated with the Runge Kutta optimizer (RUN) to predict the water yield and temperature of the tower, which outperformed other models. **Ammar H. Elsheikh et al. [17]**, The study introduces a LSTM neural network model for forecasting the freshwater yield of a stepped solar still and a conventional one, comparing their thermal performance and evaluating the heat transfer coefficients of convection, evaporation, and radiation processes. The yield of the stepped solar still is enhanced by about 128% compared to the conventional solar still. The proposed LSTM neural network method is utilized to forecast the hourly yield of the solar stills, with a high coefficient of determination of 0.97 and 0.99 for the conventional and stepped solar still, respectively. **Ammar H. Elsheikh et al. [18]**, The paper presents an artificial intelligence model that uses a hybrid long short-term memory (LSTM) model optimized by a moth-flame optimizer (MFO) to forecast the water yield of a modified solar distiller integrated with evacuated tubes and an external condenser. The model's performance is compared with that of a standalone LSTM model, and both models are trained and tested using experimental data of the modified distiller and a conventional distiller. The maximum daily distillate output achieved for the modified distiller was 3920 l/m2. The forecasted data of both models were compared using several statistical measures, and the LSTM-MFO model outperformed the standalone LSTM model, with a determination coefficient of 0.999 for both solar distillers**. Ammar H. Elsheikh et al. [19],** Solar energy can be used for steam and vapor generation, but conventional methods have limitations in terms of power supply and heat loss to bulk water. Thin film technology offers a promising solution by localizing heating on a thin layer of water. The paper reviews recently developed thin film-based steam generation devices, discussing their physical mechanisms, fabrication methods, and materials used. It also explores different types of thin-film materials and substrates, as well as preparation and synthesis methods. The paper suggests future research directions in this field. **E. Ghandourah et al. [20],** The paper discusses the performance enhancement and economic analysis of a pyramid solar still with a corrugated absorber plate (PSSCAP) compared to a conventional solar still (CSS) in Patan, Gujarat, India. The PSSCAP, which utilizes a triangular glass cover and a corrugated absorber plate, showed a 52.54% higher yield and an average thermal efficiency of 45.5% compared to the CSS. The estimated cost of producing 1 liter of yield was approximately 0.53 INR for the PSSCAP and 0.68 INR for the CSS. **E. Ghandourah et al. [21],** The paper proposes a hybrid artificial intelligence model to predict the thermal behavior of two designs of solar stills (SSs) with aluminum and polycarbonate absorber plates, both having an air cavity. The model combines an optimized Artificial Neural Network (ANN) model with the Golden Jackal Optimizer (GJO) algorithm. The performance of the proposed model is compared with a conventional ANN model, as well as two other optimized models using Genetic Algorithm (GA) and Particle Swarm Optimizer (PSO). The results show that the ANN-GJO model outperforms the other models in predicting overall heat transfer coefficient, energy efficiency, exergy efficiency, and distillate output. Additionally, the study finds that the solar still with an aluminum absorber plate (ALSS) performs better than the one with a polycarbonate absorber plate (PCSS) in terms of water productivity, exergy efficiency, energy efficiency, and distillate output. The average exergy efficiency and energy efficiency of PCSS are 2.30% and 42.40%, respectively, while for ALSS, they are 3.44% and 48.80%, respectively. The maximum distillate output for PCSS and ALSS is 3.40 l/m2/day and 3.80 l/m2/day, respectively. **E. Ghandourah et al. [22]**, The paper investigates a novel solar distiller called the double slope wick type solar distiller (DSWSD) coated with lanthanum cobalt oxide (LaCoO3) nanoparticles doped in black paint. The