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EXPERIMENTAL STUDY TO EVALUATE THE THERMAL PERFORMANCE OF MULTI STAGE PARABOLIC TROUGH SOLAR COLLECTOR USING A TWISTED ABSORBER TUBE

Saja Hamza Sabah[1*], Kadhim Fadhil Nasir[1]

[1]Al-Mussaib Technical College, Al-Furat Al-Awsat Technical University, Hillah, Iraq.
Email: saja.hamza.tcm91@student.atu.edu.iq, kad2020@atu.edu.iq
[*]Corresponding author E-mail: saja.hamza.tcm91@student.atu.edu.iq
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Abstract. *This study investigates the performance of two collectors from parabolic trough solar collectors for moderate heated water production. The goal to enhance thermal energy storage, boost heat transport, and maximize efficiency in order to boost performance. of parabolic trough solar collectors. Through experimental study under three distinct mass flow rates, it also looks into the effects of twisted tubes and external conditions (pollution, wind). Because of its high specific heat capacity, which enables it to store and transfer significant amounts of thermal energy, water is utilized as a working fluid. Its availability, affordability, low viscosity, and good thermal conductivity all contribute to its safety and environmental friendliness while also lowering pressure loss and improving heat transfer efficiency. Two solar energy-collecting devices of the parabolic trough type (PTC) were constructed, run, and assessed. In this study, the effectiveness of a set of PTC devices with a combined aperture area of 3.24 m² for both collectors was evaluated. Stainless steel sheet are uitilized to coat the parabolic trough. Copper twist tube absorbs heat . The exterior and inside diameters are 0.0125 meters and 0.0105 meters, respectively. The volume flow rate of water used as a heat transfer medium was 2, 4, 6 L/min. The thermal efficiency, usable heat, and alternative measures of The parabolic trough solar collector's efficiency ,were calculated. and exit temperature experimental and an evaluation of the outcomes of experiments between the three cases was made and the work also included the determination of the coefficient of heat transfer, pressure drop, for insert in parallel flow. The results showed a rise in pressure drop because of the high friction resulting from the bends. The experiments outdoor measures were used to evaluate the immediate thermal efficiency and usable heat gain. The impacts of ambient circumstances, collector temperature at the input and mass flow rate of the working fluid ,were examined in the PTC array's performance investigation. With a non-evacuated glass cover, solar collectors operated at a maximum inlet temperature of 78.5,70,66.4 °C and an exit temperature of 80.5,71.9,68.7 °C sequentially at a 6 l/min flow rate under turbulent flow conditions, achieving maximum efficiencies of almost 40%, 29%, and 13%. The collector's efficiency formula, which was obtained from this investigation, is in good agreement with previous publications.*

Keywords: *Efficiency; parabolic trough; solar collector; twisted tube*

1. INTRODUCTION

A parabolic trough collector is one kind of concentrating solar power technology. It uses reflectors with a parabolic shape to direct sunlight onto receiver tubes. generating high temperatures for applications like refrigeration and desalination, showcasing their versatility and efficiency potential [1]. This technique

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increases heat transfer efficiency by using a twisted tube, which enhances internal fluid mixing and reduces thermal losses. This design leads to increased energy absorption and improved thermal performance.

Tang, Dai & Zhu [2], experimental studies demonstrated that the twisted trilobed tube increased friction by 8.4%. while simultaneously permitting a 5.4% improvement in heat transfer. Nonetheless, it demonstrated superior thermal efficiency, making it a superior choice for applications involving heat transfer.

Sandeep Arunachala [3], the enhancement of heat transmission in parabolic trough collectors (PTCs) is investigated. The findings indicate that in contrast to recipients who were not evacuated, Evacuated receivers have a 65-70% boost in thermal efficiency. an almost 10% increase. Internal inserts (such twisted tapes) and nanofluids improve heat transmission even further. which, when combined, can enhance heat transmission by as much as 340%. increasing the efficiency and sustainability of solar thermal systems.

Farnam, Khoshvaght-Aliabadi & Asadollahzadeh [4], a U-tube heat exchanger's construction was modified to include twisted tapes to improve thermal conductivity in twisted tubes. In these investigations, utilizing The working fluid is water, and the flow is turbulent, Numbers of Reynolds ranged from 4,250 to 12,750. The outcomes show that adding tapes and twisted tubes significantly increases the coefficient of the reduction in pressure and heat transmission, in contrast to employing tubes that are straight. Additionally, twisted tapes increase mixing and turbulence. It enhances thermal efficiency. With an increasing Reynolds number, the benefits in heat transmission and pressure drop become more apparent. All things considered, twisted tubes with twisted tapes offer a practical way to improve heat exchanger performance. perhaps lowering operational expenses and size.

