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Enhanced Performance of Flat Plate Solar Collector with Twisted Tape Double Cutting Rectangle Shape

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Abstract

Solar water heating uses solar collectors to capture sunlight and convert it into heat energy. It has grown remarkably and is now widely used for water heating in homes and manufacturing plants worldwide. Various techniques have been employed to enhance heat transfer in collectors, such as enlarging the collector's surface area or inducing fluid turbulence in the tubes. This article aims to boost the effectiveness of a flat plate solar collector through the use of a twisted strip to generate turbulence in the flow. Three twisted tapes, made of Aluminum and copper, were placed inside the collector's tubes, each with a different shape. All the twisted tape shapes - square, rectangle, and triangle - were identical in size, measuring 1000 mm in length and 1 mm in thickness. Both experimental tests and a numerical study were conducted on these three shapes of twisted tape. For each shape, three pitches were used: 2,3 and 4 cm. The results indicated that the efficiency of the collector using the double-cutting rectangular twisted tape with a 2 cm pitch was superior to other collector shapes. Moreover, the copper tapes exhibited greater efficiency than the aluminum tapes.

Keywords: Heat transfer enhancement; Liquid Flat Plat; Solar Water Heater; Thermal Performance; Solar Collector; Solar Flat Plate Collector; Twisted Tape Inserts; Turbulentfluid

1. Introduction

Solar collectors come in various forms but are always built with the same fundamental idea in mind [1],[2]. Solar energy is generally focused and collected using certain materials, which are then utilized to heat water [3],[4]. The most basic of these devices circulate a black substance via pipes. The surrounding water heats the black substance, effectively absorbed by the sun's energy. This is a very basic design, but it cannot be very easy for collectors. Absorber plates may be used if a high-temperature rise is not required, but equipment using reflective materials to concentrate on the sun would usually increase temperature [5],[6]. With the development of high-performance thermal systems, strategies for enhancing heat transmission have become increasingly prevalent. A range of strategies are known as "heat transfer augmentation techniques," which aim to maximize heat transfer rates while lowering the system's overall performance [7],[8]. Most methods of improving heat transfer work by either increasing the effective heat transfer surface area or creating turbulence in the fluid moving through the device, lowering thermal resistance [9]. Heat exchangers are frequently utilized in heating and cooling applications. Turbulence generation, one of the most effective passive heat transfer methods, uses twisted tape in the flow passage [7].

Augmentation techniques are popular because of their ease of fabrication, operation, and low cost. Maintenance. In the study by Jaisankar et al. [10], heat transfer, friction factor, and thermal performance of left-to-right twisted tape solar water heaters with different twists were experimentally tested. The ratios with Reynolds numbers ranging from 3000 to 23,000 were examined and contrasted with a plain tube collector under the same operating conditions. Within 15% of the experimental data, the empirical correlates for the Nussle number and friction factor with different left-right twist ratios (Y = 3, 4, 5, 6) were fitted. According to the results, the heat transfer enhancement in the left-right twisted tape collector was superior to that of the plain tube collector. At a minimum twist ratio of 3, heat enhancement and pressure drop were more significant than at other twist ratios.

Sarada et al. [11] studied the excessive pressure drops connected to full-width twisted tape inserts. Utilizing varying widths of twisted tape inserts with air as the working fluid improved heat transfer. The reduced-width twisted tapes range from 10 mm to 22 mm for a horizontal tube. The tapes were narrower than the inside diameter of the tube. At constant heat flux, experiments were conducted on plain tubes with and without twisted tape inserts, including flux and varying mass flow rates. The twisted tapes had three different twist ratios (3, 4, and 5), each with five variations.

Kini et al. [12] investigated two unique designs, one with a symmetrically placed flat fin at the absorber tube and the other with a serrated fine tube design. The premise underlying these two designs is that there is potential for a higher convectional heat transfer from the unglazed collector to the absorber tubes. Compared to the best model, the numerical findings obtained using conjugate heat transfer and computational fluid dynamics demonstrate that the heat transfer flux rises at lower flow rates.

Sekhar et al. [13] used experimental simulation to analyze convective heat transfer under constant heat flux. The boundary conditions for a horizontal circular pipe containing fluid in a mixed laminar flow range were investigated. The heat transfer coefficient and pressure fluctuation dropped at various volume concentrations and twisted tapes. The flow for water and water-based Al2O3 Nanofluids was investigated. The dependence of particle concentration and Reynolds number on improvements in heat transfer and increased pumping power due to pressure drop was investigated.

Shelke and Patil [14] considered a circular tube with a diameter of 12.7 mm. ANSYS CFD FLUENT software was used to conduct the numerical analysis. An analysis compared the temperatures at the entrance and outflow for various heat fluxes. Additional examination was carried out about the various configurations of the elliptical tube outlet. There was good agreement when the water's temperature was compared to the circular results.

Ameen et al. [15] investigated the improvement of heat transmission in flat plate collectors (FPCs). Single, double, and mixed-twisted tapes (ST, DT, SDT) were compared to plain tubes with twist ratios of two (TR=2). The investigation was conducted under a fully developed turbulent flow. Four 1.25-cm-diameter, 1mm-thick pipes that serve as heat-removing fluid. The channels are positioned above the plate in the prescribed FPC. The system comprised two tanks, each holding 20 liters, and two collectors, each measuring 40 cm by 160 cm by 15 cm. The type of twisted tape of collector plate metal (copper or Aluminum). The number of glass covers and the collectors' orientation in the south direction were some of the useful factors that determined the heat gain from solar radiation. The heat transfer enhancement of DT, which raised the working fluid's output temperature, made it more efficient than ST and SDT. Additionally, the scientific investigation demonstrated that the mixed twisted tape collector's outlet water had a temperature of 10 °C greater than that of the other varieties of flat tube collectors.

Balachandar and Narendran [16] used two copper tubes to investigate the flat plate of the collector: a plain copper tube with a thickness of 0.7 mm and a newly developed inner grooved tube with a thickness of 0.5 mm. The grooved surface increased the working fluid's contact with the copper tube to lower the material's weight and cost. The most significant amount of heat is transferred from solar light. The result indicated that, in comparison to the FPC with the plain copper tube, the effectiveness of the FPC with the inner grooved tube had improved. This design's average instantaneous performance improved by 5% compared to flat tube efficiency. This indicated that the output temperature had increased when the inner grooved tube was used, resulting in a drop in material costs and an increase in surface area. This arrangement had the potential to replace the conventional.

