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A Review of Heat Transfer Enhancement Techniques in Thermosyphon Solar Water Heating Systems

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Abstract - Interest in transitioning to renewable energy sources, particularly solar energy, has surged due to its clean nature and ability to meet thermal and electric needs while minimizing environmental pollution and global warming risks. Thermosyphon Solar Water Heating Systems (TSWHS) are noted for their efficiency in converting solar radiation to thermal energy. Research primarily focuses on enhancing heat transfer, categorized into active methods utilizing external energy sources - and passive methods, which improve transfer by modifying flow geometry through techniques like fins, twisted tapes, adding a nanofluid, or dual-layer staggered pipes.

1. INTRODUCTION

A variety of scholars have examined both experimental and numerical research as methods for improving solar water heater efficiency. They have examined many strategies, including geometric modifications and the utilization of diverse working fluids. These initiatives, especially with flat plate collectors, aim for optimal results as researchers contribute to the advancement of the field and the full exploitation of solar water heating systems. The research was classified as either experimental or numerical; the experimental studies were further grouped based on the specific study and enhancement technique utilized in the Thermosyphon solar water heating system (TSWHS).

2. LITERATURE REVIEW

2.1 Experimental studies

2.1.1 Improved by geometry

Aldulaimi, R.A.K.M. [1] This research focused on analyzing pressure differences and temperature distributions for fluid flow in a novel twisted tube design, utilizing both overlapping and reverse flow with five variations of receiver tube models. The study highlighted that single twisted tube (STT) models showed significant improvements in heat transfer performance, while the triple twisted tube (TTT) model, featuring an overlapping design, outperformed conventional designs. Notably, the TTT model demonstrated increased pressure differentials and higher efficiency, achieving a performance enhancement of 38.528% to 42.917% compared to standard models. The collector efficiency and pressure loss were assessed using the Nusselt number and the modified thermal coefficient of performance.

Abdulaziz A. Moshab and Aldulaimi, R.A.K.M. [2] A proposed absorber tube was designed to improve the solar energy capture efficiency of a thermosiphon water heating system (TSWHS) and validated through experiments. The first set analyzed temperature and pressure differences due to fluid flow, including the Nusselt number (Nu) and energy efficiency coefficient (EEC). Five receiver tube models were tested at various flow rates (100–250 mL/min) and flow directions. Model Rt4, featuring a 12 mm inner and 35 mm outer tube with py flow, achieved a thermal efficiency of 70.5%. The second validation compared model Rt4's performance within a flat-plate collector against a standard model, yielding a 17% enhancement in the temperature gradient of the horizontal tank, indicating improved heat transfer compared to traditional designs.

Himangshu Bhowmik and Ruhul Amin [3] presents a technology to enhance the efficiency of solar thermal collectors. Their prototype solar water heating system features an adjustable reflector that improves reflectivity and optimizes sunlight concentration, leading to a 10% increase in collection efficiency. This system exhibits the highest thermal efficiency among existing solar water heating systems.

Ra'ad K. Mohammed Aldulaimi [4] a novel experimental model proposed to improve solar thermal dish collector receivers' energy absorption. The model features a two-layer staggered arrangement of multiscale diameter tubes. It utilizes inactive zones of the solar receiver, optimizing performance by positioning the pipes to maximize direct solar radiation exposure in areas with weak absorption. Examining five models, the Dcr5 model showed improved energy transfer to the heat transfer fluid (HTF) with a staggered diameter ratio of 0.269, resulting in increases in thermal efficiency (η_{th}) and exergetic performance (η_{ex}) by 78.8% and 19.8%, respectively, at a flow rate of 0.07 kg/s.

S. Jaisankar et al. [5] conducted experiments on the heat transfer characteristics of a thermosyphon solar water heater with a uniform twist ratio (Y = 3) using helical and Left-Right twisted tape geometries. The study revealed that both twisted collectors enhance heat transfer compared to a standard tube collector, with the Left-Right twisted tape collector achieving a 375% increase in heat transfer and friction factor, outperforming the helical twisted tape collector. Overall, the Left-Right design significantly enhances thermal performance in solar water heaters.

J. Ananth and S. Jaisankar [6] A detailed study has been done into the effects of regularly spaced left-right tube inserts, along with rods and spacers, on the heat transfer and friction factor characteristics in a thermosiphon solar water heater. An attempt has been made to look into the possibility of applying customized designs with left-right twist as tube insert and to

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increase the internal convective heat transfer with reduced pressure drop between the tube wall and fluid in the collector. The modified twist designs reduce the pressure drop by 47.2% to 8.9% compared to the full-length twist and enhance the total instantaneous thermal efficiency by 53.3% to 38.7% relative to the plain tube collector.