nano LaCoO3/black paint is applied to the jute wick surface to enhance solar irradiance absorption for effective desalination. The influence of water flow rate on the internal mass and heat transfer of the DSWSD is analyzed. The experiments were conducted in Vijayawada, India, and it was observed that the DSWSD with the LaCoO3/black paint coating had higher internal heat transfer coefficients (HTCs) and distilled yield compared to the distiller without the coating. The daily productivity of the DSWSD with the coating was 5.40 kg/m2.day, while without the coating it was 3.85 kg/m2.day at a saline water flow rate of 0.05 kg/min. The evaporative and convective HTCs, as well as energy efficiency, were also higher with the coating. **Hamdy Hassan et al. [23],** The study investigates the impact of different saline water mediums (pure saline water, steel wire mesh, and sand saturated with saline water) on the freshwater productivity and system efficiency of a modified solar still with a tracked parabolic trough collector (TPTC) compared to a conventional solar still. The findings show that using wire mesh and sand in the basin of the solar still increases the daily yield of freshwater and enhances the system efficiency, both in winter and summer. Additionally, the cost of producing freshwater is reduced when using sand and wire mesh **Hardik K. Jani et al.[24]**, The paper presents an experimental evaluation of a double slope single basin solar still with circular and square cross-sectional hollow fins. The performance of the solar still was tested at a specific location, and the productivity was measured for different water depths in the basin. The results showed that a water depth of 10mm was the most productive for both types of solar stills. The circular finned solar still achieved a maximum distilled water output of 1.4917 kg/m2-day, while the square finned solar still achieved a maximum output of 0.9672 kg/m2-day. The addition of fins on the absorber plate of the solar still led to higher productivity without increasing the basin area. The higher desalinated water output for the 10mm water depth was attributed to a higher fraction of heat transferred from the absorber plate to the thin layer of water. The cost analysis showed that the payback period for the solar still setup was 342 operating days, equivalent to 1.37 years. **Hardik K. Jani et al. [25],** Solar desalination is a method used for purifying saline water, and the device used for this purpose is called a solar still. The yield of potable water from single slope solar stills is low, so dual slope solar stills have been developed to increase productivity. Different glass cover geometries have been studied to maximize solar radiation to the absorber plate, and various methods have been explored to improve heat transfer from the absorber plate to the basin water, such as using nanofluids, corrugated absorber plates, and fins attached to the absorber plate. **Abd Elnaby Kabeel et al. [26],** The study focuses on enhancing the performance of pyramid solar stills by using hollow circular fins and phase change materials (PCM) Experimental tests were conducted on three types of pyramid solar stills: conventional, with hollow circular fins, and with hollow circular fins and PCM. The tests were carried out under Egyptian weather conditions with a constant saline water depth of 2 cm. The results showed that the addition of hollow circular fins increased the daily productivity by 43%, while the addition of PCM further enhanced the daily productivity by 1015%. The modified pyramid solar still with hollow circular fins and PCM demonstrated efficient performance compared to previous experimental and theoretical studied **Abd Elnaby Kabeel et al.[27],** The study aims to enhance the performance of a tubular solar still by using v-corrugated absorbers and wick materials to maximize evaporation and increase distillate water productivity. The modified design with v-corrugated wick materials showed a 44.82% improvement in distillate production and a 46.86% improvement in average efficiency compared to the conventional tubular still.

