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Influences of the Twisted Strips Insertion on the Performance of Flat Plate Water Solar Collector

Jafar M. Hassan* **Qussai J. Abdul-Ghafour****
Mohammed F. Mohammed***
*,**,*** *Department of Mechanical Engineering / University of Technology*
*Email: Jafarmehdi1951@yahoo.com
**Email: kaisygj@yahoo.com
***Email: mohammed2007msc@yahoo.com

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Abstract

In order to enhance the efficiency of flat plate solar water collectors without changing in its original shape and with low additional cost, twisted strips are inserted inside its riser pipes. Three flat plate collectors are used for test. Family of twisted strips are inserted inside each collector risers with different twisted ratios (T_R=3,4,5). The collectors are connected in parallel mode (Z-Configuration) and are exposed to the same conditions (solar radiation and ambient temperature) .The experimental results show that, the highest heat transfer rate occurs at twisted ratio (3) .Consequently, for the same twisted ratio the daily efficiencies for the solar collector at different flow rate used (60,100 and 150) ℓ /hr. were 49 %, 57% and 63% respectively.

Keywords: *Twisted strip, solar collectors.*

1. Introduction

Extensive researches, both numerically and experimentally had been conducted on the operating and performance study of thermosyphon and forced circulation on the solar water heating systems. These studies, however, were mainly focused on the design and optimization of the overall system with little attention given to study the thermofluid behavior inside the collector. In recent years, many techniques have been proposed for enhancement of the heat transfer rate. These can be classified into two main groups: Passive technique not requiring additional power sources and active technique requiring additional external power inputs. In the case of the passive technique, convection heat transfer from surfaces with attachments of different solid shapes at different geometries, such as baffles, fins, ribs, twist strips, have been exploited, especially; twisted strip which is widely used in many industries**.** The experimental investigations of twist strip and wire coil for enhancing heat transfer and efficiency have been being appeared by Rose and Briggs [1] experimentation both strip and wire coil that's carried out in the range of Reynolds number from (5000 – 45,000) and Prandtl number from (0.7–30). The maximum heat enhancement for twisted strip and wire coil insert is 3.5 and 2.0 times higher than the plain one. Influences of the twisted strip insertion on heat transfer and flow friction characteristics in a concentric double pipe heat exchanger have been studied experimentally by Watcharin et al. [2] the swirling flow was introduced by using twisted strip placed inside the inner test tube of the heat exchanger with different twist ratios (T_R=5,7). The experimental results revealed that the increase in heat transfer rate of the twisted-strip inserts is found to be strongly influenced by strip-induced swirl generation or vortex motion. Over the range investigated, the maximum Nusselt numbers for using the enhancement devices are (188%) and (159%) respectively, higher than that for the plain tube. Alireza and Kamran [3] study experimentally the impact of heat enhancement devices on the thermal performance of Single-tube flat-plate solar collector. Different passive heat enhancement devices that include twisted strip, coil-spring wire and conical ridges were studied. The flow rate is close to the typical flow rates in thermosyphon (natural). The comparison showed that the heat enhancement devices are ineffective in enhancing heat transfer rate in the studied range and geometry. Nagarajan et al. [4] investigate experimentally the heat transfer and friction factor characteristics of solar parabolic through collector fitted with full length twisted strips inserts of twist ratio (6, 8 and 10) have been presented. The transitional flow regime is selected for this study with the Reynolds number range (1192 to 2534). The experimental data obtained were compared with those obtained from plain tube published data. The effects of full length twisted strip inserts on heat transfer and friction factor were presented. The heat transfer coefficient enhancement for twisted inserts is higher than that for plain tube for a given Reynolds number. Herrero M. et al. [5] present an enhancement techniques that be applied to flat-plate liquid solar collectors towards more compact and efficient designs. Tube-side enhancement passive techniques can consist of adding additional devices which are incorporated into a smooth round tube (twisted strips, wire coils), modifying the surface of a smooth tube (corrugated and dimpled tubes) or making special tube geometries (internally finned tubes). For the typical operating flow rates in flat-plate solar collectors, the most suitable technique is inserted devices. This type of inserted device provides better results in laminar, transitional and low turbulence fluid flow regimes. Akeel and Ameer [6] Study the heat transfer in a horizontal tube by means of six types of twisted tape inserts for the range of Reynolds number extends from 4500 to 23500 as follows : normal twisted tape regularly spaced twisted tape, triangular-cut twisted tape, rectangular-cut twisted tape, semicircular-cut twisted tape, and drilled twisted tape. The experiential results show that the enhancement of heat transfer increases as the type of twisted tape changes from one to six, respectively. Withada and Amnart [7] present a numerical analysis of laminar fully developed periodic flow and heat transfer in a constant temperature-surfaced circular tube with single twisted tape inserted. The twisted tape is introduced and inserted in the middle of the tested tube. The effects of twisted ratios (1, 2, 3, 4, 5and 6) are presented for Reynolds number values ranging from Re = 100 to 2000. They found that the heat transfer in the circular tube with the twisted tape is more effective than that with no twisted tape inserted. The increase in the twist ratio leads to decrease in the Nusselt number and friction factor. The objective of the present work is to enhanced the performance of the flat plate solar collector by inserting twisted strips with ratios (T_R=3, 4 and 5). The task was accomplished by connecting three collectors in (Z-Configuration) parallel mode at different flow rates.

