

Comparative Study of Thermal Performance of a Copper Flat-Plate Solar Water Heater at Various Tilt Angles

CH Sai Sandeep¹, N.V. Narasimha Rao², N. Alagappan³, CH V K N S N Moorthy⁴, Markndeyulu Vuggirala⁵

^{1,2,5}Department of Mechanical Engineering, St. Ann's College of Engineering and Technology, Chirala, 523187, Andhra Pradesh, India

³Department of Mechanical Engineering, Annamalai University, 608002, Tamil Nadu, India

⁴Department of Mechanical Engineering Vasavi College of Engineering, Ibrahim Bagh 500031, Telangana, India.

Abstract- The demand for solar water heaters is steadily rising, driven by rapid urbanization, supportive government policies, low installation costs, and their eco-friendly role as an alternative to conventional fossil fuels. In recent years, significant progress has been made in the research and development of solar energy technologies. However, the selection of an appropriate solar system remains crucial for achieving efficient energy utilization in domestic water heating applications. This study investigates the performance of a solar water heater integrated with a flat plate collector, using pure water as the working fluid. The system is evaluated at different flow rates of 60, 90, and 120 kg/hr, and at tilt angles of 25° and 45°, to assess their impact on thermal efficiency. The findings reveal that the system performance is strongly influenced by both the flow rate and the collector inclination. Based on the observed results, suitable recommendations are provided, and conclusions are drawn to improve the overall efficiency of solar water heating systems.

Key words: Solar water heater, Copper tubes, Absorber plate, Thermocouples.

1. INTRODUCTION

Solar water heating systems using flat plate collectors (FPCs) have been extensively studied due to their simplicity, cost-effectiveness, and suitability for domestic applications. Among the various parameters affecting their performance, tilt angle plays a critical role in determining the amount of solar radiation incident on the collector surface and, consequently, the thermal efficiency.

Early studies have established that the orientation and inclination of solar collectors significantly influence energy absorption. Research shows that the tilt angle directly affects the intensity of solar radiation received, and optimizing this angle can maximize energy capture and reduce environmental impact. It is generally recommended that collectors face south (in the northern hemisphere) with a tilt angle close to the local latitude for year-round performance.

J. Manikandan [1] An experimental investigation was conducted on a double-glazed flat plate solar water heater using different absorber plate geometries, namely flat plate, V-grooved, and square pulse designs. Mild steel absorber plates with dimensions of $1.42 \times 0.7 \text{ m}^2$ were utilized. Two glass covers of the same size were provided to minimize heat loss to the surroundings. The performance of the system was evaluated for different absorber geometries at mass flow rates of 0.0041, 0.0083, and 0.0125 kg/s. The results indicated that the flat plate absorber exhibited higher temperature, greater thermal efficiency, and increased heat gain by the water compared to the other geometries during the experiments. Ruhul Amin [2] A reflector was integrated with the solar collector to enhance its reflectivity and improve energy capture. The reflector directs both direct and diffuse solar radiation onto the collector surface, thereby increasing the intensity of incident radiation. To achieve maximum energy concentration, the reflector angle was adjusted throughout the day in accordance with the sun's position. The absorbed solar energy is converted into heat and subsequently transferred to the working fluid, water. The collector efficiency was found to be 51% without the reflector and increased to 61% with the reflector, indicating an approximate 10% improvement in overall efficiency due to the use of the reflector. Shiv Kumar Tripathi [3] An experimental study was conducted to evaluate the thermal performance of a flat plate collector solar water heater using low-cost, readily available circulating pumps. A solar water heater is a system that utilizes solar energy to provide hot water for applications such as bathing, washing, and cleaning. The results showed that the maximum outlet water temperature reached 50°C at 13:00 hours, with an overall system efficiency of 17%. J. Ramesh [4] studied the flat plate solar collector for hot water generation technology as it is very useful as it is used for approximately all solar energy applications such as steam and power generation, water heating, air heating etc. An experimental setup has been developed to investigate the performance of the solar flat plate collector. S Manavalan [5] studied the G.I. sheet collector boxes are replaced by copper tube, stainless steel water tank, thick costly PUF insulations and toughened glass. Pebbles are used as a medium of heat storage this increases the capacity of solar water heater. by using this method