3. MATHEMATICAL MODELS AND EQUATIONS

3.1. Solar Radiation Model

One of the fundamental equations in this field deals with the estimation of solar radiation incident on a flat plate collector. The most commonly used model for this is the **Hottel-Whillier-Bliss (HWB)** equation:

$$I_t = I_0 \cdot \exp\left(-\tau \cdot X / \sin(\beta)\right)$$

Where:

- I_t is the solar radiation incident on the collector (W/m²).
- I_0 is the extraterrestrial solar radiation on a horizontal surface (W/m²), typically calculated using solar geometry equations.
- τ is the transmissivity factor, representing the optical efficiency of the cover or glazing.
- X is the thickness of the cover material (m).

β is the tilt angle of the collector (degrees).

3.2. Collector Efficiency Model:

The efficiency of a flat plate collector is crucial in determining its performance. The efficiency model considers various losses, including heat losses and optical losses. The overall efficiency (η) can be expressed as:

$$\eta = Q_c / A \cdot I_t$$

Where:

- Q_c is the useful heat output from the collector (W).
- A is the area of the collector (m²).

The collector efficiency depends on parameters like the collector's heat removal factor (F_r), the collector heat loss coefficient (U_l), and the collector heat gain factor (F_{RUL}).

3.3. Energy Balance Equation:

The energy balance equation for a solar water heater relates the heat absorbed by the collector to the heat supplied to the water. It can be expressed as:

$$Qc=A\cdot I_t\cdot \eta-U_l\cdot A\cdot (T_c-T_a)$$

Where:

- Q_c is the useful heat output from the collector (W).
- A is the area of the collector (m²).
- I_t is the solar radiation incident on the collector (W/m²).
- η is the collector efficiency.
- U_l is the collector heat loss coefficient (W/(m²·K)).
- T_c is the collector's temperature (K).
- T_a is the ambient temperature (K).

These equations are fundamental in analysing and designing solar water heater systems with flat plate collectors. Researchers and engineers often use software tools like TRNSYS, SAM (System Advisor Model), or MATLAB to perform simulations and calculations involving these equations in practical applications. Feel free to use LaTeX or a similar tool to format these equations for your specific needs.

4. COMPUTATIONAL FLUID DYNAMICS (CFD)

4.1. Governing Equations:

The governing equations for a CFD model of a solar water heater with flat plate collectors include the following:

4.1.1. Continuity Equations (Mass Conservation)

This equation describes how mass is conserved within the system.

$$\partial \rho/\partial t+\nabla\cdot(\rho \mathbf{V}) =0$$

Where:

- ρ is the fluid density.
- $\mathbf{V}$ is the velocity vector.

4.1.2. Navier-Stokes Equations (Momentum Conservation):

These equations describe the conservation of momentum within the fluid.

$$\partial(\mathbf{V}\rho)/ \partial t +\nabla\cdot(\rho\mathbf{VV}) =-\nabla P+\nabla\cdot(\tau)+\rho\mathbf{g}$$

Where:

- P is the pressure.
- τ is the stress tensor.
- $\mathbf{g}$ is the gravitational acceleration vector.

4.1.3. Energy Equation:

This equation governs the temperature distribution within the system, taking into account heat transfer mechanisms.

$$\partial(\rho E)/ \partial t +\nabla\cdot(\rho E\mathbf{V}) =\nabla\cdot(k\nabla T) +\rho\mathbf{V}\cdot\nabla T+Q$$

Where:

- E is the total energy per unit mass.
- k is the thermal conductivity.
- T is the temperature.
- Q represents heat sources or sinks.

4.2. Boundary Conditions

To complete the CFD model, you'll need to specify appropriate boundary conditions for the fluid flow, heat transfer, and radiation within the solar water heater system. This includes conditions at the inlet and outlet, as well as conditions for the flat plate collector, heat exchanger, and other components.

4.3. Turbulence Model

Turbulence models in Computational Fluid Dynamics (CFD) are used to simulate the behavior of turbulent flows, which are characterized by chaotic and swirling motion. These models provide a way to predict the distribution of turbulence properties within a fluid domain. One commonly used turbulence model is the Reynolds-Averaged Navier-Stokes (RANS) model. Here's an explanation of the RANS model with its key equations:

4.3.1. Reynolds Averaged Navier Stokes (RANS) Models:

The RANS model aims to predict the time-averaged flow properties, including velocity and pressure, as well as the turbulent properties, such as turbulence kinetic energy (k) and turbulent dissipation rate (ε). The key equations of the RANS model are the Reynolds-averaged Navier-Stokes equations, along with equations for turbulence quantities:

Reynolds-Averaged Navier-Stokes Equations (RANS Equations):

The Reynolds-averaged Navier-Stokes equations are based on the decomposition of flow variables into mean and fluctuating components. The equations for the mean velocity components (u, v, w) and pressure (P) are as follows:

- Continuity Equation (for incompressible flow):

$\nabla \cdot \mathbf{U}=0$

- Momentum Equations (for the x, y, and z directions):

$\partial(u)/\partial t+(u\cdot\nabla)u=-1/\rho(\nabla P)+v\nabla^2 u-\partial(u'u')/\partial x- \partial(u'v')/\partial y - \partial(u'w')/\partial z + \partial(\tau ij)/\partial x$

(Similar equations for v and w)

Where:

- $\mathbf{U}=(u,v,w)$ is the mean velocity vector
- ρ is the fluid density
- v is the kinematic viscosity
- P is the mean pressure
- $u'u'$, $u'v'$, $u'w'$, and τij represent the Reynolds stresses (turbulent components of the stress tensor), which are modelled based on turbulence models.

Turbulence Quantities Equations (k-ε Model):

In a k-ε turbulence model, two additional transport equations are solved to predict turbulence kinetic energy (k) and the turbulent dissipation rate (ε):

- Transport Equation for Turbulence Kinetic Energy (k):

$\partial(k)/ \partial t +(u\cdot\nabla)\ k=\partial/\partial x_j\ [(v+vt)\ \partial k/\partial x_j] -u_i'u_j'\ \partial u_i/\partial x_j -\rho\epsilon$

- Transport Equation for Turbulent Dissipation Rate (ε):

$\partial(\epsilon)/ \partial t +(u\cdot\nabla)\ \epsilon= \partial/\partial x_j\ [(v+v_t)\ \partial\epsilon/\partial x_j] +C_1\epsilon/k\ [2ui'uj'\ \partial k/\partial x_j] -C_2\rho\epsilon^2/k$

Where:

- v_t is the turbulent viscosity, typically modelled as $v_t = C\mu k^2/\epsilon$
- C_1 and C_2 are model constants
- $u_i'u_j'$ represents the Reynolds stresses

5. CONCLUSION

In conclusion, solar water heaters with flat plate collectors represent a remarkable fusion of renewable energy technology and sustainable heating solutions. These systems offer a promising pathway towards reducing our reliance on fossil fuels, mitigating environmental impacts, and lowering energy costs. Throughout this discussion, we've explored the key principles and components of these systems, touching upon essential mathematical models and Computational Fluid Dynamics (CFD) considerations.

Solar water heaters, driven by the inexhaustible power of the sun, embody our commitment to a cleaner and more sustainable future. The flat plate collector, at the heart of these systems, is a testament to ingenious design simplicity coupled with high efficiency. It plays a pivotal role in capturing solar radiation and converting it into usable thermal energy, thereby meeting our daily water heating needs with minimal environmental impact.

The mathematical equations associated with solar water heaters, including those governing solar radiation, collector efficiency, and energy balance, provide the foundation for understanding and optimizing these systems. These equations facilitate the prediction of system performance under various conditions and guide engineering decisions aimed at improving efficiency and reliability.

Moreover, the development of Computational Fluid Dynamics (CFD) models for solar water heaters opens new horizons for in-depth analysis and optimization. Incorporating the Navier-Stokes equations, energy equations, and turbulence models, CFD simulations offer insights into fluid flow patterns, temperature distributions, and system efficiency, enabling engineers to fine-tune design parameters and improve overall performance.

In our pursuit of a sustainable future, solar water heaters with flat plate collectors stand as a symbol of innovation and environmental responsibility. Their deployment not only reduces carbon emissions and energy costs but also aligns with global efforts to combat climate change. As we continue to advance our understanding and application of these technologies, we move closer to a world where clean, renewable energy sources like the sun play a central role in meeting our energy needs.

In essence, the journey of harnessing solar energy for water heating epitomizes our aspiration for a greener, more efficient, and environmentally conscious world. The sun, as an abundant and perennial energy source, offers boundless opportunities for us to create a sustainable and resilient future. Through ongoing research, technological innovation, and practical implementation, we are poised to unlock even greater potential in the realm of solar water heaters, forging a brighter and cleaner path for generations to come.