S. Jaisankar et al. [7] conducted experimental research on heat transfer and friction factor in a thermosyphon solar water heater featuring a full-length Left-Right twist, with modifications using a rod and spacer. The study analyzed configurations with lengths of 100, 200, and 300 mm at twist ratios of 3 and 5. Results indicated deviations of ±7.41% for the Nusselt number and ±14.97% for the friction factor compared to theoretical equations. Using a rod decreased the Nusselt number by 11%, and the spacer by 19%, while the friction factor dropped by 18% and 29%, respectively. The enhancement in heat transfer was greater with the rod than with the spacer due to the swirling flow created by the rod.

A. Saravanan et al. [8] conducted experiments on the thermal performance and friction factor of a V-trough thermosyphon solar water heater incorporating helical twisted tapes at various twist ratios (Y=3, 4, 5, & 6). Results showed that the V-trough system (PVT) outperformed the flat plate (PFP) system, with a difference of ±15.06% in the Nusselt number and ±3.91% in the friction factor when compared to basic equations. The enhanced thermal performance of the PVT collector is attributed to increased solar concentration due to reflected components, while the helical twisted tape induces a swirling flow that improves pressure drop and thermal efficiency, achieving a 19.01% increase at a minimum twist ratio of 3.

Jinbao Huang et al [9] show the analysis of a thermosyphon flat-plate solar water heater with a mantle heat exchanger revealed that its mean daily efficiency can reach up to 50%. This efficiency is higher than that of an all-glass evacuated tubular solar water heater but lower than that of standard flat plate models.

Yi He et al [10] examine how size influences strategies to enhance thermal performance, using numerical simulation models to analyze microchannel structural characteristics and flow resistance. Experimental evaluations confirmed the numerical model's accuracy. Results show that enlarging microchannels and increasing corrugation height can boost thermal efficiency up to 86.10%. The stainless-steel microchannel ensures consistent temperature distribution, optimizing heat absorption and improving FPSC durability.

Koholé Yemeli Wenceslas and Tchuen Ghislain [11] this study conducts a flat-plate solar collector used in thermosyphon solar water heating systems, analyzing its performance based on various construction factors such as absorber plate thickness, spacing of absorber tubes, and insulation thickness. The theoretical model was validated by empirical data, showing that increased plate thickness (0.005 m) allows aluminum to perform similarly to copper, while increasing insulation thickness to 0.05 m significantly reduces heat loss coefficient, improving system efficiency.

Kabas Aziz Hassan and Raad K. Mohammed Al Dulaimi [12] this thesis investigates methods to enhance the heat transfer efficiency of a flat plate thermosyphon solar water heater by integrating a twisted tape into one of the tube models, comparing it with regular and twisted tube types. Through experimental evaluation, the twisted tube with twisted tapes demonstrated superior thermal performance and self-circulation. Notably, the most effective design achieved a Nusselt number (Nu) of 913.71, an exergy efficiency (ηex) of 0.25%, and a thermal efficiency (ηth) of 0.81%.

2.1.2 Improvement by geometry and nanofluids

Hossein Nabi et al [13] this study examines the use of hybrid nanofluids and turbulence-inducing elements to enhance convective heat transfer in flat plate solar collectors. It comprises three stages: first, a comparison of various turbulence-inducing parts against a Base pipe, showing that CASE 3 significantly improves heat transmission by 31.31% and 31.06% at Reynolds numbers of 10,000 and 4,000, respectively. The second stage evaluates different hybrid nanofluids, revealing that SWCNT-CuO/H2O hybrid nanofluids have a superior heat transfer coefficient. The third stage finds that at a Reynolds number of 4000, a 5% concentration of hybrid nanofluids increases the heat transfer coefficient by 8.79%.

Gianpiero Colangelo et al [14] this study evaluated thermal efficiency in a modified flat panel solar thermal collector using two heat transfer fluids: distilled water and a 3.0% volume fraction Al2O3-distilled water nanofluid. The modified design minimizes nanoparticle cluster deposits, allowing the use of high-concentration nanofluids. Efficiency calculations showed that using distilled water resulted in thermal efficiency values between 0.4921 and 0.3285, while the nanofluid produced efficiencies ranging from 0.5412 to 0.4570. The Al2O3-nanofluid demonstrated a 7% higher efficiency compared to distilled water, especially at elevated temperatures, highlighting the advantages of nanofluids in improving collector performance.

H. Yahyazadeh and M. Gorji [15] show the effects of using Helium and Argon gases in the layers of a Gas Filled Double Glazed Flat Plate Solar Collector (GFDGFPSC), which enhances heat gain and reduces heat loss, resulting in a 12.39% performance improvement over an Air Filled Double Glazed Flat Plate Solar Collector (AFDGFPSC). At a 60° angle, AFDGFPSC efficiency increased by 6.09%, while GFDGFPSC improved by 2.88%. The development of inner optical thickness significantly boosts GFDGFPSC performance to 53.44%, with increases in both optical thicknesses elevating efficiency further.