2. Experimental Work

2.1. Experimental Test Rig

The experimental test rigs consist of three identical flat plate solar collectors, each one with absorbing area (80cm * 120cm) with one glass cover as shown in Fig. 1. Also, it consists of eight equally spaced (10cm) parallel copper riser pipes of (10.5mm inner and 11mm outer) diameters, and (1200mm) length. These pipes are connected with two headers, one on each end. The joints between headers and copper pipes ends are made by adapter screws as shown in Fig. 2. The main purpose of these adapter screws is for easy separating of riser pipes from the headers to inserting twisted strips inside them. A copper sheet with (0.5mm) thickness is used as the solar radiation absorber as shown in fig. 3. The riser pipes are fixed on the absorbing plate by welding lead along the riser's pipes. The absorbing plate was manufactured in fabricated way through the work as curve surrounds riser pipes to increase the surface area of contacts between them as shown in Fig. 4.

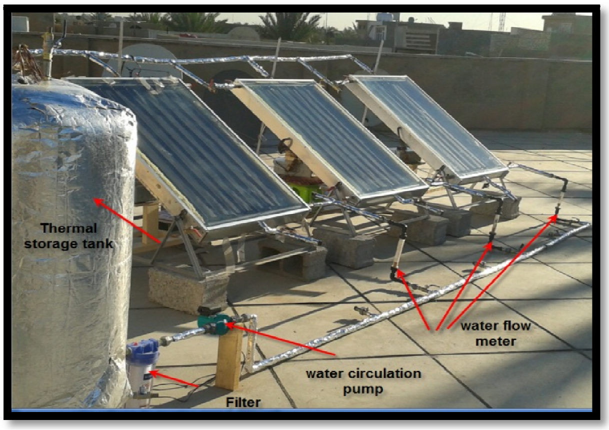


Fig. 1 Experimental test rig.

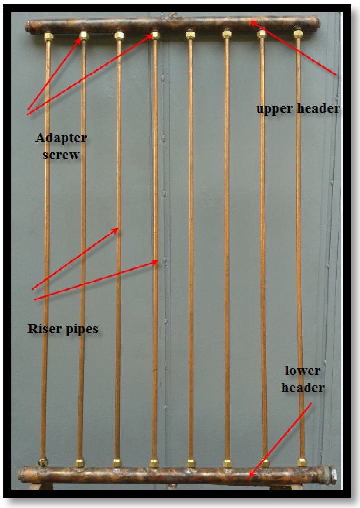


Fig. 2. Joins header and riser piped end by adapter screw.

Fig. 3. copper sheet welding to the riser pipes.

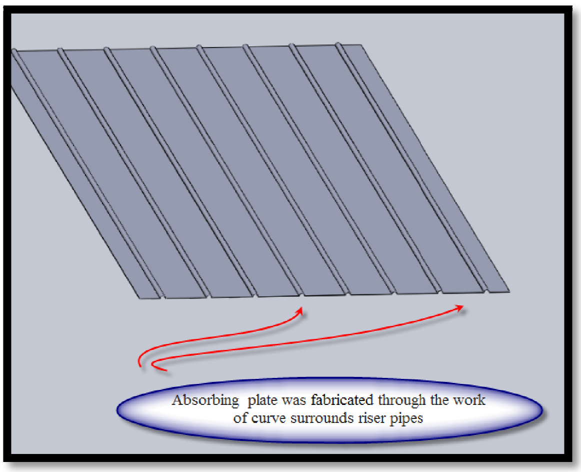


Fig. 4. Absorbing plate geometry.

The collector frame is made of aluminum bars of (1.5mm) thick. A glass sheet is used as a transparent cover (4mm) thick of the collector. A glass wool insulation of (50 mm) thickness was used as insulator to decrease the collector back and side heat losses. A cylindrical galvanized steel tank with (0.58 m) outside diameter and (1 m) height is used for storing hot water. The tank is insulated by a (50mm) thickness glass wool. In order to circulate the water in the system, a small circulation water pump (CRS25/4-180) is used in closed loop to make the forced circulation. The water flow rate in the closed loop is controlled by using valves and measured with flow meter (lzs-15-Range (60-600LPH) with accuracy 4%. The flow rates used, are (60,100 and 150) ℓ /hr. The spray paint (RUSTOLEUM high heat) as the absorber surface paint is used. This Coating has high absorptance (0.92-0.96) for solar radiation is used to substrates with low emittance (0.24) [8].