REFERENCES

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

Energy Storage 41, 102933. https://doi.org/10.1016/j.est.2021.102933.

[2] Abdelgaied, M., Zakaria, Y., Kabeel, A.E., Essa, F.A., 2021. Improving the tubular solar still performance using square and circular hollow fins with phase change materials. J. Energy Storage 38, 102564.

[3] Abdullah, A.S., 2013. Improving the performance of stepped solar still. Desalination 319, 60–65. https://doi.org/10.1016/j.desal.2013.04.003.

[4] Abdullah, A.S., Younes, M.M., Omara, Z.M., Essa, F.A., 2020. New design of trays solar still with enhanced evaporation methods – Comprehensive study. Sol. Energy 203, 164–174. https://doi.org/10.1016/j.solener.2020.04.039.

[5] Abujazar, M.S.S., Fatihah, S., Lotfy, E.R., Kabeel, A.E., Sharil, S., 2018. Performance evaluation of inclined copper-stepped solar still in a wet tropical climate. Desalination 425, 94–103. https://doi.org/10.1016/j.desal.2017.10.022

[6] Alaian, W.M., Elnegiry, E.A., Hamed, A.M., 2016. Experimental investigation on the performance of solar still augmented with pin-finned wick. Desalination 379, 10–15. https://doi.org/10.1016/j.desal.2015.10.010.

[7] Ali, C., Rabhi, K., Nciri, R., Nasri, F., Attyaoui, S., 2015. Theoretical and experimental analysis of pin fins absorber solar still. Desalin. Water Treat. 56, 1705–1711. https://doi.org/10.1080/19443994.2014.956344.

[8] Alsaiari, A.O., Shanmugan, S., Abulkhair, H., Bamasag, A., Moustafa, E.B., Alsulami, R.A., Ahmad, I., Elsheikh, A., 2022. Applications of TiO2/Jackfruit peel nanocomposites in solar still: Experimental analysis and performance evaluation. Case Stud. Therm. Eng. 38, 102292.

[9] Benhadji Serradj, D.E., Anderson, T.N., Nates, R.J., 2021. The use of passive baffles to increase the yield of a single slope solar still. Sol. Energy 226, 297–308. https://doi.org/10.1016/j.solener.2021.08.054.

[10] D'Cotha, J.S., Sajeesh, P., Suresh, P.R., Jithu, J., 2021. Inherent configuration characteristics altering the distillate enhancement of passive stepped solar still: A review. J. King Saud Univ. – Eng. Sci. https://doi.org/10.1016/j. jksues.2021.10.001.

[11] El-Agouz, S.A., 2014. Experimental investigation of stepped solar still with continuous water circulation. Energy Convers. Manag. 86, 186–193. https://doi.org/10.1016/j.enconman.2014.05.021.

[12] El-Naggar, M., El-Sebaii, A.A., Ramadan, M.R.I., Aboul-Enein, S., 2016. Experimental and theoretical performance of finned-single effect solar still. Desalin. Water Treat. 57, 17151–17166. https://doi.org/10.1080/ 19443994.2015.1085451.

[13] El-Sebaii, A.A., Ramadan, M.R.I., Aboul-Enein, S., El-Naggar, M., 2015. Effect of fin configuration parameters on single basin solar still performance. Desalination 365, 15–24. https://doi.org/10.1016/j.desal.2015.02.002.

[14] El-Sebaii, A.A., Shalaby, S.M., 2015. Parametric study and heat transfer mechanisms of single basin v-corrugated solar still. Desalin. Water Treat. 55, 285–296. https://doi.org/10.1080/19443994.2014.913998.

[15] Elashmawy, M., Ahmed, M.M.Z., 2021. Enhancing tubular solar still productivity using composite aluminum/copper/sand sensible energy storage tubes. Sol. Energy Mater. Sol. Cells 221, 110882.