Asboei et al. [17] investigated inserting twisted tapes with alternate axes and regularly spaced tapes in a round tube under wall heat flux conditions to improve heat transfer and friction factor. This technique is the mechanics of twisted tapes fitting in a circular tube. The flow velocity was considered in this attempt and was predicted to be in the 500 Reynold 1750 range. Every check was carried out, assuming that the surroundings were laminar.

Chaudhari et al. [18] examined a solar flat plate collector that worked with circular absorber tubes and aerofoil. A comparison between both solar flat plate collectors and the experimental data. The FPC can deduce that aerofoil-shaped absorber tubes received more solar energy radiation than absorber tubes with a circular form based on these testing results. The bulk flow rate of water was shown to be increasing. Flowing through the absorber tubes, the efficiency of both tubes was increased. Collectors' absorber-shaped aerofoil also increased, providing optimum efficiency due to increased surface area. As a result, it was possible to conclude that using aero foil shape absorber tubes was advantageous in conventional flat plate collectors.

[19] investigated the output solar collector with a square tube, and the square tubes determined the heat flow properties and fluid. The idea was to improve the solar collector's thermal efficiency by using various tube shapes. This led to an improvement in the area of the tubes as opposed to other forms of constant volume. The area of the tubes enhanced the performance of the solar collector by using a closed coiled spring as an insertion in each tube of the solar heater that remained the water in the tubes for a more extended period.

Khudhair and Khudhur [20] investigated the fluid flow and heat transfer across cylinders immersed in a horizontal two-packed bed of spherical particles of porous media (silica gel and molecular sieve). The general shape of all temperature contours showed that the high porosity near the cylinder wall enhances heat transfer from the heated cylinder surface. After that, the air temperature gradually decreased when going away from the cylinder surface. It was also seen that the pressure drop decreases as particle diameter increases.

2. Numerical Analysis

The geometry Model is a twisted tape inserted into two types of tube metal, one aluminum, and the other copper, for a different shape: square, rectangle, and triangle, all at 1000 mm in length and 1 mm in thickness. They were placed inside tubes of the same length. It is fixed to a copper plate with a length of 1000 mm and a width of 500. A pump is connected to raise water from the tank to the flat plate solar collector. It is installed at two angles, one at 45° and the other at 90°. The following are the specifications for each of the twisted tape shapes:

- The riser pipe has a length of 1000mm and inner and outer diameters of 24mm and 27mm, respectively. The head pipe thickness is 1 mm, and the length (500mm) and inner and outer, as shown in Fig. 1
- Type of twisted tape (insertion twisted tape) made cutting in single copper twisted tape with a length of (1000 mm*2. There are three twisted tape insertions in the riser pipes.

As shown in Fig. 2, tri-angle-shaped twisted tape insertions on each side of the twist (double cut) with dimensions of (9mm * 9mm * 1mm) depict Aluminum, copper, and pitch 2,3,4.

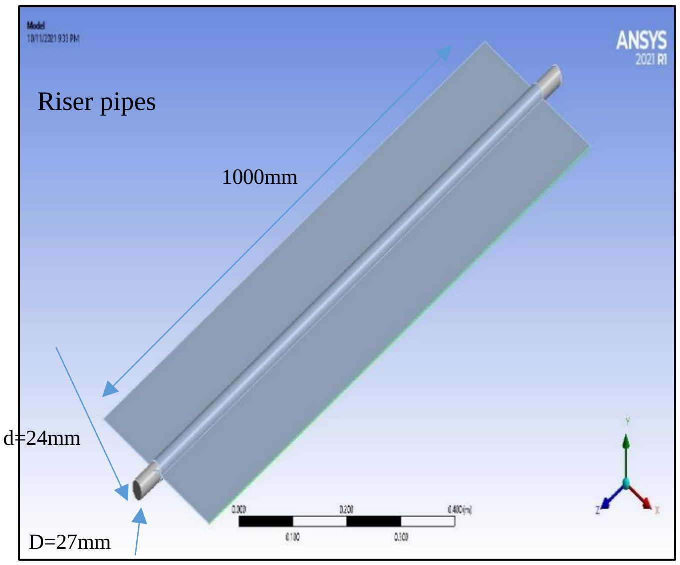

Figure 1. The photo ANSYS of a symmetric riser pipe

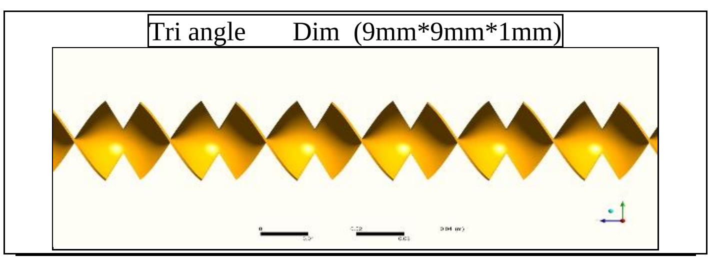

Figure 2. Twisted tape tri-angle shape

B-square-shaped twisted tape insertions on each side of the twist (double cut) with dimensions of (9mm * 9mm * 1mm) aluminum and copper and pitch 2,3,4, as shown in Fig. 3.

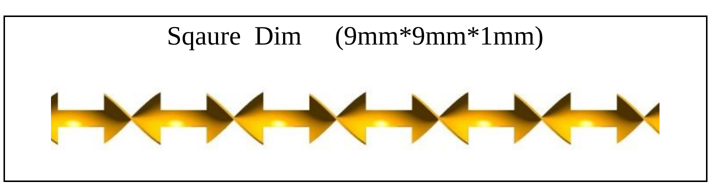

Figure 3. Twisted tape as square shape (3pich)

C—Rectangle-shaped twisted tape insertions on each side of twisted (double cut) with dimensions (18mm *9mm *1mm), Aluminum, copper, and pitch 2,3,4, as shown in Fig. 4.