2.2. Measuring Devices and Data Analyzing

In order to measure the temperature at various points of the absorbing plate, inlet and outlet of collectors, T-type thermocouple (copper-constantan) with the accuracy of (±0.5 °C) is used [9]. The thermocouples were calibrated before beginning of the experiments. The measurement of the temperature distribution of the absorbing plate is done using three thermocouples, one located at the centerline of the absorbing plate and the others at top and bottom with space distance of (50cm) from the centerline as shown in Fig. 5. All thermocouples are connected to the data logger, that's connected to a digital electronic thermometer (UT325-0.1C resolution). The data is interfaced to the computer and then displayed as a table. The ambient temperature is measured using a digital electronic thermometer. The solar power radiation on the collector is record by solar meter with rang varied from (0 to 2000 W/m^{2}). This device measures the total solar radiation (beam and diffuse) per unit area of the collector surface. The solar power meter was oriented due to the south at the collector tilt angle (30). This device can read the data and save them in (SD Ram).

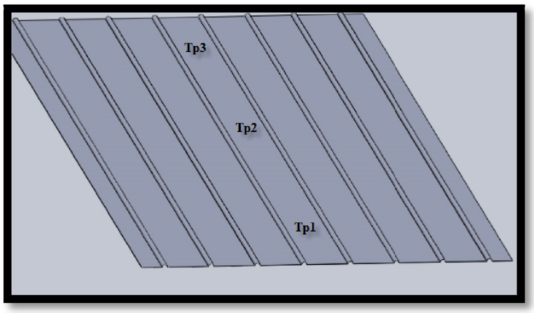


Fig. 5. Position of thermocouples of absorber plate.

The governing equations used in the present work are**:**

1. Water mass flow rate ($\dot{m}_w$)

$$\dot{m}_w = \rho_w \cdot \dot{V}_w \quad \ldots(1)$$

The water density varies with its temperature according to the equation [10]

$$\rho_w = 1000 * (1 - (T + 288.9414)/(508929.2 * (T + 68.12963)) * (T - 3.9863)^2 \quad \ldots(2)$$

2. Useful energy (Q_u)

$$Q_{u_{water}} = \dot{m}_w \cdot (C_p)_{water} \cdot (T_{fout} - T_{fin}) \quad \ldots(3)$$

3. The collector efficiency for individual solar collector

$$\eta\ water = \frac{Q_{u_{water}}}{A_c \cdot G_T} \quad \ldots(4)$$

4. The mean fluid temperature is calculate by

$$T_m = \frac{T_{fin} + T_{fout}}{2} \quad \ldots(5)$$

2.3. Test Model

In this model, using twisted strip was to investigate the influence of heat enhancement devices on the thermal performance of the flat plate solar collector arrays. In this study, the twisted strips elements are made from thin, flat strips of thickness (0.7 mm) and (10.5mm) wide of aluminum material and are twisted through (180 degree) to form helices shapes. The strips are twisted in different ratios (T_R=3,4,5) as shown in fig. 6 .Helices rotations of this ratios are formed for a full length of riser pipes of (1100 mm) as shown in Fig. 7. In this model, three flat plate solar collectors connection in parallel (Z configuration)as shown in fig.8 (Collector one with twist ratio 3, Collector two with twist ratio 4 and Collector three with twist ratio 5) for different flow rates .The twist ratio is defined as:

$$T_R = \frac{P}{W} \quad \ldots(6)$$

The twist strip geometry as shown in Fig. 9.

2.4. Test Procedure

The forced circulation of solar flat plate collectors were connected as a closed loop. The experiment was carried out in Baghdad from (15th April to 10th May 2014) and these experiments were carried out during sunny days only .The slope angle of three closed looped collectors in (30 deg. due to south). The collectors was tested under steady-state conditions in which the solar intensity, ambient temperature, inlet and outlet temperature difference were considered constant for period of time. The period was taken as half an hour for a clear day. The type of test was to estimate the instantaneous performance of the system. The system was tested with three different flow rates of water through the collector loop . These flow rates were (60,100 and 150)ℓ /hr. In each case, experiments usually started at 8 am and continued until 5 pm .In each test and each time period all the measurements of temperatures, solar radiation intensity were recorded for each collector. Each test was repeated twice at different periods of time to ensure the experimental repeatability.

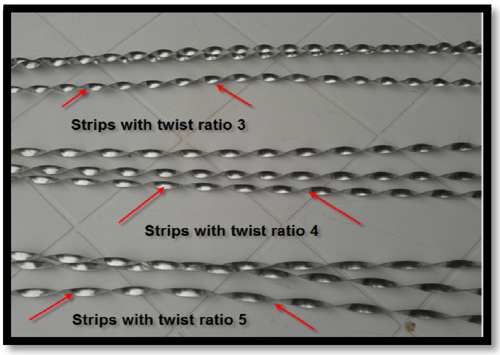


Fig. 6. A twist strips with different twist ratios.

Fig. 7. A twisted strip inside riser pipe.

