Thermal Performance Analysis of Thermosyphon Solar Water Heating System Fitted with a Spiral Tube

Kabas Aziz Hassan , Ra'ad K Mohammed Al Dulaimi
Mechanical Engineering Department, Engineering College/ Al-NahrainUniversity, Iraq.
T5gr1v282@gmail.comdr.raadaldulaimi@eng.nahrainuniv.edu.iq

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Abstract

The aim of this thesise is work to improve the heat trnsfer of the thermosyphon solar water heater flat plat type experimentaly by adding twisted tap to one tube model and compered the results with two other tubes types to reach the best improvement results in thermal efficincy and exergy. As a result, goal of this study is to produce the best absorbers of solar raddition , from the suggested.The three used tubes models (normal tube,twisted tube and twisted tube fitted with twisted tapes) in a same determinig measurming and arrengment as flat plat.The last type estemite should achieve the highest result.The flat shap is one of the best shapes,that due to it make largest surface area it provides in front of the solar raddition . As a result, a largest amount of solar heat will transfer to the fluid flow inside the tubes.In this work three models of SWH are used. The purpose of inserting the twisted tape was to facilitate contact between the HTF particulate and the tube's biggest heated surface, which was heated by solar radiation.. This done by the swirel path of the tube, making circlation in motion of HTF, there fore more particales will be contacted with heat tube surface and eventoly, will be mixed with each other. The twisted tapes inside the twisted tube repeate this mothion ,where the circlation in this way will be doubled .This can be effective way to achieve greater heat absorption in less cost and without need extra external device in order to improve the thermal performance of SWH.The three types were tested experimentally for two objectives: high self-circulation and high thermal performance.The test was done by filling the storge tank with water every morning , then took reading as water level reached a stable state inside the tanke. Temperature difference ΔT, self circulation , pressure difference Δp, thermal efficiency ηth , exergetic performance ηex , and Nusselt number Nu were calculation by mathmatical equations.The test was done in Baghdad/Al-Nahrain university .With continuous work [1-30 , 2022 march] and repeated the tests for each model were performed until the most accurate results were obtaind. It was proven that the new design tube model(TTTT) was The most effective one compered to the other types regarding the setled goals. The results showed that the new design had the following measures: (Nu= 913.71),(ηex=0.25%) ,($\eta th = 0.81\%$)

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Abbreviations:-

SWH = Solar Water Heater	ETC = evacuated tube solar collector
HTF = Heat Transfer Fluid	PC= parabolac collector
PV = PhotoVoltage cell	SWC = Solar water collector
CSP =Concentrated Solar Powe	CIRC = Circulation
TTTT = Twisted tube with Twisted tap	HT= heat transfer
FP = Flat plat	TT= Twisted tap

1. Initialization One of the main sources of affordable, obtainable, safe energy is solar energy. Electricity is produced by solar energy [1, 2]. Sunlight energy can be converted to electricity in a variety of methods, including directly using PV, indirectly using CSP, or a mix of both [3]. Three different types of solar collectors, including (FP), (PC), and (ETC). Solar energy can be captured in two different ways, either through solar-electric conversion or solar-thermal conversion [4]. Due to the flat shape's ability to create a huge surface area towards the sun, flat-plate collectors are frequently used. In the 1950s, Hottel and Whillier were the first to design FPSC [5]. Comparing FPSC to focusing collectors It has been demonstrated that the situation where the fluid directly meets the absorbing surface is mechanically simpler [6]. There are essentially two types of solar collectors: stationary solar collectors and sun tracking and concentrating solar collectors. The first one was extensively utilized since it had less coastline, was simple to use, and had an equal area for absorbing and intercepting solar energy. [7] . The flat-plate collector typically comprises of an absorber constructed of a metal sheet with a high thermal conductivity, an insulated box, and a transparent cover to minimize heat losses from the collector's back and sides [8]. The sun irradiation has an impact on the HTF volume flow rates in the solar collector. The volume flow rate is high