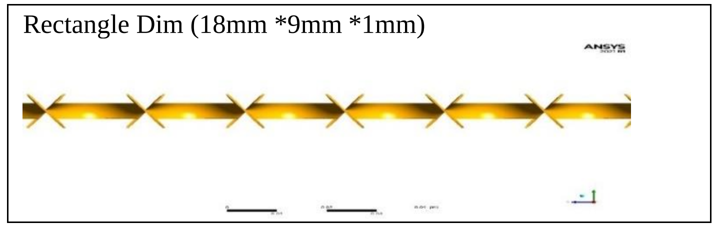

Figure 4. Twisted tape rectangle shape

Fig. 5 and 6 represent the mesh used in general on the plat of copper (heat conduction plat) and twisted tape, and it can be observed that the types of mesh are used closely through the following drawing—a system using hybrid meshing to simulate the model, as shown in Fig. 6 to Fig 9. The hybrid mesh is divided into hexagonal, tetrahedral, and prism/wedge. Each type has its own set of specifications, features, and conditions for use. The hexagonal mesh is one of the most widely used techniques when compared to other methods because it has many advantages, such as lower memory requirements, more precise results due to lower diffusion, and the ability to link complex engineering shapes and prisms used in cylindrical shapes at the places of entry and exit of fluid, part of which is regular on the surface.

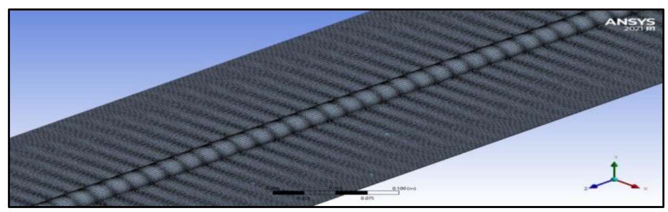

Figure 5. The photo of a mesh of solar collector in general

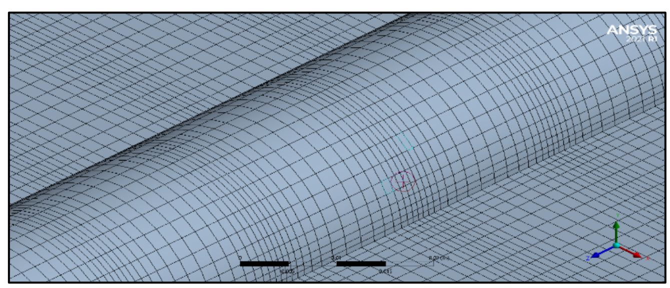

Figure 6. Hexagonal mesh

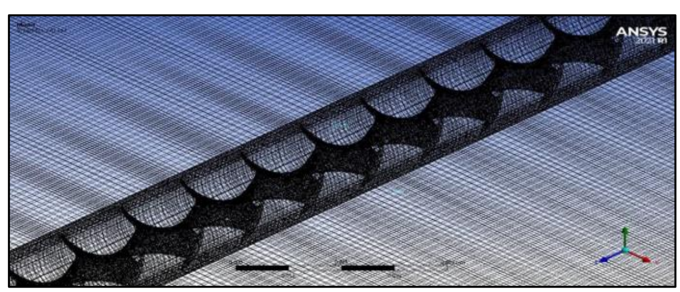

Figure 7. Tetrahedral mesh in a tube and twisted tape

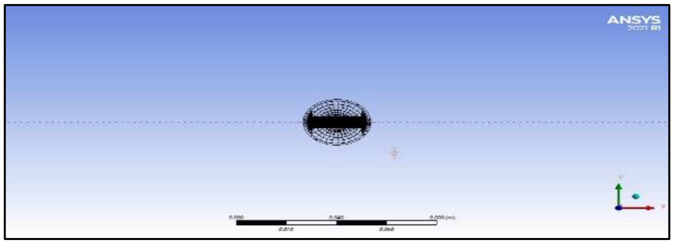

Figure 8. Tetrahedral mesh in a tube and twisted tape

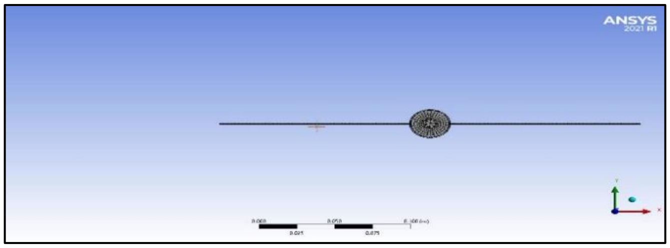

Figure 9. Prism mesh in a tube and twisted tape

Fig. 10 to Fig. 12 show the mesh in rectangles, squares, and rectangles.

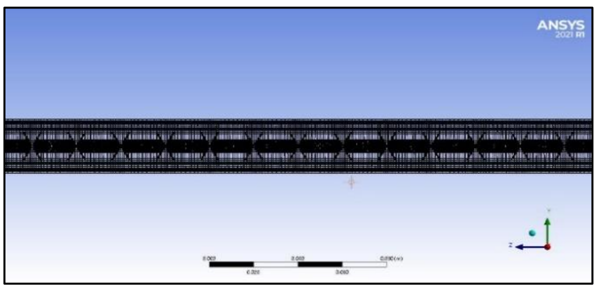

Figure 10. Mesh twisted tape in a rectangle shape

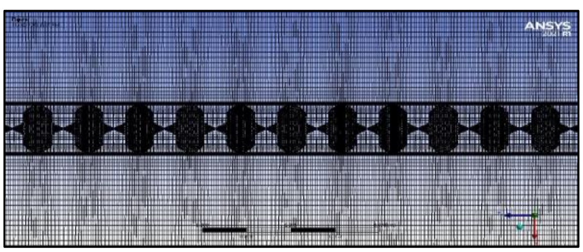

Figure 11. Mesh twisted tape in a square shape

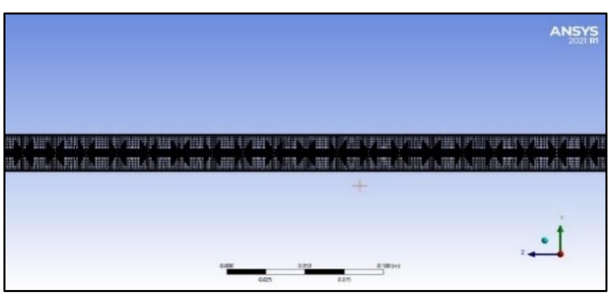

Figure 12. Mesh twisted tape in a triangle shape

Data used in calculation Reynold number

Dimension of Area of copper plate =1m*0.5m=0.5m²

Dimension of outer diameter= 2.7cm=0.027m

Dimension of inner diameter=2.4=0.024m

Dimension of thickness of pipes (riser pipes and header pipes) =1mm

Dimension of mass flow rate=0.000216m³/L=26L/min

Dimension of v

$v = Q/A$ (1)

V= 0.000572m/S

$Re = (\rho u D)/\mu$ (2)

Re=(ρuD)/μ= 14075

1. calculation efficiency:

a. Calculation of efficiency in a horizontal plan at an angle of 90°(position base of rig)

$\eta = \frac{Qu}{AcI}$ (3)

M*reading of flow meter=20L/min

η =0.53*100=53%

b. Calculation of efficiency of the plane inclined at an angle of 45°

M*reading of flow meter=20L/min

η=0.74*100=74%

2. Experimental Work

Rig (apart of the system), shown in Fig. 13, is made up of

- two risers' pipes to collect heat.
- A heat exchanger places water (working fluid) in the storage tank.
- A down–comer returns the water from the heat exchanger to the risers' pipe.
- An advice thermometer measures the temperature of the water (working fluid) that is outside from the pump and inside the flat plat solar collector.
- A pump to riser the water from the tank flat plat.