L.S. Sundar et al [16] this research evaluates the effect of nanofluids on the thermal performance of flat plate collectors, particularly regarding thermal efficiency. Various water-based mono and hybrid nanofluids were assessed for their potential to enhance efficiency and reduce solar collector costs for residential and industrial applications. The study analyzed parameters such as Nusselt number, friction factor, and thermal efficiency, revealing that while increasing volume fraction initially improved efficiency, excessive concentration led to decreased efficiency due to increased viscous forces and reduced heat transfer. The enhanced thermal conductivity from nanofluids was identified as the main contributor to improved collector efficiency, although the specific mechanisms remain unclear. Notably, carbon nanotubes and carbon nanohorns produced the highest efficiency levels, and better performance at higher temperatures was observed with nanofluids compared to water.

Ahmed M. Ajeena et al [17] examine the impact of SiC/distilled water nanofluids on the thermal and exergy efficiency of a solar collector flat plate. The nanofluid was produced by infusing distilled water with SiC nanoparticles (45 to 60 nm) at volume fractions of 0.025%, 0.05%, 0.075%, and 0.1%. Key assessments of thermophysical properties and stability were performed. The solar collector tests were carried out at mass flow rates ranging from 0.025 to 0.041 kg/s. Results showed that SiC nanoparticles improved the thermal conductivity up to 30.3%. At a 0.1% volume fraction and 0.041 kg/s flow rate, peak thermal efficiency reached 77.43%, a 35.53% increase over the base liquid. Additionally, exergy efficiency increased by 37.4% compared to distilled water at the same volume fraction.

Mostafa AbdEl-Rady Abu-Zeid et al [18] this research compares two solar collector systems: Flat Plate Solar Collector (FPSC) and Parabolic Through Solar Collector (PTSC), examining the impact of nanofluids on solar water heating performance. Evaluations were made at flow rates of 0.47, 1.05, and 1.75 kg/min, focusing on thermal efficiency, useful energy gain, stored energy, outlet hot water temperature, and temperature differential. The findings revealed that PTSC outperformed FPSC. Utilizing ethylene glycol nanofluid, the average thermal efficiencies were 64.1% for FPSC and 80.6% for PTSC. Additionally, CO2 emissions decreased by 31.26 kg/day for FPSCs and 39.28 kg/day for PTSCs with the presence of ethylene glycol nanofluid, highlighting the significant role of solar collectors in reducing emissions.

R. Venkatesh et al [19] this study enhances desalination efficiency by combining flat plate collectors with conventional still systems and using hybrid nanofluids. These nanofluids, comprised of alumina (Al2O3), silicon dioxide (SiO2), and copper oxide (CuO) nanoparticles at 0.3% concentration, showed that Al2O3/CuO has superior thermal conductivity (0.631 W/m.K), exergy (6.7%), and thermal efficiencies (61.4%). This approach addresses the critical issue of water scarcity.

Jalaluddin et al [20] this research examines the effectiveness of a solar water heating system that uses an Al + Al2O3 composite for thermal storage in flat-plate collectors. The study compares a conventional collector with one utilizing the composite, revealing that the composite model significantly enhances thermal efficiency. Specifically, the model with 35% alumina and 65% aluminum demonstrates improvements of 5.1% at 0°, 7.5% at 10°, and 2.5% at a 30° angle. However, higher alumina concentration negatively affects the thermal properties of the composite.of the current designations.

2.2 Experimental and Numerical studies.

Tiko Rago Desisa [21] this study explores heat transfer improvements in a flat plate collector using Al_2O_3/water, Ti_2O/water, and Si_2O/water nanofluids at 1%, 2%, and 3% concentrations with a parallel tube setup. Experiments involved mass flow rates of 0.1 to 0.4 kg/min and nanoparticles with diameters of 15–50 nm. Results showed CuO produced the highest enhancement, while Si_2O had the least. Increasing both the concentration and mass flow rate bolstered the thermal efficiency, with a notable 32.1% rise in efficiency for 1% Al_2O_3-water nanofluid when the flow rate increased from 0.1 to 0.4 kg/min. At a steady rate with 1% concentration, CuO and Al_2O_3 exhibited thermal efficiencies of 46% and 43.8%, respectively.

Basim Freegah et al [22] this research investigates and compares the thermal reaction of conventional and novel solar flat plate collectors using computational and experimental methods. The new design features longitudinal channels and curvy fins, with elliptical riser pipes aimed at increasing the solar radiation exposure. Results show that the novel model outperformed the conventional one, achieving a 23.6% higher liquid temperature in the container, a 7.9% greater mass flow rate, and a 22.4% increase in overall thermal efficiency.

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