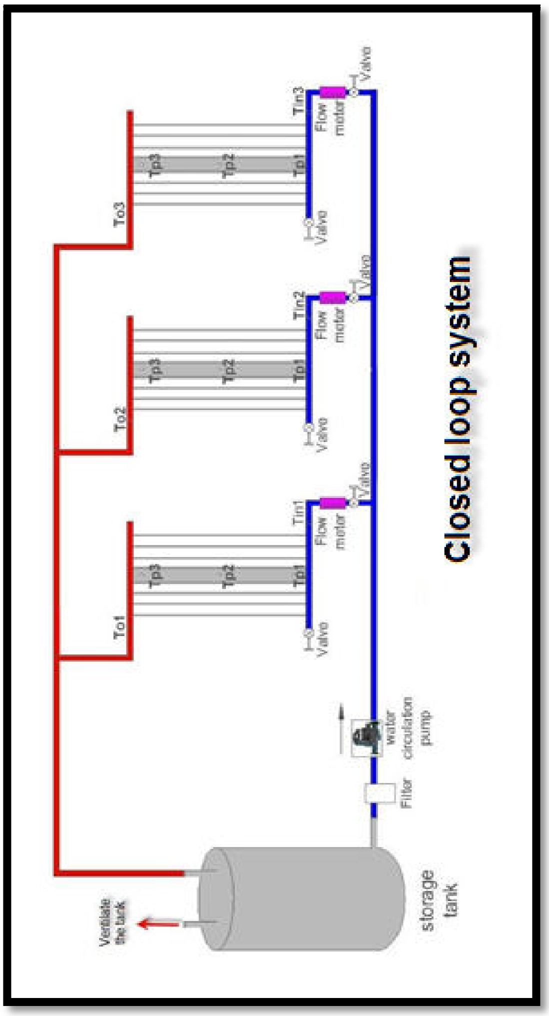


Fig. 8. Schematic diagram of test rig .

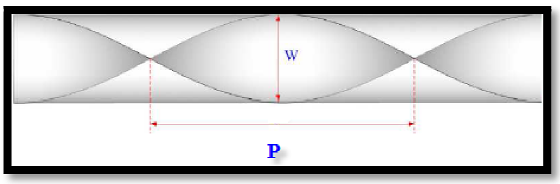


Fig. 9. Twisted strip geometry.

3. Results and Discussion

3.1. Relationship between Solar Energy and Useful Energy

Fig 10. Shows the useful energy have the same trends of the solar radiation. The results show that, when the water flow rate inlet to the collector increases, the useful energy gain increases. This affects due to, as the flow rate increases, the temperature rise through the collector decreases. This causes lower losses and therefore a corresponding increase in the gain of the useful energy. The value of useful energy of the collector with inserted strip of twist ratio 3 is higher than the others for the same solar intensity. This effect results the intensity of swirl generation. As the twist ratio decrease, swirl generation increase, which would maximize the particle mixing and hence the heat transfer coefficient.

3.2. The Absorber Plate Temperature Variation

Fig.11 shows, the temperature distribution of the absorber plate and ambient temperatures with time with different twist ratios. Among the various twist ratios, the minimum twist ratio (3) is found to have the lowest absorber plate temperature for all flow rate ranges due to effective of heat transfer by swirl and fin effects. As the twist ratio increase, the swirl generation and fin effect decreases and minimizes the heat transfer and increase the absorber plate temperature. Table (1,2 and 3) shows the variation of absorber plate temperature with time for the flow rate inlet at 150ℓ/hr.

3.3. Effect of Twist Ratio on Thermal Performance Analysis

According to the flow rates range in the present work The instantaneous collector efficiencies curves are shown in Fig's (12,13 and 14) been observed clearly that as the flow rate increases, the efficiency of the solar collector also increases. The increase in the flow rate, leads to temperature difference decreases. The decreasing of the temperature difference lead to the maximum energy transfer from the riser tube to fluid, then the collector efficiency will increase. For the same values of the solar radiation the maximum efficiency is obtained in minimum twist ratio (3), because the swirl generation is maximum in this twist ratio, which would increase the heat transfer of fluid travel. The experimental daily efficiencies for the solar collector used strips with twist ratio (3) and flow rate of order 60,100 and 150 l /hr. are 49 %, 57% and 63% respectively. Tables (4, 5 and 6) show the instantaneous collector efficiencies with time for different flow rates.

Table 1,
Absorber plate temperature at twist ratio (3).

Time	Tp1	Tp2	Tp3
8.00 am	30.8	32.9	37
8.30am	32.3	34	39.5
9.00am	36.6	39.5	43.5
9.30am	41.2	43.2	46
10.00am	44.6	48.3	52
10.30am	47.4	50.2	53.2
11.0am	51.2	52.9	56.3
11.30am	54.3	56.8	58.6
12 noon	57.4	60.9	63.4
12.30pm	61.8	64.3	67
1.00pm	64.7	68.4	70
1.30pm	66	68.8	70.5
2.00pm	67.7	70.5	72.4
2.30pm	68.3	70.4	71.5
3.00pm	66.3	68.5	70.7
3.30pm	64.2	66.5	68.7
4.00pm	62.1	65	67.3
4.30pm	60.2	64	65.2
5.00pm	58.5	61.5	63

Table 2,
Absorber plate temperature at twist ratio (4).