Wu, Yang & Huang [5], the effects of Reynolds number (Re) and diameter (d) on the features of thermal transmission and pressure loss in twisted elliptical tubes are numerically studied. The results show that although heat transfer improves by 16% to 19%, the pressure drop increases by 58% to 60% due to the twisted walls. Additionally, the tubes increase heat exchanger efficiency by reducing thermal resistance. The twist pitch also affects overall performance, with the 128 mm diameter tube showing the best results.

Aldulaimi [6], the study found that innovative absorber tube designs increased the efficiency of solar collectors. A conventional tube's efficiency was 41.9%, but the TTT model's was 59.8%. Greater pressure differences and lower temperature disparities were the outcomes of higher flow rates. Experimental findings supported theoretical predictions, supporting advancements in solar energy technologies.

Hari Haran, & Venkataramaiah [7], two distinct heat transfer fluids are compared to examine parabolic trough collector efficiency. namely, both water and saltwater. Furthermore, this study used several materials on absorber tubes, specifically polished copper, copper coated with nickel chromium, copper coated with nickel aluminum, and unpolished copper. Thermal spraying techniques were used to cover the absorber tubes. whereas a sun tracking technology was used to optimize solar irradiation. Performance was assessed using temperature and discharge data as a guide. whereas the WASPAS approach offered a way to identify the optimal parameters. Based on the results. Advanced coatings and heat transfer media are used to increase collector efficiency because it was discovered that Ni-Al and Ni-Cr coated copper tubes performed better when used with seawater.

Tahjib, Tanzin Azim & Rahman [8], A solar thermal collector's efficiency using a parabolic trough ,in absorbing solar radiation was examined and confirmed. The steam-powered system could purify water, produced electricity efficiently, and had low production costs. The study focused on its sustainability as a feasible renewable energy source.

Li, Yu, Li, & He [9], this study suggested an improved M2 analytical approach to measure the photo-thermal-elastic efficiency of evacuated receivers in parabolic trough collectors. The study used 1D thermo-hydraulic, 3D FVM, and 3D FEM models to investigate transient thermal loads and deformations under various conditions. The results showed significant thermal changes and deflections, especially during cold-start and low mass flow rates, underscoring the need for effective transient thermal load control.

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Lotake & Wagh [10], According to the study, when the mass flow rate ,was increased, the total thermal efficiency of the unpainted receiver grew by 1.3 times, while the black-painted receivers increased by 1.37 times. It was discovered that the black-painted receiver was 1.16 times more efficient than the uncoated one. Additionally, it was discovered that the manual tracking procedure increased the efficiency of the uncoated receiver by a factor of 1.1 and the black-painted receiver by a factor of 1.04. These findings show that controlling the surface treatment, mass flow rate, and tracking systems can significantly boost the parabolic trough solar collectors' efficiency.

Norouzi, Siavashi, Ahmadi & Tahmasbi [11], the study suggested a novel method for improving PTC performance, representing parabolic trough collectors, which entailed rotating the absorber tube with a solar-powered motor. Tests showed that rotation increased efficiency by 17%, reduced the fluid-tube temperature differential by 60%, and lowered the surface temperature by 15%. This approach proved to be a successful and cost-effective method of improving existing systems.

Donga, Kumar & Kumar [12], the study looked into how receiver positioning problems affected the effectiveness of PTC systems. The results showed that an offset of 1.63% caused temperature swings up to 199.7 K and reduced overall efficiency by 14% and optical efficiency by 32%. This demonstrates why precise receiver orientation is essential for achieving optimal efficiency.

Mushatet, K. S., and Razzaq, A. K. A. [13], An analysis of a twin twisted tube ,heat exchanger using numerical methods , in the study revealed that a lower twist ratio (Tr = 5) increased heat transmission by 14% and total performance by 13%. Heat transmission and flow resistance are traded off, was required due to the twisted design's higher pressure drop and thermal turbulence.

Alsulaiei, Hasan & Fagr [14], this study uses ANSYS 17 to numerically examine Heat transfer and fluid movement in twisted tubes with internal obstructions. Various twist pitch ratios (y = 3, 5) and obstacle height ratios (OHR = 0-0.625) were investigated. The results show that internal barriers further boost efficiency but raise flow resistance, while twisted tubes improve heat transmission. Pressure drops (f) and heat transfer (Nu) are balanced in the ideal design to provide maximum thermal performance with the least amount of energy loss.

Zheng, Yan & Shi [15], the study looks at a multihead twisted spiral tube (MTST) to enhance heat transfer. According to the results, efficiency rises with more spiral heads, twisted nodes, and a bigger diameter ratio.