natural sources of energy can be used instead of depending on electric water heaters. K. Hemachandra Reddy [5] investigations were carried out to analyze the performance characteristics of solar flat plate collectors with different selective surface coatings and varying concentrations of heat transfer fluid mixtures. The system performance was evaluated using a 40% propylene glycol–water mixture as the working fluid instead of conventional water, under different volume flow rates. Additionally, the effect of incorporating an ETFE foil between the absorber plate and the glass cover was examined, both with and without its presence. Ashish Khatwar [6] specific objective of this study is to find or develop new models and models that can improve the efficiency of the solar water heater. This investigation discusses improving the performance of a flat plate solar water heater by inserting the various type of insert in the riser tubes. They promote higher heat transfer coefficient by disturbing or altering the existing flow behaviour (except for extended surfaces) which also leads to increase in the pressure drop. S. Sandhya [7] Solar radiation incident at tilt angles ranging from 1° to 90° was simulated to determine the optimum annual tilt angle for different cities. Based on the results, a mathematical correlation was developed to estimate the optimal tilt angle for any location in India using its latitude. The findings of this study are expected to contribute significantly to the efficient utilization of solar energy and support sustainable development. N. Khedher [8] studied the thermal performance of a solar flat plate water heater under Hail weather conditions (latitude 27°52'N longitude 41°69'E) was experimentally investigated. Izhak Paul [9] reveals the different design of the flat collectors used to enhance the efficiency of the collector. The new technique of simulation gives the deep study of collector with the help of latest software like EES, TRANSYS, MATLAB, CFD to understand the losses and even the efficiency of collector soon, and by this the development ratio of new collector design can be increased to get the optimum value. Nilesh. P [10] the performance enhancement of flat plate collectors has been extensively studied through both analytical and experimental approaches. Various design improvements, such as reverse flat plate configurations, bifacial absorbers, and concentric collectors, have been implemented to minimize side and rear heat losses.

Ramani Kannan [11] studied the metaheuristic optimization technique, namely Search Group Algorithm (SGA), for energetic optimization of solar water heating systems using flat plate collectors (SWH-FPC). Sujit Kumar Verma [12] focused on synergistic approaches, processes, design criterions and advances in working fluids to achieve optimum thermal and exergy efficiency for solar collectors mainly flat plate solar collectors, evacuated tube collectors and concentrating collectors. Abdel-Rahman [13] studied the thermal performance of the FPSC using alumina oxide-water and copper oxide-water nano fluids. The effect of nanoparticle volume fraction and nanoparticle type are investigated theoretically and validated experimentally.

Elumalai Vengadesan [14] studied the serpentine copper tubes for water to have a more surface area and flow duration. Baffles are provided to increase air flow residence duration. In addition, multifunctional heat storage tubes are fixed on the absorber. The heat storage integrated collector's peak energy and exergy efficiencies are 88.8 % and 3.5 %, respectively, higher than the collector without heat storage at the water flow rate of 0.025 kg/s and air mass flow rate of 0.0132 kg/s. M A I Rahmadhani [15] investigated the performance of SWH numerical simulation by integrating phase change material paraffin wax onto an absorber plate collector at the bottom for thermal storage. Rasaiah Naveenkumar [16] integrated SWHs with storage collectors, combining SWHs with photovoltaic cells, integrating thermosyphon and twisted tapes, enriching collectors with nanofluids, phase change materials and using different types of evacuated tube solar collectors. Improvement in materials, design and operating conditions have led to performance enhancement of parabolic trough and linear Fresnel Solar collectors. performance and economic suitability, making them more viable and sustainable energy devices.

2. EXPERIMENTAL SETUP

The experiment is carried out to analyse the performance of a flat plate solar water heater. The setup includes a water tank, pump, and rotameter, which are used to regulate and measure the water flow. The investigation is performed by varying the flow rates (60, 90, and 120 kg/hr) and the collector tilt angles (25° and 45°) to study their influence on system performance. Copper tubes with fins act as the main flow passages, while the fins and black-coated absorber surface enhance solar heat absorption. Solar energy is absorbed by the collector and transferred to the water flowing through the tubes. Temperatures are measured at different points using thermocouples to evaluate the thermal behaviour of the system.