A tank with 20L to store the following section can thoroughly explain each of them.

3.1. Results chart for Experimental Work (Unsteady state)

3.1.1. Charts of Temperature y for Rectangle cutting section twisted tape [2] pitch Copper of Experimental work at 90◦ (position base of rig)

Fig. 14 depicts the temperature of the inlet water (working fluid) in a solar collector at 35°C at 8 o'clock on the horizontal axis at 90°, with the degree of temperature outlet higher than the inlet, which increased to 57.7° during the 6-hour day.

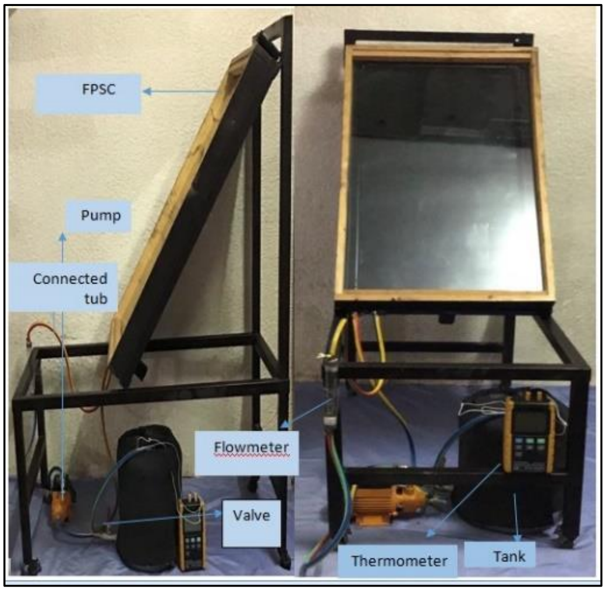

Figure 13. Photo Flat plat solar collector under examination

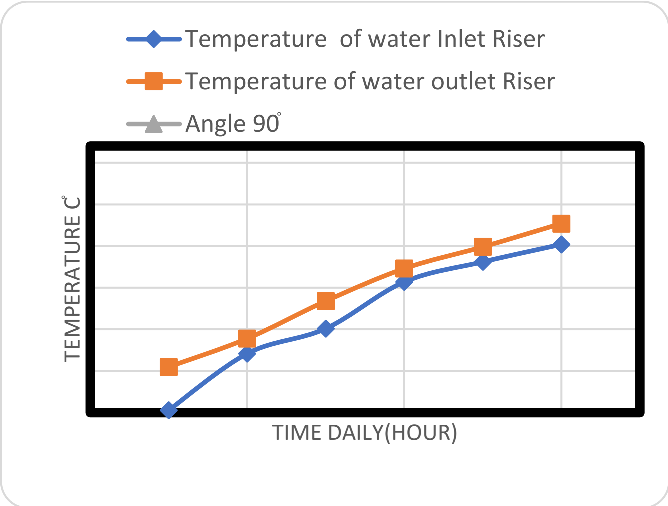

Figure 14. Temperature of water inlet & outlet riser at (13th of August)

Fig. 15 depicts the temperature of the inlet water (working fluid) in a solar collector at 33.4°C at 8 o'clock on the horizontal axis at 90°, with the degree of temperature outlet higher than the inlet, which increased to 58.5° during the 6-hour day.

Fig. 16 depicts the temperature of the inlet water (working fluid) in a solar collector at 32.9°C at 8 o'clock on the horizontal axis at 90°, with the degree of temperature outlet higher than the inlet, which increased to 56.1° during the 6-hour day.

Fig. 17 depicts the temperature of the inlet water (working fluid) in a solar collector at 32.4°C at 8 o'clock on the horizontal axis at 90°, with the degree of temperature outlet higher than the inlet, which increased to 56.3° during the 6-hour day.

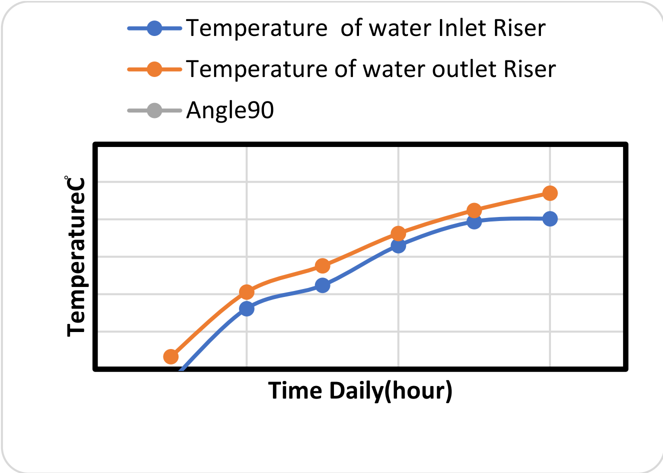

Figure 15. Temperature of water inlet &outlet riser at (14th of August)

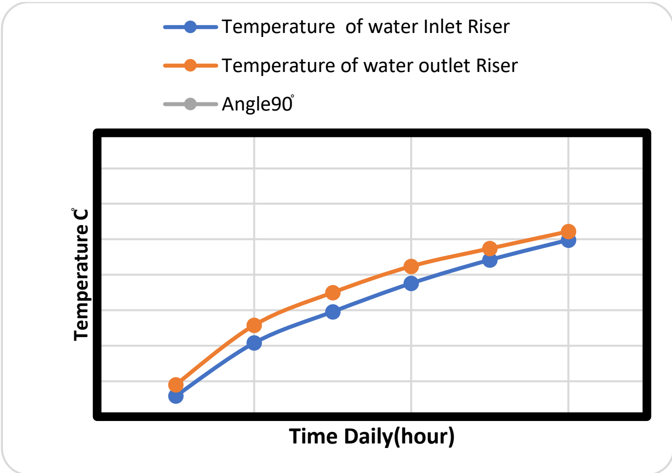

Figure 16. The temperature of the water on the third day (15th of August)