Reddy, Subramanya, Vishwanath, Karthikeyan & Kanchiraya [16], it was examined how a rotating receiver tube affected the thermal transmission in parabolic trough collectors (PTCs). The results showed that thermal performance improved as the water temperature rose by 18.5°C and friction increased by 137.5 times at 4 rpm. However, the friction factor increased significantly with rotation.

Rao & Reddy [17], the study proposed a way to optimize PTC design by combining structural and optical considerations. It optimized tracking errors, slope errors, rim angle, and collector breadth while accounting for wind impacts. This technique improved the efficiency of collecting solar energy.

Sangotayo, Opatola, Abdulraheem & Adeyemo [18], The impact of operational and environmental factors on energy efficiency was investigated, of parabolic trough collectors (PTCs) that generate hot water. In order to comprehend heat exchange mechanisms and their impact on solar energy conversion efficiency, it examined receiver tubes that were uncoated, grey-coated, and black-coated. The PTC included a mild steel mainframe, a segmented mirror reflector with 0.85 reflectivity, a 90° rim angle, a 2 m² aperture area, and an 11.7 concentration ratio.

Jurmut, Nasir & Al-Hamadani [19], the average water temperature in the collector's thermal performance and the storage tank during the winter have been examined in connection with the usage of helical tape in an evacuated tube. The highest collector efficiency rose to 36% when helical tape was used inside evacuated tubes, but it dropped to 28% when the collector was used without helical tape. The highest mean temperature of water within the storage tank rises by over 19% when helical tape is used inside the evacuated tubes as opposed to not utilizing the tape in all tests. Therefore, in comparison to not using the

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tape, it raises the collector efficiency by around 27%. The research investigated the impact of operational and environmental factors on the energy efficiency of parabolic trough collectors (PTCs) that generate hot water. In order to comprehend heat exchange mechanisms and their impact on solar energy conversion efficiency, it examined receiver tubes that were uncoated, grey-coated, and black-coated. The PTC included a mild steel mainframe, a segmented mirror reflector with 0.85 reflectivity, a 90° rim angle, a 2 m² aperture area, and an 11.7 concentration ratio.

Itabiyi, Sangotayo, Olojede, Akinrinade, Oluwafemi & Bhadmus [20], this research inspects the outcome of The impact relationship between tilt angle and mass flow rate in a parabolic trough collector's heat efficiency, with the intention of enhancing performance and encouraging sustainable energy use.

Wellmann, J., Khalil, M., Rieck, J., & Behrendt, F. [21,] In contrast to smooth tubes, heat transmission, in CCD tubes was almost five times better. There was less heat loss, a good balance between performance efficiency and pressure drop, and a 11.4% rise in the outlet fluid temperature.

Munusamy & Shreedhara Murthy [22], Using aluminum-covered twisted copper dimple tubes, this study enhances parabolic trough solar water heaters, increasing efficiency by 31.25% at a 1.5 kg/min flow.

Soudagar & Naveenkumar [23], By using a solar-powered motor to rotate the PTC receiver tube, the payback period was shortened by 20 days, the water's temperature increased from 28 to 51 degrees Celsius, thermal stress was decreased, and efficiency was increased by 38%.

Farkas & Touaref [24], This work uses an elliptical tube and hybrid nanofluids to increase solar collector efficiency by 45.46% and improve heat transmission by 25%. Its design is straightforward and efficient, and it does a good job of desalinating water. Additional testing and AI tuning will take place in the future.

Gu & Geng [25], In comparison to conventional tubes, this study demonstrates that using a helical rotor in addition to, the PTC's heat collecting tube enhances fluid flow and heat transmission, resulting in a roughly 30% increase in heat collection and efficiency.

The sustainability and efficiency of solar energy systems could be enhanced by this discovery, which makes it significant. In parabolic trough solar collectors, a twisted-tube absorber can dramatically boost The heat transfer rate, increasing the system's overall thermal efficiency. Additionally, this update provides a practical and cost-effective substitute for conventional straight-tube designs while reducing heat losses and improving the collector's dependability. " By supporting the broader global movement toward clean and renewable energy technology, Additionally, the study facilitates the transition,to environmentally friendly and sustainable energy alternatives.

How does using a twisted-tube absorber instead of a conventional straight tube Does increasing a parabolic trough solar collector's thermal performance impact its pressure drop, heat-transfer coefficient, and overall thermal efficiency?