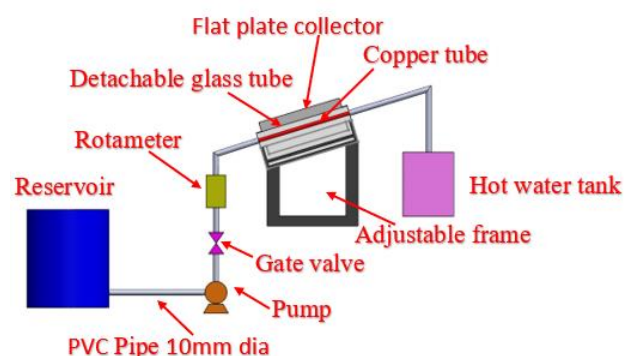


Fig-1: Solar water heater Experimental setup with names



Fig. a

Fig. b

Fig-2: Solar water heater for different Tilt angles a) 25° b) 45°

3. RESULTS AND DISCUSSIONS

3.1 Evaluation of Solar Water Heater Efficiency at Different Tilt Angles:

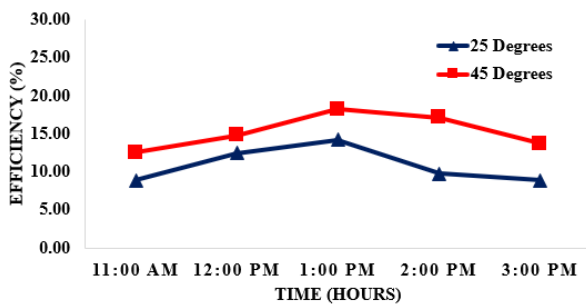


Fig-3: Efficiency Curve at a 25° and 45° Tilt Angle with a Flow Rate 60 Kg/hr

The graph Fig.3 illustrates how collector efficiency (%) varies with time for two tilt angles, 25° and 45°. At a 25° tilt angle, the efficiency begins at approximately 9% at 11:00 AM, rises to about 14% at 1:00 PM, and then decreases to nearly 9% by 3:00 PM. In comparison, the 45° tilt angle shows better performance throughout the day, starting at around 12–13%, peaking at 18–19% at 1:00 PM, and dropping to about 13–14% at 3:00 PM. Overall, the 45° tilt angle consistently provides higher efficiency than the 25° tilt angle. The maximum efficiency occurs at 1:00 PM, and the subsequent decline is due to reduced solar intensity and increased heat losses. Therefore, a 45° tilt angle is more effective for improving the performance of the solar collector.

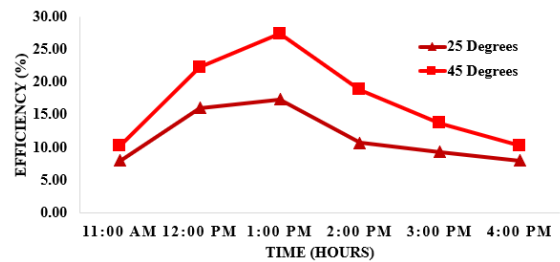


Fig-4: Efficiency Curve at a 25° and 45° Tilt Angle with a Flow Rate 90 Kg/hr

The graph Fig.4 shows how collector efficiency (%) changes with time for two tilt angles, 25° and 45°. At a 25° tilt angle, the efficiency starts at about 8% at 11:00 AM, rises to nearly 17% at 1:00 PM, and then declines steadily to around 8% by 4:00 PM. In contrast, the 45° tilt angle exhibits higher efficiency throughout the day. It begins at approximately 10% at 11:00 AM, increases significantly to about 27% at 1:00 PM, and then decreases to nearly 10% at 4:00 PM. Overall, the 45° tilt angle consistently performs better than the 25° tilt angle. The highest efficiency is observed at 1:00 PM, and the reduction afterward is due to decreasing solar intensity and increasing heat losses. Hence, the 45° tilt angle is more effective for improving collector performance.

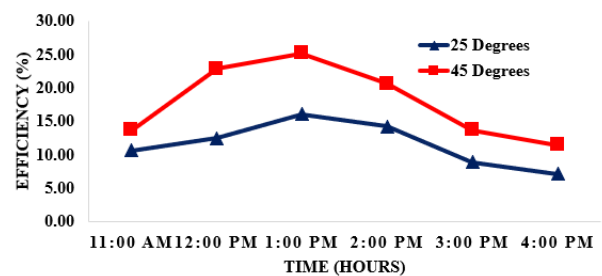


Fig-5: Efficiency Curve at a 25° and 45° Tilt Angle with a Flow Rate 120 Kg/hr

The graph Fig.6 depicts how collector efficiency (%) varies with time for two tilt angles, 25° and 45°. At a 25° tilt angle, the efficiency starts at around 10–11% at 11:00 AM, increases to approximately 16% at 1:00 PM, and then falls to about 7% by 4:00 PM. In comparison, the 45° tilt angle shows higher efficiency throughout the day. It begins at about 13–14% at 11:00 AM, rises significantly to nearly 25% at 1:00 PM, and then decreases to around 11–12% at 4:00 PM. Overall, the 45° tilt angle consistently outperforms the 25° tilt angle. The highest efficiency is observed at 1:00 PM, and the reduction afterward is due to decreasing solar intensity and increasing heat losses. Thus, the 45° tilt angle is more effective for improving collector performance.