Time	Tp1	Tp2	Tp3
8.00 am	31	33.5	38.4
8.30am	33	34.5	40.6
9.00am	37	40.6	43.5
9.30am	42.2	44.2	46.5
10.00am	45	49	52.6
10.30am	48.6	50.7	53.2
11.0am	52	54.3	57.1
11.30am	55.2	57.7	59.3
12 noon	58.5	61.5	64
12.30pm	62.8	65.2	67.7
1.00pm	65.5	69	70.5
1.30pm	67	69.1	70.4
2.00pm	68.1	71	72.4
2.30pm	69	71.4	72.2
3.00pm	67.4	69.3	71.2
3.30pm	65.3	67.5	69.5
4.00pm	62.1	65	67.3
4.30pm	60.2	64	65.2
5.00pm	58.5	61.5	63

Table 3,
Absorber plate temperature at twist ratio (5).

Time	Tp1	Tp2	Tp3
8.00 am	31.7	34	39.9
8.30am	34	35.3	41
9.00am	38.2	41.2	44.5
9.30am	42.7	45.3	47.1
10.00am	45.5	49.7	53.2
10.30am	49.2	51.6	55.2
11.0am	52.9	55.1	58.6
11.30am	55.8	58.2	60
12 noon	59	61.8	64.5
12.30pm	63.5	65.8	68
1.00pm	66	69	70.7
1.30pm	67.4	69.3	71.7
2.00pm	68.5	71.5	72.9
2.30pm	69.6	71.9	72.7
3.00pm	68.3	69.5	71.5
3.30pm	66.8	68.5	70
4.00pm	65	66.5	68.5
4.30pm	63.7	65	67.3
5.00pm	61.5	63.5	65.7

Table 4,
Instantaneous collector efficiencies with time at flow rate (60 ℓ/hr.).

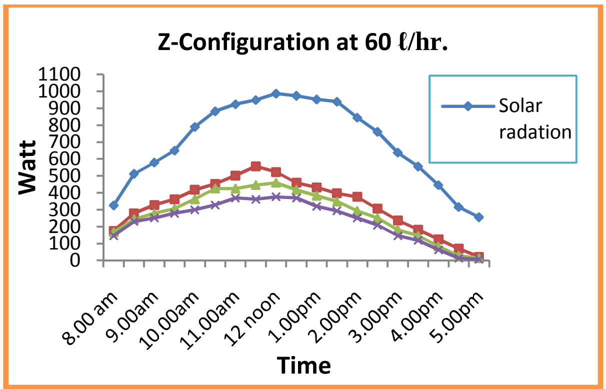
Time	η_i-TR3	η_i-TR4	η_i-TR5
8.00 am	0.533	0.5145	0.45
8.30am	0.544	0.47	0.44
9.00am	0.56	0.48	0.4333
9.30am	0.55	0.47	0.4287
10.00am	0.52	0.45	0.3792
10.30am	0.51	0.481	0.3712
11.0am	0.54	0.46	0.39
11.30am	0.58	0.47	0.38
12 noon	0.529	0.4658	0.38
12.30pm	0.471	0.4289	0.3788
1.00pm	0.453	0.4023	0.33
1.30pm	0.422	0.371	0.3116
2.00pm	0.445	0.3465	0.297
2.30pm	0.402	0.329	0.2747
3.00pm	0.37	0.284	0.2295
3.30pm	0.32	0.2633	0.2132
4.00pm	0.28	0.187	0.1408
4.30pm	0.221	0.089	0.044
5.00pm	0.08	0.054	0.02

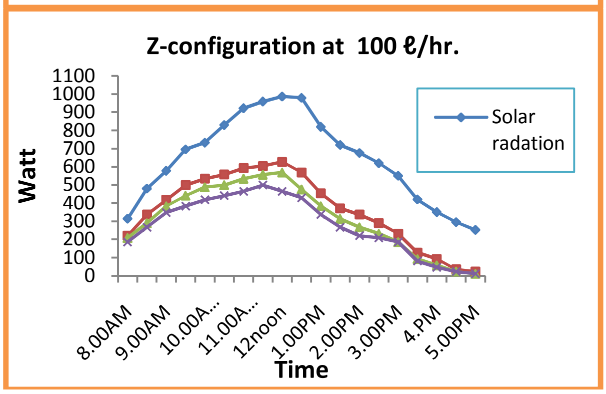
Table 5,
Instantaneous collector efficiencies with time at flow rate (100ℓ/hr.).