The novel aspect of the publication is the analysis of a twisted absorber tube with varying flow rates (2, 4, and 6 L/min) in combination with a parabolic trough solar collector ,while simultaneously addressing thermal efficiency, heat gain, pressure drop, and temperature difference. Unlike previous research that only focused on either thermal performance or hydraulic losses, this study provides a comprehensive comparison that highlights the compromise between greater pressure drop and improved heat transmission. The findings provide fresh insights on how to maximize the efficiency of twisted tubes by improving their shape.

2. EXPERIMENTIAL SET-UP

2.1. EXPERIMENTAL RIG

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This study used a twisted copper tube and measuring equipment as the primary elements that comprise the experimental apparatus, as seen in Fig. 1, in order to examine the solar collector's parabolic trough thermal efficiency.

Fig. 1. Experimental work of solar collectors with parabolic troughs (a) wind speed meter (b) solar power meter (c) digital pressure manometer (d) temperature recording (e) storage tank (f) flow meter (g) water pump.

In January and February of 2025, the system was installed and tested on the top of the Al Mussaib College Technical Faculty. Iraq's approximate latitude is 32.48389°, and its approximate longitude is 44.43111°. This solar collector's tilt angle is intended to be appropriate for the local latitude. The PTSC is tilted 45 degrees to the south. From 9 AM to 2 PM, practical exams were carried out in a cold setting. The PTC, which stands for Parabolic Trough Collector, was composed of a reflector composed of steel sheets

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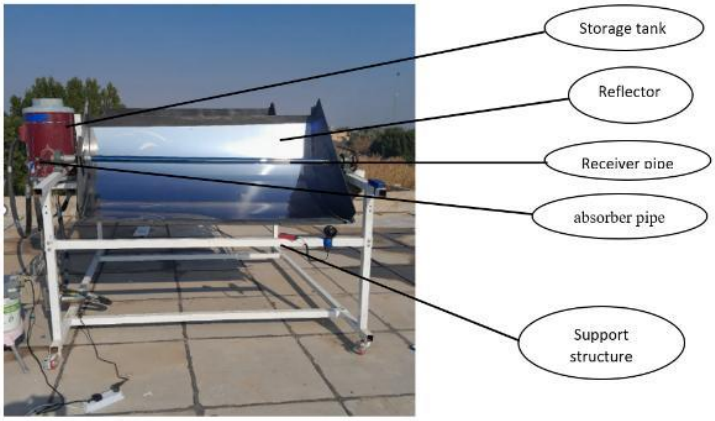
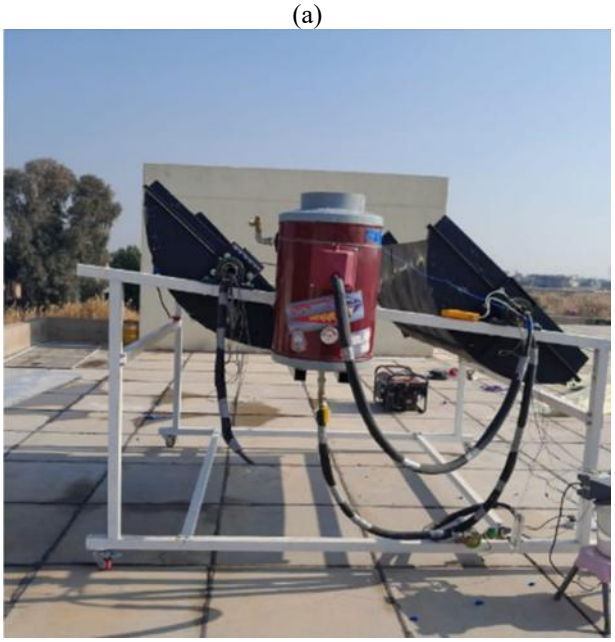
coated in chrome and curved using the formula $x^2 = (4fy)$. Its focal length was one meter, and its aperture width was 1.4 meters. Steel angles and fiber or wood side ribs are used to secure the reflector, and a circular hole is used to hold the glass receiver tube in place. The copper absorber pipe is housed in a 2-inch diameter steel tube that is attached to the PTC, which is fixed to a steel support structure. The structure has wheels for convenient positioning and adjustment. as described in Fig. 2.



(a)



(b)

Fig. 2. Displays the experimental set-up, (a) Afront view of the installed collector, (b) side view of the parabolic trough solar collector with storage tank and connected piping .

A glass tube, bushings, an O ring, and a support plate make up a thermal receiver. Two coaxial borosilicate glass tubes comprise the glass tube, as seen in Fig. 3. While one end is sealed, the other is open for inlets and outlets. The following are the glass tube's parameters: the cover tube is 1800 mm long, the absorbing double-twisted copper tube is 3600 mm long, and 47 mm is the inner diameter and 58 mm is the outer diameter.. A 1.6 mm thickness characterizes the glass. An aluminum nitrite selective coating enhances absorption and covers the exterior within the inner tube. The receiver sits on the parabolic trough's focal line. Glass tube specifications are listed in Table 1.