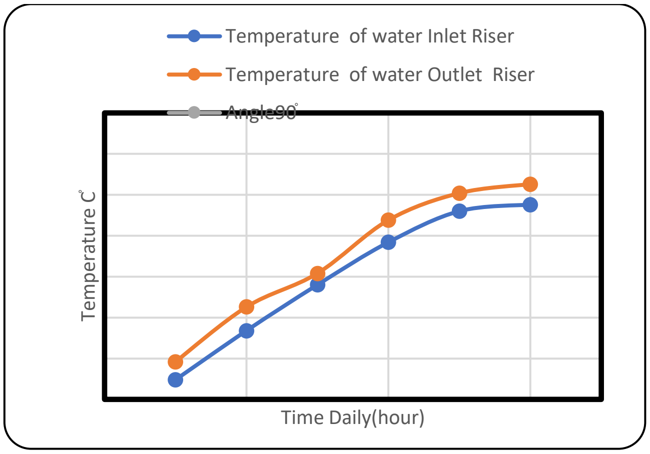

Figure 17. Temperature of water inlet &outlet riser at (16th of August)

Fig. 18 depicts the temperature of the inlet water (working fluid) in a solar collector at 32.1°C at 8 o'clock on the horizontal axis at 90°, with the degree of temperature outlet higher than the inlet, which increased to 56.5° during the 6-hour day.

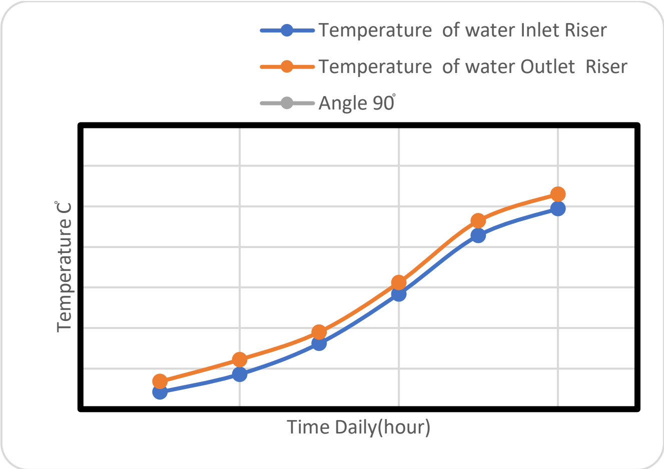

Figure 18. Temperature of water inlet &outlet riser at (17th of August)

Fig. 19 depicts the temperature of the inlet water (working fluid) in a solar collector at 31.8°C at 8 o'clock on the horizontal axis at 90°, with the degree of temperature outlet higher than the inlet, which increased to 56.9° during the 6-hour day.

3.1.2. charts of Temperature y for Rectangle cutting section twisted Tape (2pitch) Copper of Experimental work at 45∘ (position baseof rig)

Fig. 20 depicts the temperature of the inlet water (working fluid) in a solar collector at 31.1°C at 8 o'clock on the horizontal axis at 45°, with the degree of temperature outlet higher than the inlet, which increased to 64.4° during the 6-hour day.

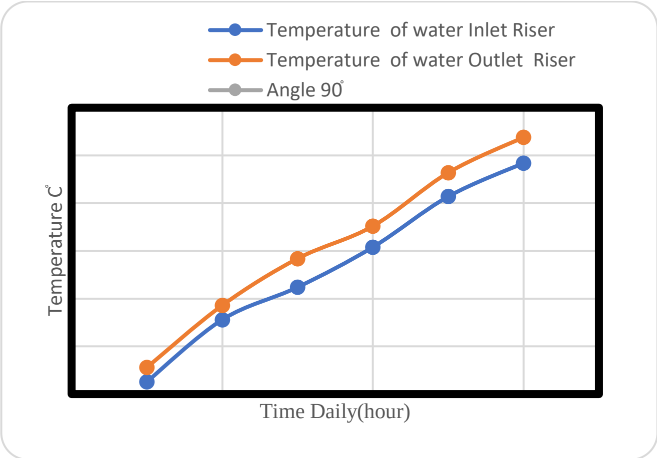

Figure 19. Temperature of water inlet &outlet riser at (18th of August)

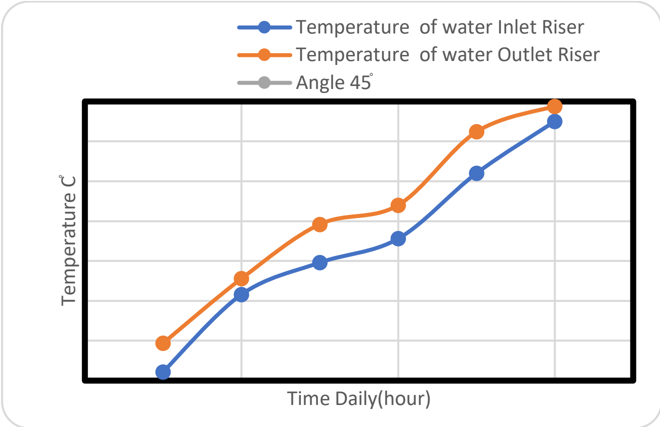

Figure 20. Temperature of water inlet &outlet riser at (19th of August)

Fig. 21 depicts the temperature of the inlet water (working fluid) in a solar collector at 31.6°C at 8 o'clock on the horizontal axis at 45°, with the degree of temperature outlet higher than the inlet, which increased to 61.8° during the 6-hour day.