Time	η_i-TR3	η_i-TR4	η_i-TR5
8.00 am	0.7	0.6662	0.5921
8.30am	0.7017	0.6049	0.5565
9.00am	0.7234	0.6631	0.6028
9.30am	0.7177	0.6343	0.5508
10.00am	0.7287	0.6653	0.5703
10.30am	0.6715	0.6015	0.5316
11.0am	0.6419	0.5789	0.5034
11.30am	0.6291	0.5807	0.5202
12 noon	0.6352	0.5764	0.4705
12.30pm	0.5808	0.486	0.4386
1.00pm	0.5522	0.4673	0.4106
1.30pm	0.516	0.4354	0.3709
2.00pm	0.4981	0.395	0.3263
2.30pm	0.46	0.3745	0.32
3.00pm	0.42	0.3378	0.3378
3.30pm	0.3041	0.2211	0.1935
4.00pm	0.26	0.1659	0.1327
4.30pm	0.11	0.0787	0.0787
5.00pm	0.0921	0.0461	0.0461

Table 6,
Instantaneous collector efficiencies with time at flow rate (150 ℓ/hr.).

Time	η_i-TR3	η_i-TR4	η_i-TR5
8.00 am	0.7776	0.73	0.6957
8.30am	0.7983	0.79	0.69
9.00am	0.7569	0.7569	0.72
9.30am	0.77	0.77	0.7
10.00am	0.78	0.73	0.65
10.30am	0.7587	0.7	0.6225
11.0am	0.7461	0.7088	0.6342
11.30am	0.7112	0.67	0.57
12 noon	0.7256	0.6	0.55
12.30pm	0.6352	0.58	0.52
1.00pm	0.6134	0.55	0.5
1.30pm	0.5681	0.5289	0.45
2.00pm	0.53	0.48	0.4
2.30pm	0.5066	0.46	0.37
3.00pm	0.47	0.39	0.2909
3.30pm	0.43	0.36	0.3
4.00pm	0.3475	0.28	0.15
4.30pm	0.2143	0.1	0.0536
5.00pm	0.0781	0.07	0.6957





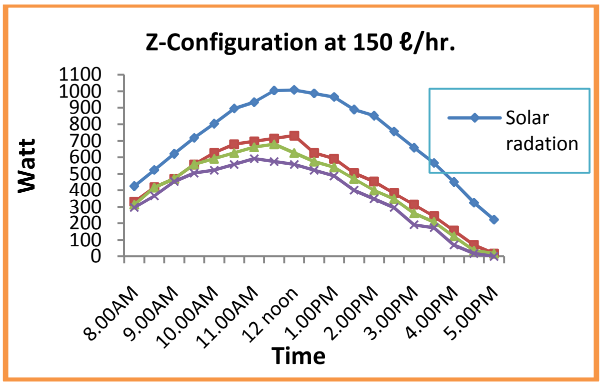
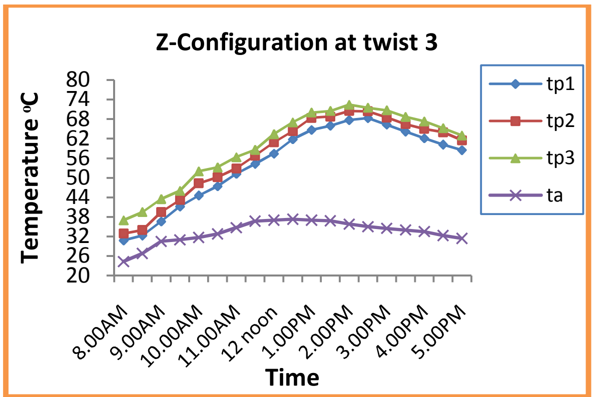
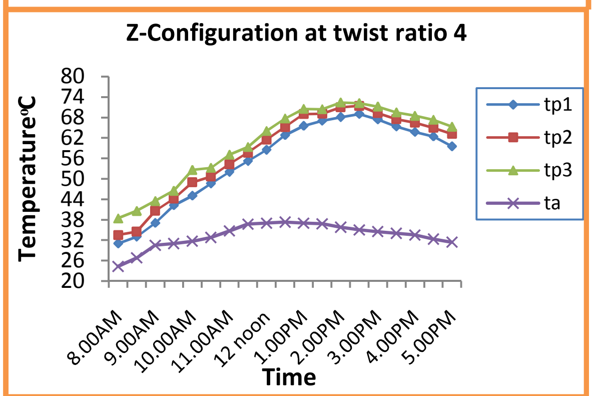


Fig. 10. Relationship between useful energy and solar radiation for different twist ratio and flow rates in Z-Configuration.





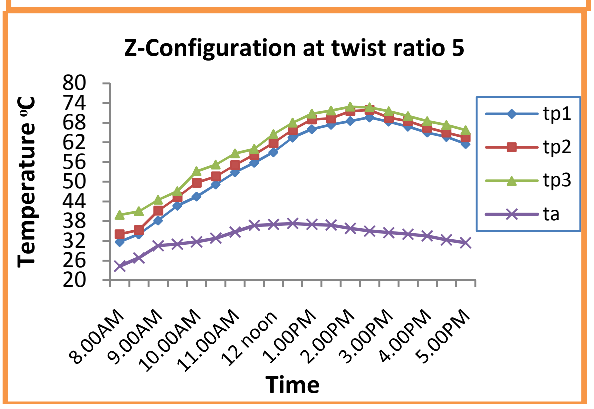


Fig. 11 Relationship between absorber plate and ambient temperatures during day hours at 150 ℓ/hr.