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Fig. 2. Non evacuated glass tube.

Table 1. Glass tube specifications.

ITEM	Value
Cover diameter	58 mm
Receiver length	1800 mm
Emissivity	0.08
Coated surface absorptance	0.93
Cover transmittance	0.91

The collectors' absorber pipes, which have an outside diameter of 1/2″ and are enclosed, double-twisted copper pipes painted black, are used to absorb heat. The enclosed pipes have one end welded to the other, while the other ends remain free. The enclosed pipes are used for simultaneous fluid entry and outflow, as shown in Fig. 4. On the other Using the hand, the absorber pipes were placed inside the glass receiving tube with a diameter of 44 mm.. A fiberglass bung is positioned at the glazing receiver's opening and encloses ,To seal the opening of the glass tube, use two copper pipes firmly, preventing convection from passing between the annular and double-glazed vacuum tubes. Teflon is utilized to support the copper pipes inside and prevent them from coming into contact with the glass framework at the far and near ends of the glass tube.

Fig. 4. Twisted copper pipe.

2.2. EXPERIMENTAL PROCEDURE

- Recording Intervals: Parameters were recorded every 30 minutes.
- Cleaning the reflectors (mirrors) of Any dust or dirt that has gathered must be removed.
- Water from the main line is then used to fill the storage tank. Because it is open, the water recirculation network's storage tank may hold 40 liters of water. The storage tank can be connected to the troughs system by connecting its inlet to the troughs' outlet and its outlet to the troughs' inlet. Installing the flow meter allows you to monitor the water's rate. of passage through the pipes after the pump has been set up. After the water has warmed up and gathered heat, it returns to the storage tank.
- The absorber tube's input and outflow temperatures are recorded.

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- Thermocouples are placed at various locations along the PTSC.
- A solar power meter measures the amount of energy the sun produces.
- The temperature thermometer records thermocouple readings.

3. THERMAL EFFICIENCY

The thermal performance of the PTSC can be described as the ratio of the collector's heat to the total amount of incident solar energy. The following formula can be applied to find the thermal efficiency at equation (1) [26, 27]:

$$\eta = \frac{Qu}{Ac \cdot I} \tag{1}$$

Where Ac is a perture The collector's area (in m2), *Solar radiation is what I.* and Heat gain that is useful (Qu). The HTF's immediate thermal energy gained during the flow between the PTC's inlet and exit is known as the useful heat gain at equation(2) [28]:

$$Qu = \dot{m}^{\circ} C_p (T_{out} - T_{in}) \tag{2}$$

Where $\dot{m}^{\circ}$ is te mass flow rate (kg/s), T_{out} denotes the outlet water temperature (C°), C_p denotes The water's specific heat ($kJ/kg.C^{\circ}$) and T_{in} denotes the inlet temperature of the water (C°).

4. RESULTS AND DISCUSSION

Parabolic trough solar collectors use black-coated twisted copper pipes to increase solar energy absorption and heat conversion efficiency. Compared to straight pipes, the twisted design improves heat transfer efficiency by creating a vortical flow even at low speeds.

The temperature of the surrounding air and the amount of sunshine have a significant influence on how successful parabolic trough solar collectors are. The experiment's testing period lasted from 9:00 AM to 2:00 PM. By 2:00 PM, the outside temperature had risen from 10.1°C to almost 23°C.

The intensity of solar radiation has a significant impact on how much energy the solar collector can capture. At 8:30 AM, the sun irradiation was roughly 495 W/m²; at 12:00 PM, it rose to 997 W/m²; and at 2:00 PM, it dropped to 743 W/m². Until 2:00 PM, the experimental sessions continued.

The variation in outlet temperature profiles increased in tandem with the rise in solar radiation. It also peaked when solar radiation was at its highest. When the flow rate is 6,4,2 L/min, the PTSC's highest inlet temperature was 78.5, 70,66.4 °C, while its maximum exit temperature was 80.5,71.9,68.7 °C.

. The output temperature profiles showed the same pattern as the differences in the rate of mass flow. proving that when solar radiation increased, the outlet temperature increased and peaked at the maximum of solar energy intensity. Additionally, because there was less sunlight in the afternoon, the temperature profiles dropped.