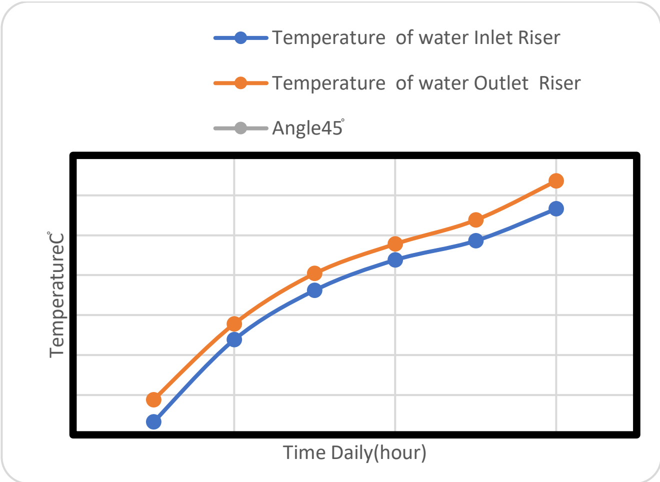

Figure 21. Temperature of water inlet &outlet riser at (20 of August)

Fig. 22 depicts the temperature of the inlet water (working fluid) in a solar collector at 30.3°C at 8 o'clock on the horizontal axis at 45°, with the degree of temperature outlet higher than the inlet, which increased to 61.9° during the 6-hour day.

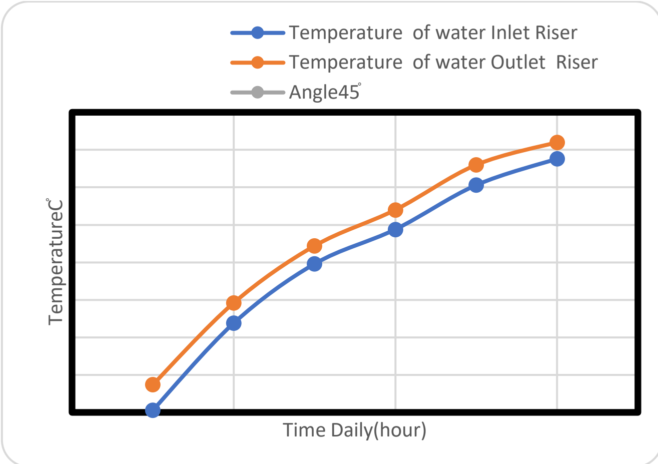

Figure 22. Temperature of water inlet &outlet riser at (21 of August))

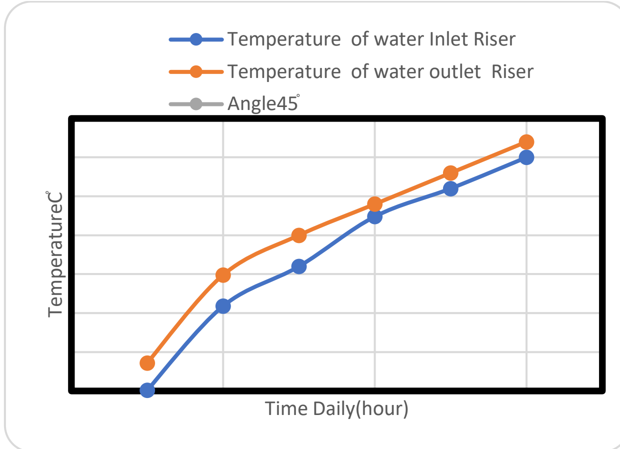

Figure 24. The temperature of the water inlet &outlet riser on (23 of August))

Fig. 23 depicts the temperature of the inlet water (working fluid) in a solar collector at 30.1°C at 8 o'clock on the horizontal axis at 45°, with the degree of temperature outlet higher than the inlet, which increased to 61.6° during the 6-hour day.

Fig. 25 depicts the temperature of the inlet water (working fluid) in a solar collector at 29.9°C at 8 o'clock on the horizontal axis at 45°, with the degree of temperature outlet higher than the inlet, which increased to 65.6° during the 6-hour day.

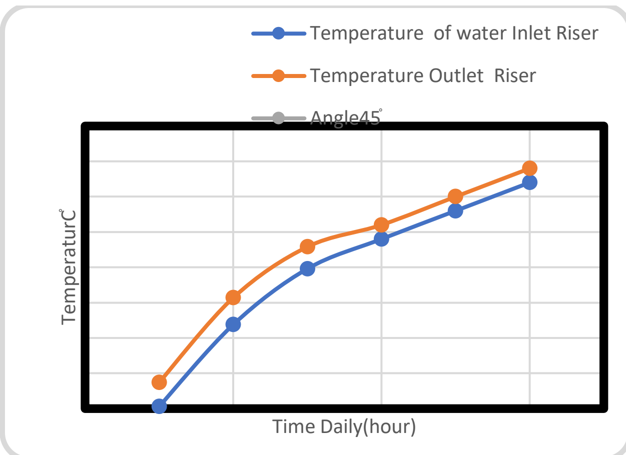

Figure 23. Temperature of water inlet &outlet riser at (22 of August)

Fig. 24 depicts the temperature of the inlet water (working fluid) in a solar collector at 30.8°C at 8 o'clock on the horizontal axis at 45°, with the degree of temperature outlet higher than the inlet, which increased to 61.8° during the 6-hour day.

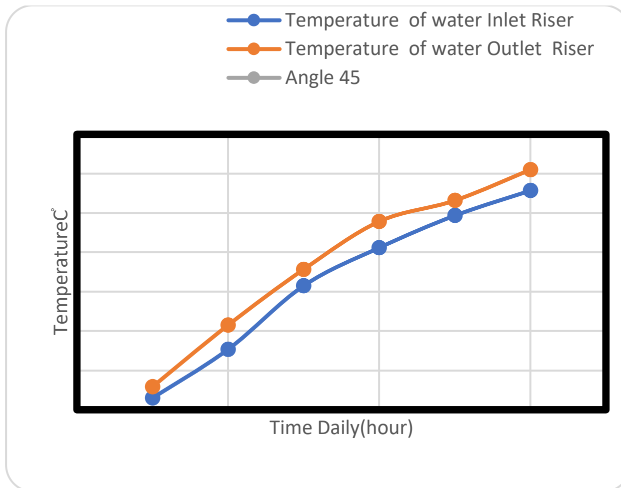

Figure 25. Temperature of water inlet &outlet riser at (24 of August)

3.2 Profiles of Temperature for Rectangle cutting section twisted Tape (2pitch) Copper Experimental Work at degree 90.

Fig. 26 represents the temperature of the water inlet and outlet during the risers in the flat plate solar collector on August 13th, changing the water from cold liquid at 35.3 °to hot liquid at 57.7 °in horizontal shape at 90°.