when it is high [9, 10]. By inserting twisted tape, J. Ananth and S. Jaisankar [11] improved heat transfer and friction factor of thermosyphon solar water heater. External power is not necessary for this procedure. In this experiment, laminar flow conditions were used with full length helical twists of twist ratio 3, twist with rod and spacer of lengths (125, 250, and 500 mm). The findings demonstrate that the Nusselt number rises as the Reynolds number rises. The test's findings indicate that while pressure drop increases with increasing rod and spacer length, there is a small but significant decrease in Nu in 125 mm and 500 mm spacers, respectively, of roughly 6% and 38%. Friction factor decreasing is 11% and 40% for lengths between 125 and 250 millimeters. Helical and Left-Right twist taps of twist ratio 3in riser tap were experimentally explored by S. Jaisankar et al. [2] [12] to improve HT, thermal performance, and friction factor of thermosyphon SWH system. Riser tubes were inserted by TT. They can draw the conclusion that one benefit of adding a left-right twisted tap is to increase the surface area where fluid contacts the surface more, causing more heat to flow to the fluid and resulting in greater friction factors than plain tubes of 3.75 (375%) and 1.42 (142%). 1.58% Nusselt number the complete S. Jaisankar et al. researched the Left-Right twist tap. [3] [13], twist fitted with rod and spacer at the trailing edge for lengths of 100, 200, and 300 mm for twist ratio(3 and 5) to demonstrate characteristics of thermosyphon enhancement, such as enhanced heat transmission and friction factor SWH. They conducted the experimental test outside, facing in the opposite direction of south, with a tilt angle of 18. The test was completed after several phases, and results were taken every 15 minutes. According to these findings, Nu has a direct correlation with Reynolds number while friction factor has a reverse relationship with Reynolds number. Nu decreases by 11% and 19% for twists fitted with rods and twists with spacers, respectively, and friction factor decreases by about 18% and 29% as well. To enhance the HT and friction factor of the thermosyphon SWC, S. Jaisankar et al. [2] [14] conducted a test using twist ratios (Y 14 3, 4, 5, 6). They were able to demonstrate the reverse relationship between twist ratio value and the rate of heat transfer and pressure drop, leading them to the conclusion that tiny twist ratio (Y 14 3) has higher thermal performance than other twist ratios. S. Naga Sarada, et al. [3] [15] performed an experimental investigation to examine the solar collector with variable width and twist ratio TT inserts to promote turbulent flow HT. They employed three twist ratios in their test (three, four, and five), testing each with five different widths (26 full width, 22, 18, 14 and 10 mm, respectively). Air served as the working fluid, and the Reynolds number range was from 6000 to 13500. The difference in HT enhancement over plain tube was found to vary from (36 to 48%) for full width and (33 to 39%) for width 22 mm. Nusselt values are decreased for tape widths of 10 and 22 mm by 29% and 8%, respectively.

In this Work improve thermal performance by used twisted (tube and tap)to circulate through the tube in the spiral path and created turbulent flow due to enhancing mix properties, enhance in heat transfer would enhance the amount of gained solar energy and will improve the overall thermal performance of the system. Comparative between three models of tube (normal, twisted tube, twisted tube fitted with twisted tap) with water as working fluid.

2-Experimental system setup The empirical test system as shown in Figure (1), Solar water heater collector (SWHC) made as flat plat type(to ensure the heat transfer to working fluid byproviding more surface areafacing the sun) in three tube models (one as a normal tube, the second twisted tube and twisted tube fitted with twisted tape). The three models shown in figure (2) were manufacturing in same dimensions approximately and number of tubes to compere between them witches one give high thermal performance. Firstly, manufacturing of the three designs done according determining specification and the copper was the material of their which had a thermal conductivity of 386 w/m k. The working fluid was water and all models have single path flow to inlet it.

Figure (1) experimental system

Figure (2)three model types of tubes FSC

After that, complete three models of tube and add extra plat on the tube as shown in figure (3) to increase the surface area in order enhance heat transfer from sun radiation to solar collector,

Figure (3) the three types of SC after added copper plate.

The experimental tests were carried out at Al-Nahrain University /Baghdad /Iraq (Latitude: 33◦.27’N; longitude: 44◦.38’E) [16]. The period of the experiments occurred at March (12- 30, 2022). The local weather conditions during measurement was clear sunshine, average relative humidity of around21.31% and the average wind speed was 1.8m/s. The fixed system of the panels used, this system used widely according to fewer coasts than track system. Tilt angle 37° was used, after done a test of three angles and prove this angle is the best which high solar radiation recorded in this angle. South direction has been installed according to the arc of the sun direction.we install the sensors on the tubes and connected them with measuring device .The HTF was the water. After that the isolated tank was completely filled with water by pump which was driven by an electric motor before started working delay for each model. In the experiment test the goal, to investigate the HT and CIRC. ,of the insert (TT) a comparative investigation with the plain tube (without insertion) and typical twisted tube are also examined., the three model of SC (normal tube, twisted tube, twisted tap fitted in twisted tube) was studied the thermal performance of there. First type connected and takes all reading take inlet and outlet T and the surface temperature of tubes by use data logger, intensity of SR was taken by using solar power meter, ΔP by differential pressure manometer and CIRC.by flow meter .Firstly the cold water comes out of the insulated tank and then enters the collector by the lower tube and is distributed in the ten parallel riser copper collector tubes. When the water be contact with hot tube wall the heat is transferred from the riser tube wall to the fluid. Finally the hot water is collected from the upper header and return to the insulated storage tank. The cycle is repeated due to the temperature difference in storage tank so accelerates the driving force and repeated through the day until the ΔT between the inlet and outlet water is zero. .All these repeat and recorded for each model from 9am-3pm .