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At the Fig. 5, there is a noticeable downward tendency in the graph that depicts the temperature differential (ΔT) throughout a twisted tube at varying flow rates (2, 4, and 6 L/min). Since the fluid moves slowly, the temperature differential is greatest at 2 L/min. giving More time for the tube walls to absorb heat, which raises the temperature more. A lower residence period at 4 L/min results in a somewhat smaller temperature differential, although it is still greater than at 6 L/min. The fluid travels too quickly to absorb much heat, therefore the temperature difference is lowest at 6 L/min. These findings are consistent with the work of Kalash et al. (2024), who discovered that increased flow rates reduce temperature differentials due to shorter residence durations.

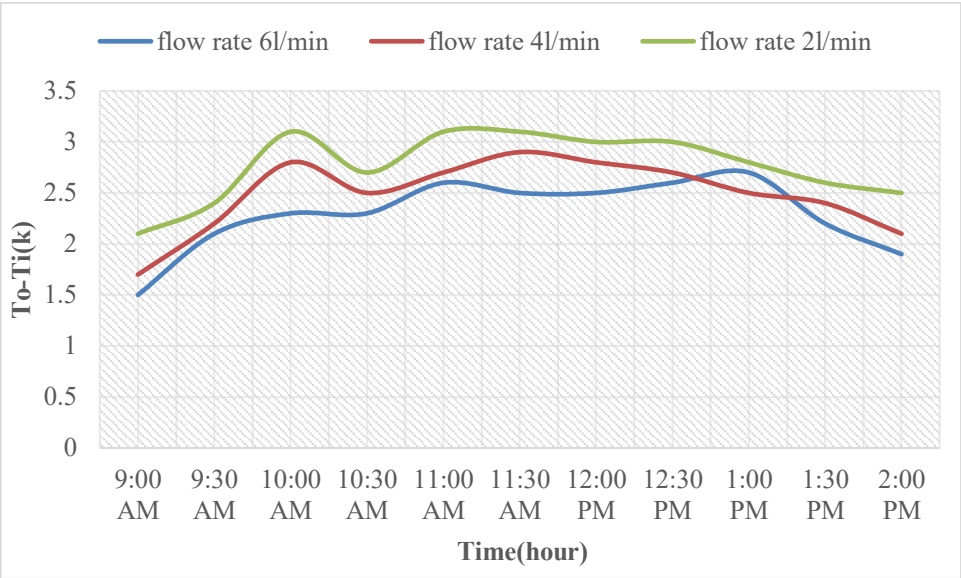

Fig. 5. Water temperature differences through collectors in relation to local time.

At Fig. 6, because of the strong turbulent flow and improved mixing brought on by the tube's twisting, which greatly enhances convective heat transfer, the maximum usable heat gain happens at 6 L/min. With slightly less residence time than at 2 L/min, the usable heat gain is reasonably high at 4 L/min, benefiting from more turbulence in comparison to lower flow. Despite a longer residence period, the beneficial heat gain is lowest at 2 L/min because the flow is slower and more laminar, which lowers the overall heat transfer rate. Despite a longer residence period, the beneficial heat gain is lowest at 2 L/min because the flow is slower and more laminar, which lowers the overall heat transfer rate. Al-Obaidi et al. (2021) [29] found comparable trends in heat gain changes with flow rate in twisted-tube solar collectors, which is consistent with their findings.

Fig. 7 shows the The solar collector's twisted tube's thermal efficiency at various flow rates. At 6 L/min, the ideal efficiency value of 40% is achieved. According to this, higher flux promotes more efficient heat transfer and reduces heat losses. Due to insufficient mixing and a reduced dynamic effect of the twisted pipe, the efficiency substantially decreases by about 4 L/min 29%. Finally, efficiency hits its lowest point at 2 L/min 13% due to inadequate flow, inadequate heat transmission, and considerable heat losses to the environment.Kalash et al. (2024) [30] found comparable patterns in thermal efficiency changes with flow rate in twisted-tube solar collectors, which is consistent with their findings.