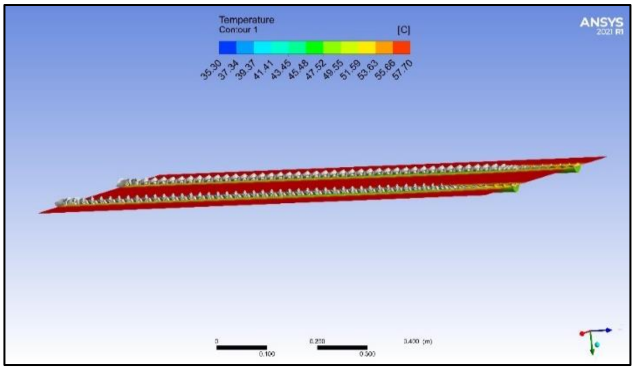

Figure 26. Temperature of water on (12th of August) all-day

Fig. 27 represents the temperature of the water inlet and outlet during the risers in the flat plate solar collector on August 13th. The water changes from cold liquid at 35.3 °to hot liquid at 40.5(first hour) °in horizontal place at 90°.

Fig. 28 represents the temperature of the water inlet and outlet during the risers in the flat plate solar collector on August 13th. The water changed from cold liquid at 42.1° to hot liquid at 43.9° (second hour) in a horizontal place at 90°.

Fig. 29 represents the temperature of the water inlet and outlet during the risers in the flat plate solar collector on August 13th. The water changed from cold liquid at 45.1° to hot liquid at 48.4° (third hour) in a horizontal place at 90°.

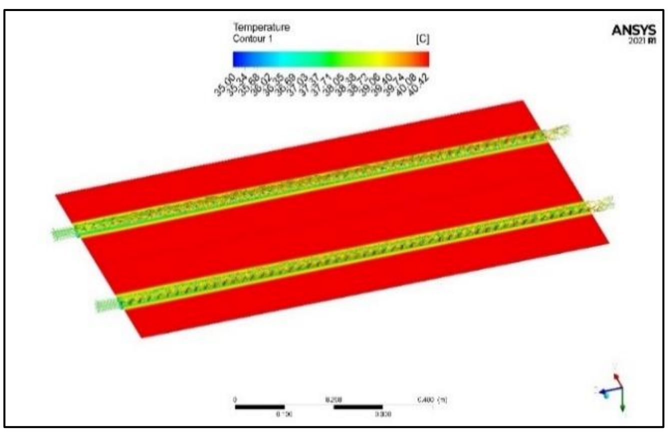

Figure 27. Temperature of water at (8 AM)

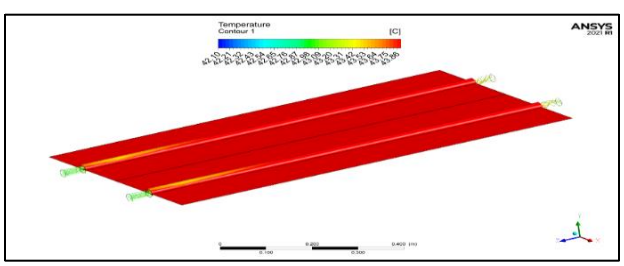

Figure 28. Temperature of water at (9 AM)

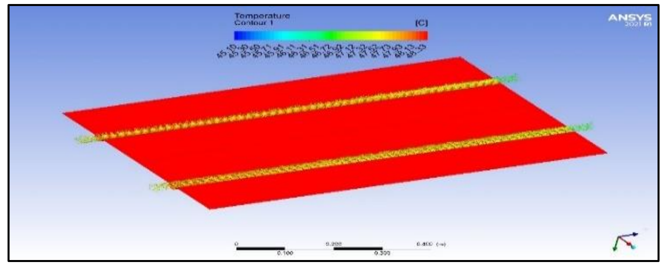

Figure 29. Temperature of water at (10 AM)

Fig. 30 represents the temperature of the water inlet and outlet during the risers in the flat plate solar collector on August 13th. The water changed from cold liquid at 50.7° to hot liquid at 52.3°(fourth hour) in a horizontal place at 90°.

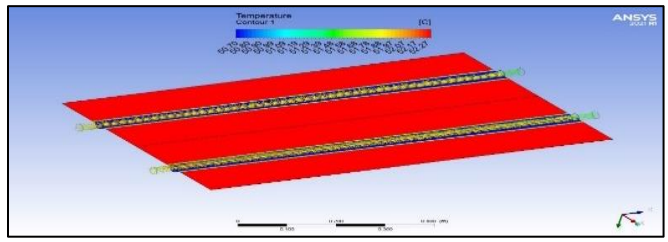

Figure 30. Temperature of water at (11 AM)

Fig. 31 represents the temperature of the water inlet and outlet during the risers in the flat plate solar collector on August 13th. The water changed from cold liquid at 53.1° to hot liquid at 54.9°(fifth hour) in a horizontal place at 90°.

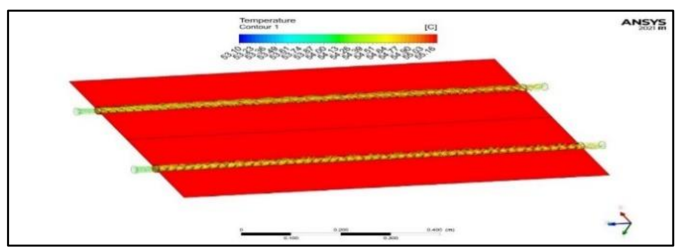

Figure 31. Temperature of water at (12 AM)

Fig. 32 represents the temperature of the water inlet and outlet during the risers in the flat plate solar collector on August 13th. The water changes from cold liquid at 55.9° to hot liquid at 57.7°(sixth hour) in a horizontal place at 90°.

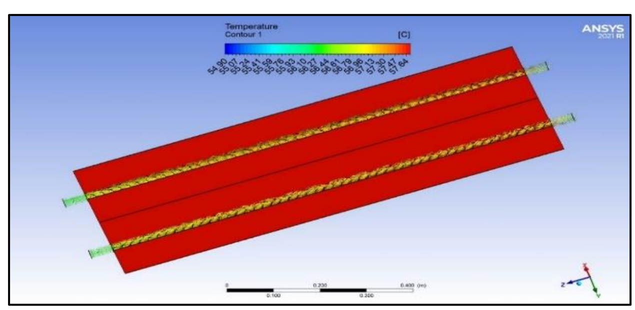

Figure 32. Temperature of water at (1 PM)

3.3. profiles of Temperature for Rectangle cutting section twisted Tape (2pitch) Copper Experimental Work at degree 45

Fig. 33 represents the temperature of the water inlet and outlet during the risers in the flat plate solar collector on August 24. It changes the water from cold liquid at 29.90 ° to hot liquid at 65.60 °in horizontal shape at 45.