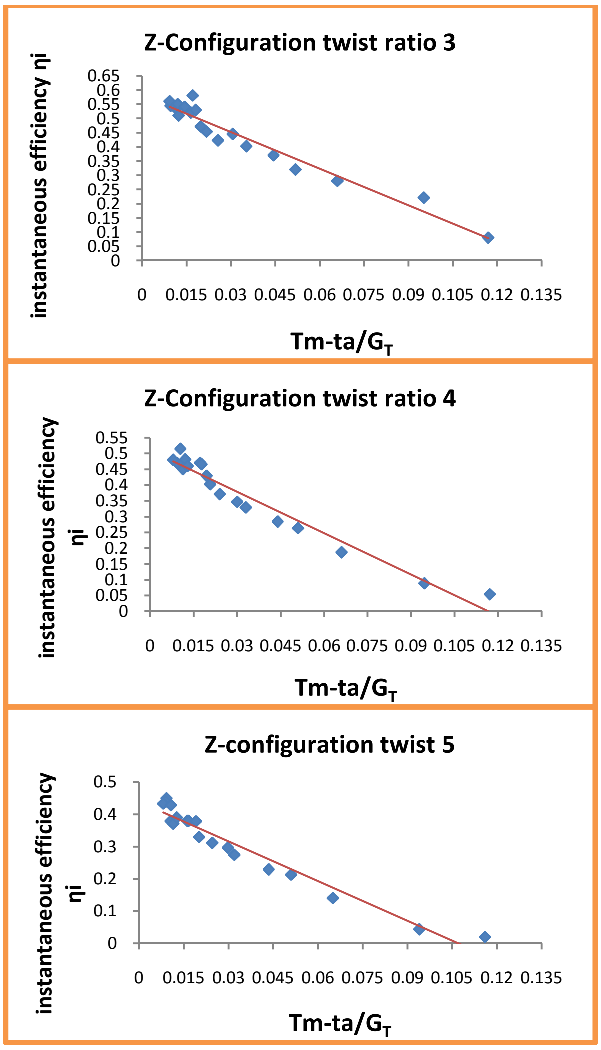
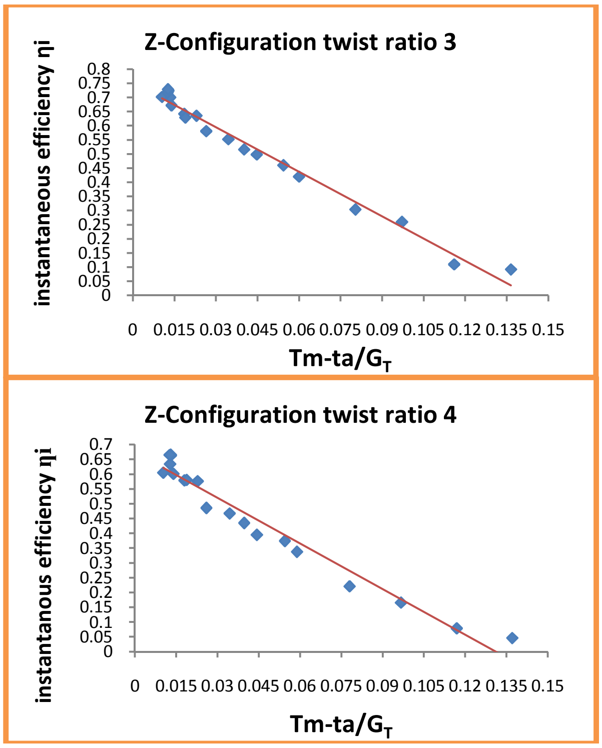


Fig. 12. Performance test 60 ℓ/hr. at different twist ratios.



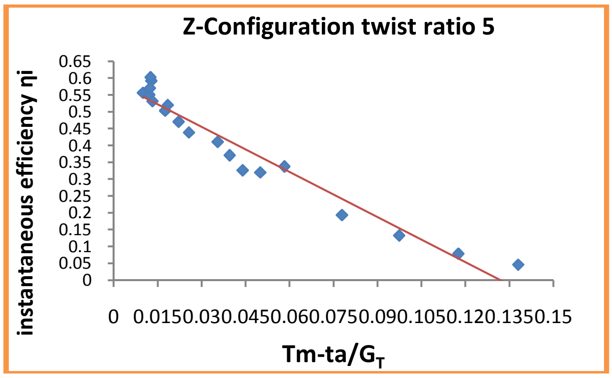


Fig. 13. Performance test 100 ℓ/hr. at different twist ratios.