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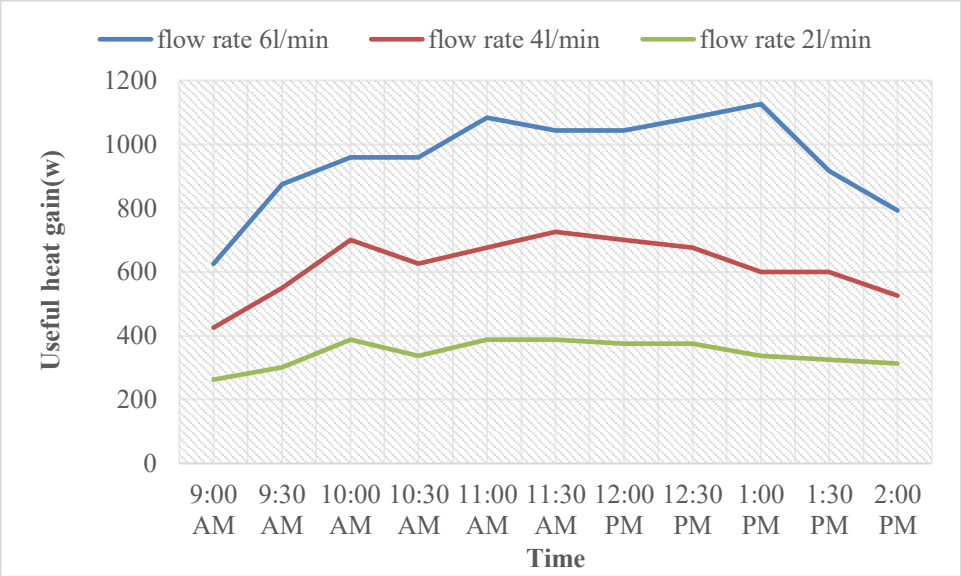

Fig. 6. Comparation between flow rate heat gain for non-evacuated receiver pipe.

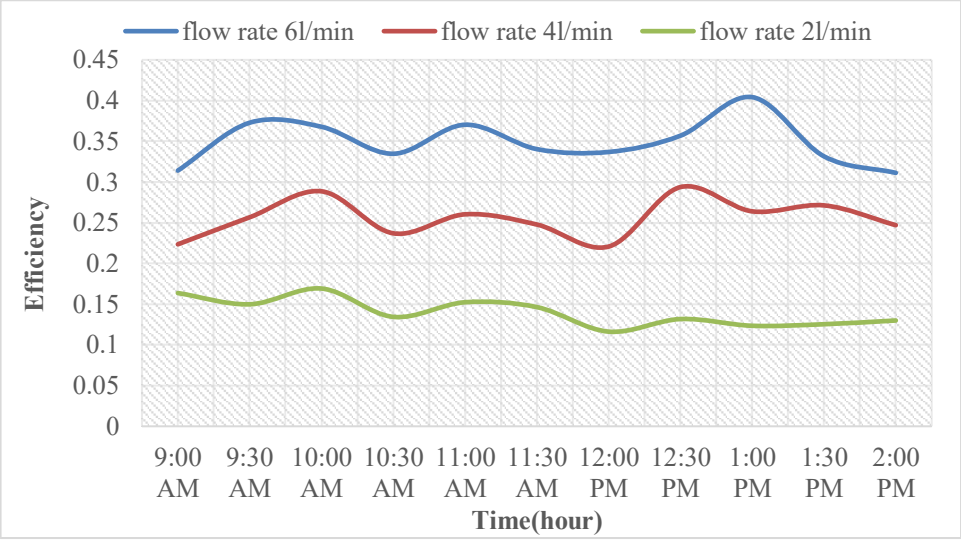

Fig. 7. Thermal efficiency comparison for various days at various flow rates.

This graph in Fig. 8 shows the pressure drop (Δp), at diffrenet flow rates (2, 4, and 6 L/min) inside atwisted tube. Due to the increased turbulence and fast speed caused by the tube's design, we can see that the greatest pressure differential happens at 6 L/min. This significantly impedes flow. With a slightly less pressure differential but still a big one due to the vortices' continuous effect, a rate of 4 L/min follows. Then, the pressure drop is reduced due to ,the relatively low velocity, it reached its lowest value at 2 L/min.

These findings are consistent with those of Al-Obaidi et al. (2021) [29], who discovered that pressure drop changes with flow rate in tubes with twisted tape insertion exhibited analogous patterns.

At Fig. 9, across a range of solar radiation intensities, the multi parabolic trough collector's efficiency curve clearly indicates an increase over the single collector's. Because of the increased absorption surface and decreased heat losses in the multi collector, this difference indicates an improvement in thermal performance.