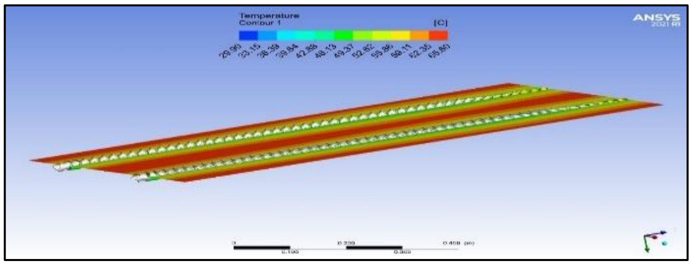

Figure 33. Temperature of water at all day (24-august)

3.4. profiles of Temperature for Rectangle cutting section twisted Tape (2pitch) Copper at numerical study

The water temperature at a numerical study in rectangle-shaped cutting is depicted in Fig. 34.

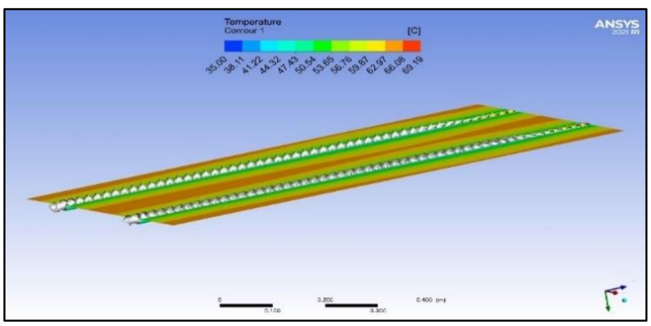

Figure 34. Temperature of water twisted tape at Numerical study

4. Experimental Numerical Evaluation

Fig. 35 represents the relationship between the experimental study at an angle of 90 and 45 and the digital, where the difference between each of the two studies is noted. The digital study has higher values than the experimental study due to losses in heat transfer in pipes and errors in measuring devices such as flowmeters, thermometers, thermocouples, etc.

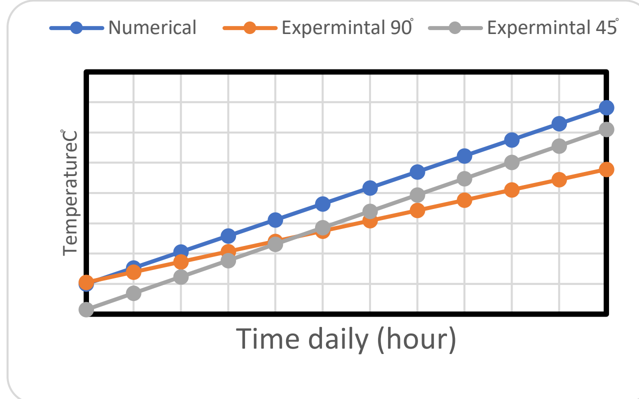

Figure 35. relationship between numerical & experminal90°,45° study (position base of rig)

5. Evaluation of the Model with Literate Model

The following drawing data was used in the previous study: a twisted tape at an angle of 45 degrees and of single copper, free of any cutting shape, with a width of (1.15), a step of (2.3), and a length of (160 * 40). It is compared with this study, with a twisted bar of copper containing a square cutting shape on each side of the twisted tape; in two cases, the angle is 90 and 45, and the dimension is (100*2.7*1) mm at pitch (2). It is noted that the efficiency of the twisted tape with the presence of pieces is better than the tape without obstruction, as the cutting helps to cause obstruction and thus helps to delay the water flow in the pipes. It helps to increase the heating period of the water for a longer period. This is shown in Fig. 36.

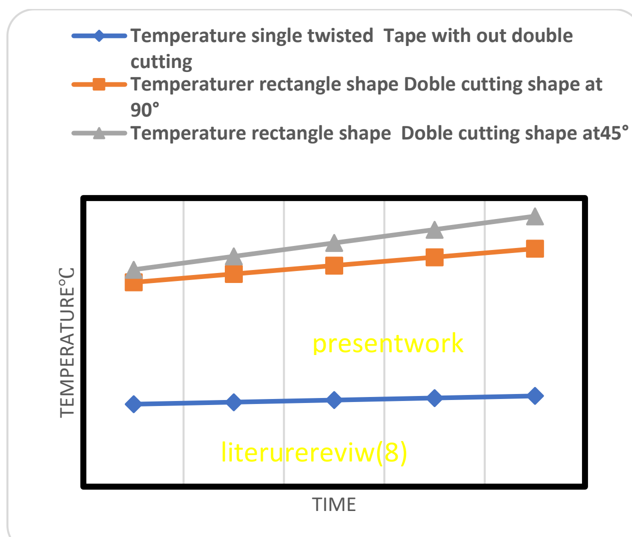

Figure 36. relationship between twisted tape at experminal90°,45° with cutting shape & single twisted tape without double cutting shape.

6. Conclusion and Future Work

The use of twisted tape raises the water outlet temperature when twisted with a rectangular double strip. The water temperature at the outlet rises by 5.2 C° on average at the horizontal axis at 90° solar collectors throughout the day from (35.3 C ° to 57.7 C °). The water temperature at the outlet rises by 5.4 C° on average at the horizontal axis at 45° solar collectors throughout the day from (29.9 C° to 65.5 C°). The Reynolds number becomes 14000 because of the tubes' turbulent state and friction factor of 7. Using two glass covers to reduce heat loss from the collector's top increases the water temperature at the outlet. When compared to one cover, the difference is approximately 4°C. The software gives accurate numerical results with high agreement compared to experimental results. It is appropriate for predicting pipe flow using twisted tape. Using other types of geometric shapes and having the pieces on the sides is recommended. A nanofluid with twisted tape may be used to increase the heating period.

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Nomenclature

Qu	Useful heat gain	W
Ac	Absorber plate area	m²
τ	Glass cover transmittance coefficient	-
α	absorptance coefficient	-
IT	Irradiance incident normal to the absorber plate	W/m2
ηc	Collector thermal efficiency	-
m*	fluid mass flow rate	
v	Kinematic viscosity	m^2/s
ρ	Density	kg/m^3

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Basima Salman proposed the research problem, verified the analytical methods, and investigated and supervised the findings of this work.

Sanaa Hassan Obaid developed the theory, performed the computations, discussed the results, and contributed to the final manuscript.

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