[16] Elsheikh, A.H., El-Said, E.M.S., Abd Elaziz, M., Fujii, M., El-Tahan, H.R., 2023. Water distillation tower: Experimental investigation, economic assessment, and performance prediction using optimized machine-learning model. J. Clean. Prod. 388, 135896.

[17] Elsheikh, A.H., Katekar, V.P., Muskens, O.L., Deshmukh, S.S., Elaziz, M.A., Dabour, S.M., 2021. Utilization of LSTM neural network for water production forecasting of a stepped solar still with a corrugated absorber plate. Process Saf. Environ. Prot. 148, 273–282. https://doi.org/10.1016/j.psep.2020.09.068.

[18] Elsheikh, A.H., Panchal, H., Ahmadein, M., Mosleh, A.O., Sadasivuni, K.K., Alsaleh, N.A., 2021. Productivity forecasting of solar distiller integrated with evacuated tubes and external condenser using artificial intelligence model and moth-flame optimizer. Case Stud. Therm. Eng. 28, 101671.

[19] Elsheikh, A.H., Sharshir, S.W., Ahmed Ali, M.K., Shaibo, J., Edreis, E.M.A., Abdelhamid, T., Du, C., Haiou, Z., 2019. Thin film technology for solar steam generation: A new dawn. Sol. Energy 177, 561–575. https://doi.org/10.1016/j. solener.2018.11.058.

[20] Ghandourah, E., Panchal, H., Fallatah, O., Ahmed, H.M., Moustafa, E.B., Elsheikh, A.H., 2022. Performance enhancement and economic analysis of pyramid solar still with corrugated absorber plate and conventional solar still: A case study. Case Stud. Therm. Eng. 35, 101966 https://doi.org/10.1016/j. csite.2022.101966.

[21] Ghandourah, E., Prasanna, Y.S., Elsheikh, A.H., Moustafa, E.B., Fujii, M., Deshmukh, S.S., 2023. Performance prediction of aluminum and polycarbonate solar stills with air cavity using an optimized neural network model

by golden jackal optimizer. Case Stud. Therm. Eng. 47, 103055.

[22] Ghandourah, E.I., Sangeetha, A., Shanmugan, S., Zayed, M.E., Moustafa, E.B., Tounsi, A., Elsheikh, A.H., 2022. Performance assessment of a novel solar distiller with a double slope basin covered by coated wick with lanthanum cobalt oxide nanoparticles. Case Stud. Therm. Eng. 32, 101859.

[23] Hassan, H., Ahmed, M.S., Fathy, M., 2019. Experimental work on the effect of saline water medium on the performance of solar still with tracked parabolic trough collector (TPTC)c. Renew. Energy 135, 136–147. https://doi.org/ 10.1016/j.renene.2018.11.112.

[24] Jani, H.K., Modi, K.V., 2019. Experimental performance evaluation of single basin dual slope solar still with circular and square cross-sectional hollow fins. Sol. Energy 179, 186–194. https://doi.org/10.1016/j.solener.2018.12.054.

[25] Jani, H.K., Modi, K.V., 2018. A review on numerous means of enhancing heat transfer rate in solar-thermal based desalination devices. Renew. Sustain. Energy Rev. 93, 302–317. https://doi.org/10.1016/j.rser.2018.05.023.

[26] Kabeel, A.E., El-Maghlany, W.M., Abdelgaied, M., Abdel-Aziz, M.M., 2020. Performance enhancement of pyramid-shaped solar stills using hollow circular fins and phase change materials. J. Energy Storage 31, 101610.

[27] Kabeel, A.E., Harby, K., Abdelgaied, M., Eisa, A., 2021. Performance improvement of a tubular solar still using V-corrugated absorber with wick materials: Numerical and experimental investigations. Sol. Energy 217, 187–199. https://doi.org/10.1016/j.solener.2021.02.008.