3.2 Evaluation of Solar Water Heater Absorber Plate Temperature for at Different Flow rates:

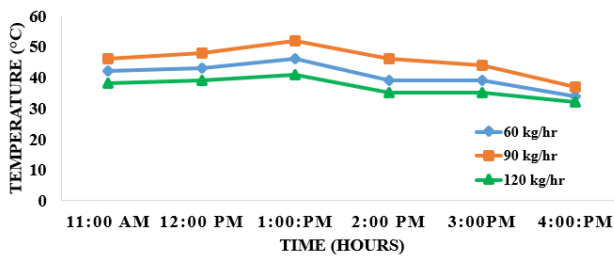


Fig-6: Absorber plate Temperature for Different flow rates (60, 90 and 120 Kg/hr) at 25 Degrees Tilt angle

The graph Fig.6 shows the variation of outlet water temperature with time for three different mass flow rates (60 kg/hr, 90 kg/hr, and 120 kg/hr) at 25 degrees Tilt angle. For all flow rates, the temperature increases from 11:00 AM and reaches a peak around 1:00 PM, after which it gradually decreases until 4:00 PM. This trend follows the solar radiation pattern, which is highest at midday and reduces in the afternoon. Among the three cases, the 90 kg/hr flow rate consistently produces the highest temperature at all times, with a maximum of about 52°C at 1:00 PM. The 60 kg/hr flow rate shows moderate performance, while the 120 kg/hr flow rate results in the lowest temperatures throughout the day. This behavior can be explained by the heat transfer characteristics of the system. At very high flow rates (120 kg/hr), the water moves quickly through the collector, reducing the residence time and limiting heat absorption, which leads to lower temperatures. At very low flow rates (60 kg/hr), although the water has more time to absorb heat, the overall heat transfer rate is lower due to reduced mass flow. The intermediate flow rate (90 kg/hr) provides an optimal balance between heat absorption and flow, resulting in higher outlet temperatures. Overall, the graph indicates that 90 kg/hr is the most effective flow rate for achieving higher thermal performance under the given conditions.

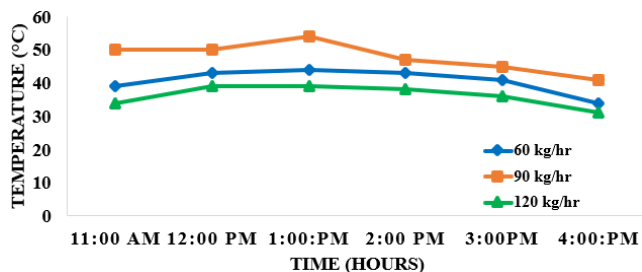


Fig-7: Absorber plate Temperature for Different flow rates (60, 90 and 120 Kg/hr) at 45 Degrees Tilt angle

The graph Fig.7 illustrates the variation of outlet water temperature with time for three different mass flow rates (60 kg/hr, 90 kg/hr, and 120 kg/hr). The temperature trend shows an initial increase from 11:00 AM, reaching near-

maximum values around 12:00 PM to 1:00 PM, followed by a gradual decline towards 4:00 PM. This pattern corresponds to the variation in solar radiation intensity, which peaks around midday and decreases in the afternoon. The 90 kg/hr flow rate consistently yields the highest temperatures throughout the day, starting at about 50°C at 11:00 AM and maintaining relatively higher values compared to the other flow rates. The 60 kg/hr flow rate shows moderate temperature values, peaking around 1:00 PM. In contrast, the 120 kg/hr flow rate produces the lowest temperatures at all time intervals. This behavior is due to the balance between heat transfer and residence time. At a higher flow rate (120 kg/hr), water passes quickly through the collector, reducing the time available for heat absorption, which results in lower outlet temperatures. At a lower flow rate (60 kg/hr), although the water has more time to absorb heat, the overall heat transfer rate is limited. The intermediate flow rate (90 kg/hr) provides an optimal balance, leading to better thermal performance and higher outlet temperatures. Overall, the graph indicates that 90 kg/hr is the most effective flow rate for achieving higher outlet temperatures under the given operating conditions.