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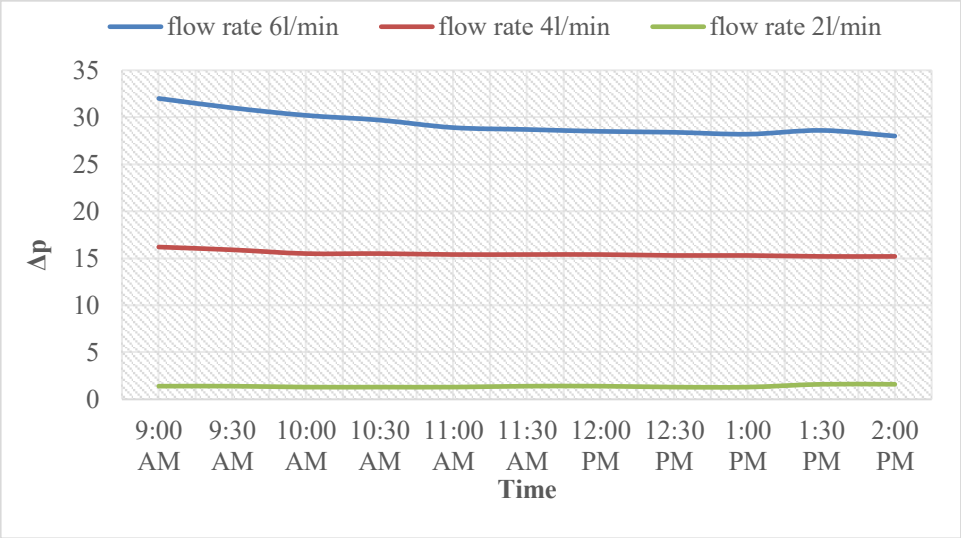

Fig. 8. Pressure drop comparisons on several days and flow rates.

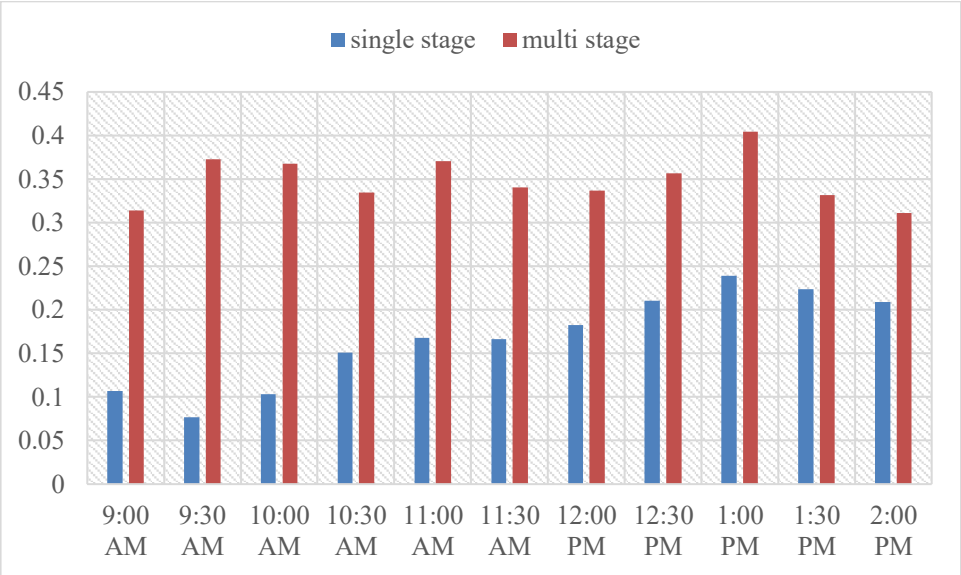

Fig. 9. Comparison between thermal efficiency at flow rates 6 l/min.

5. CONCLUSIONS

This study used an absorber with twisted tube varying volumetric 4 l/min, 6 l/min, and 2 l/min flow rates to experimentally investigate ,a solar collector with a parabolic trough. The following conclusions are drawn from the data gathered and validated findings:

- According to the report ,employing a coiled tube for absorption instead of a straight tube increased the thermal performance, of the basin solar collector substantially. 40% was the maximum thermal efficiency achievable at a flow rate of 6 litters per minute; at 4 litters per minute, it dropped to 29%, and at 2 litters per minute, it fell to 13%. Zarrag et al. (2021) [31] found that raising flow rate enhances turbulence, resulting in improved efficiency and heat transmission.
- The diffrence temperature across the collector rises as the input water flow rate decreases.
- A greater flow rate causes a higher pressure drop across the pipe's fluid entry-exit zone.

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- In tandem the usable heat gain increases as the feed water flow rate and beam radiation intensity increase.
- This study on the solar collector with a parabolic trough found that the amount of solar radiation increases thermal efficiency, temperature difference, and useable heat . This behaviour supports the findings of Muter et al. (2021[32].
- The study shown that the twisted tube enhances The solar collector's performance compared to the standard tube.

6. RECOMMENDATION

- Test different absorber coating materials to determine their impact on system functionality.
- The method can be applied to test the performance of PTCs with wider aperture widths.
- Explore the various fluid types' effects on thermal efficienc. You can use many types of nanofluids at various concentrations.

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