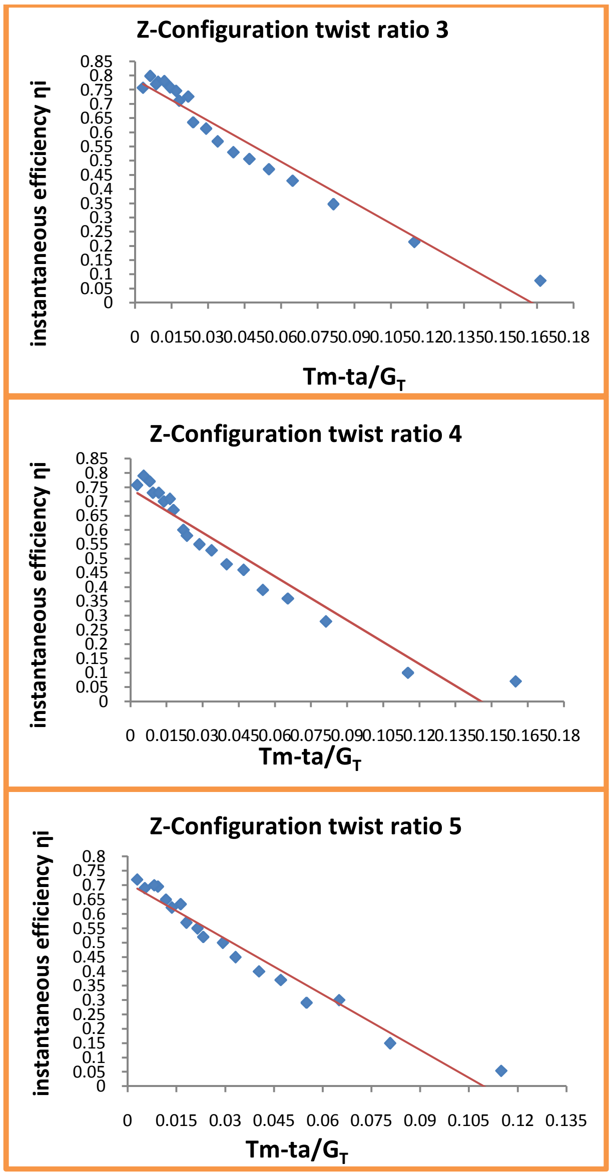


Fig. 14. Performance test for 150 ℓ/hr. at different twist ratios.

4. Conclusions

From the present work, we can conclude that:

- The collector with minimum twist ratio (3) is found to have the lowest absorber plate temperature for the same test condition.
- According to the flow rate ranges, the instantaneous collector efficiencies increase with increasing the flow rate for all twist ratios.
- The maximum efficiency is obtained in minimum twist ratio (3), for all flow rates range presented in this work
- The swirl generation and amount of heat transfer inside riser's pipes increase whenever twist ratio decreases.

Nomenclature

A_c	Collector area (m^2)
$C_{p_{water}}$	Specific heat capacity of water (kJ/kg.K)
F_R	collector heat removal factor
G_T	Incident solar radiation (W/m^2)
$\dot{m}_w$	Water mass flow rate (kg/s)
$\dot{V}_w$	Water volume flow rate (m^3/s)
P	Strip pitch (mm)
$Q_{u_{water}}$	Useful energy(W)
ta	Ambient temperature ºC
T_{fin}	Fluid in temperature ºC
T_{fout}	Fluid out temperature ºC
T_m	Mean fluid temperature ºC
T_P	Absorber plate temperature ºC
T_R	Twist ratio
W	Strip width (mm)
ρ_w	Water density kg / m^3
$\eta_{\ water}$	Collector efficiency
η_i	Instantaneous efficiency

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تأثير ادخال شرائط ملتوية على اداء مجمعات الماء الشمسية المسطحة

جعفر مهدي حسن*   قصي جهاد عبد الغفور   محمد فوزي محمد*****

،،***قسم الهندسة الميكانيكية/ الجامعة التكنولوجية*

Email: Jafarmehdi1951@yahoo.com *

Email: kaisygj@yahoo.com**

Email: mohammed2007msc@yahoo.com ***

الخلاصة

لغرض تحسين كفاءة مجمعات الماء الشمسية المسطحة بدون احداث تغيير في الشكل الاصلي مع اضافة بسيطة للتكلفة، تم اقحام شرائط ملتوية داخل انابيب رفع الماء. تم استخدام ثلاثة مجمعات شمسية مسطحة لغرض الدراسة. حيث وضعت مجموعة من الشرائط الملتوية مختلفة في نسبة الالتواء (TR=3,4,5) داخل انابيب رفع الماء لكل مجمع . تم ربط المجمعات على التوازي (شكل Z–) وتعريضها للضروف نفسها (شدة الاشعاع الشمسي و درجة حرارة المحيط). اوضحت النتائج العملية ان اعلى معدل لانتقال الحرارة حصل عند نسبة التواء (٣). ونتيجة لذلك و لنسبة الالتواء نفسها كانت قيمة الكفاءة اليومية للمجمع الشمسي لعدد من قيم معدل الجريان (60,100,150) لتر/ ساعة بلغت 49%، 57% و 63% على التوالي .