4. CONCLUSIONS

The thermal performance of the solar flat-plate water heater with a copper absorber plate was evaluated between 11:00 AM and 4:00 PM. Copper tubes demonstrated superior performance compared to steel tubes due to their higher thermal conductivity. A tilt angle of 45° produced higher efficiencies than 25°. The maximum efficiency of 27.34% was recorded at a 45° tilt angle with a mass flow rate of 90 kg/hr, exceeding the performance at 60 kg/hr and 120 kg/hr as well as at the 25° tilt condition. The efficiency increased up to midday and then gradually declined in the afternoon, following the decrease in solar radiation intensity. A sharper reduction in efficiency after 1:00 PM suggests increased heat losses or reduced solar energy input. The absorber plate temperature reached a maximum of 54°C at 90 kg/hr for the 45° tilt angle, which is higher than that observed at 25°. At a higher flow rate (120 kg/hr), water flows quickly through the collector, reducing the time available for heat absorption and resulting in lower outlet temperatures. At a lower flow rate (60 kg/hr), although the residence time is longer, the overall heat transfer rate is relatively low. The intermediate flow rate (90 kg/hr) provides an optimal balance between residence time and heat transfer, leading to enhanced thermal performance and higher outlet temperatures.

REFERENCES

- [1] J. Manikandan, B. Sivaraman (2016) Experimental Analysis of Double-Glazed Flat Plate Solar Water Heater with Various Absorber Plate Geometries. International Energy Journal 16 (2016) 151-156.

- [2] Himangshu Bhowmika, Ruhul Amin (2017) Efficiency improvement of flat plate solar collector using reflector. *Energy Reports* 119-123.
- [3] Shiv Kumar Tripathi, Dr. Mohammad Azim Aijaz (2017) Experimental Study and Analysis of Flat Plate Solar Water Heater with Different Flow Rates using of Circulating Pump. *IJRST Vol.3, Issue 10* ISSN: 2349-6010.
- [4] J. Ramesh, J. Kanna Kumar, Dr. E.V Subbareddy (2017) Fabrication and Performance Evaluation of a Flat Plate Solar Collector Water Heater. *IJRSET Vol.6 Issue 4* ISSN (Print) : 2347-6710.
- [5] J J Jayakanth1, S Ramasubramanian, M Chandrasekaran and S Manavalan (2017) Investigation of solar water heater by using flat plate collector and evacuated tubes. *Materials Science and Engineering* 183, 012035.
- [6] Ashish Khatwar, Bittu Pathak (2017) To Investigate the Performance of a Flat Plate Solar Water Heater with Twisted Tape Insert and Without Insert. *IJMERM vol.5 issue 3* 26-32 ISSN: 2320-9984.
- [7] G. Jims John Wessley, R. Narciss Starbell, S. Sandhya (2017) Modelling of Optimal Tilt Angle for Solar Collectors Across Eight Indian Cities. *IJRES ,Vol. 7, No. 1* 353-358.
- [8] Nidhal Ben Khedher, N. Khedher (2018) Experimental Evaluation of a Flat Plate Solar Collector Under Hail City Climate. *Engineering, Technology & Applied Science Research* Vol. 8, No. 2, 2750-2754.
- [9] Prasad P. Patil1, Dr.D.S.Deshmukh, Dr. A. M. Vaidya, Izhak Paul (2018) A Review on Revolution of Flat Plate Collector for Solar Water Heater. *IJRASET Volume 6 Issue V* ISSN: 2321-9653 1427-1443.
- [10] Dr. Nilesh. P. Salunke, 2 J.S. Khatik (2018) A review on the recent advancements in improving the performance of the flat plate collector. *IJCRT Volume 6, Issue 1* ISSN: 2320-2882.
- [11] Truong Hoang Bao Huy, Perumal Nallagownden, Ramani Kannan, Vo Ngoc Dieu (2019) Energetic Optimization of Solar Water Heating System with Flat Plate Collector using Search Group Algorithm. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* Volume 61, Issue 2 306-322.
- [12] Sujit Kumar Vermaa, Naveen Kumar Gupta, Dibakar Rakshit (2020) A comprehensive analysis on advances in application of solar collectors considering design, process and working fluid parameters for solar to thermal conversion. *Solar Energy* 208 1114-1150.
- [13] A. A. Hawwash and ALI K, Abdel-Rahman, Maqusood Ahamed, S. A. Nada, ALI Radwan (2021) Thermal Analysis of Flat Plate Solar Collector Using Different Nanofluids and Nanoparticles Percentages. *IEEE Access* Volume 9 52053-52066.
- [14] Elumalai Vengadesan, Dharani Bharathwaj, Brahadheeswaran Satish Kumar, Ramalingam Senthil (2022) Experimental study on heat storage integrated flat plate solar collector for combined water and air heating in buildings. *Applied Thermal Engineering* Volume 216 119105.
- [15] Jalaluddina, Rustan Tarakka, Muhammad Syahid, Muhammad Hasan Basri, M. Anis Ilahi Rahmadhani (2023) Performance investigation of solar water heating system using flat-plate absorber integrated with thermal storage. *Cleaner Engineering and Technology* 17 100696.