3-Therotical analysis Thermal efficiency and energy analysis were computed. Net power Qs is a function of the height of the collector, the spacing between rows, the incident solar radiation per unit area (I),(A), and the angle of inclination of the land in the inclined solar field. The solar energy available is computed as the product of the solar beam radiation I and the effective collector area A.

$$Qs = A.I \qquad (1)$$

The useful heat output of the FPSC to the HTF is evaluated by the energy balance:

$$Qu = \dot{m}Cp(Tout - Tin) \qquad (2)$$

Where $Cp$is estimated to be a function of the average temperature of the FPSC.Thermal efficiency of the FPSC is the important parameter for the thermal analysis. The thermal efficiency is calculated as f the instantaneous useful thermal power extracted from the water collector to the instantaneous incident solar irradiation:

$$\eta th = \frac{QU}{Qs} \qquad (3)$$

Exergy is the highest amount of work that a system is capable of producing. Exergetic performance of flat plate SC is assessed by exergy analysis, which also identifies the ideal values for the mass flow rate, absorber plate area, and maximum exergy efficiency under specific operating circumstances. Heat transfer irreversibility has an impact on how much energy solar collector systems produce**.** It is possible to write the solar collector's (Eu) usable exergy generation as

$$Eu = Qu - \dot{m}.\ cp.Tam.\ln\left[\frac{Tout}{Tin}\right] - \dot{m}\ .Tam.\frac{\Delta p}{Tfm.\rho fm} \qquad (4)$$

Where Ta is the ambient temperature, Tfm is the mean fluid temperature, and fm is the mean fluid density. The Petelamodel [17] is used to compute the exergy flow of solar irradiation (Es), which is the rate of solar exergy given by the sun (source) to the concentrator.

$$Es = Qs.\left[1 - \frac{4}{3}.\left(\frac{\mathrm{Tam}}{\mathrm{Tsun}}\right) + \frac{1}{3}.\left(\frac{\mathrm{Tam}}{\mathrm{tsun}}\right)^4\right] \qquad (5)$$

Where Ts is the apparent sun's temperature, which is roughly 5770 K (the sun's mean outer surface t emperature),

Keep in mind that Equations (3.4) and (2.5) require temperatures to be expressed in degrees Kelvin. Useful exergy product (Eu) to the exergy of solar irradiation is the definition of exergy efficiency (E)

$$\eta ex = \frac{Eu}{Es} \qquad (6)$$

The fundamental equation is used to calculate the rate of heat transfer in a single riser tube **[6].**

$$Qu = Uwo.Awo(Two - Tm) \qquad (7)$$

Two is the outside surface of the tube of the receiver, Tm is the mean fluid temperature of the fluid inlet and outlet temperatures, and Uo is the overall outside heat transfer coefficient in this equation. Awo explains the outside surface area of the tube of the SC. The mass flow rate, temperature differential between the fluid outflow and inlet, and heat transfer rate Qu are all connected. Consequently, the overall heat loss due to the conduction and internal convection of the tube of the cavity receiver may be presented as

$$\frac{1}{UoAo} = \frac{1}{hiAi} + \frac{l\,n\left(\frac{Do}{Di}\right)}{2\pi Kl} \qquad (8)$$

So Nusselt number for SCT:

Nu = hi D/ k

(9)All the fluid thermo physical properties are determined at the bulk mean temperature, Tm.

4- Results and discussion

Temperature Difference

The greatest temperature of the HTF after heating in SC with type twisted tube fitted with twisted ta p is shown in Figure (4) as the relationship between Tin and Tout for the three types. The findings d emonstrated that the temperature difference recorded maximum values with twisted tube fitted with twisted tap (TTTT) and the minimum values with (NT), that prove the flow pattern created by the swirls changes the thickness of the thermal shear layer, heightens turbulence inside the tubes, and enhances mixing between hot and cold streams close to the tube wall and in the tube's center so more heat transfer that lead recorded to high (T out). Figure (5) which depict the relationship betweenΔT and time, explains this. It shows that the thirdmodel achieved the maximum capacity to absorb solar energy, highest outlet temperature, and highest efficiency of converting solar energy to thermal energy (TTTT). It clearly to show that ΔT increased with time to reach the maximum and after that decrease slowly due to the Tout increased with time in same time Tin increased .This rise in Tin done because the circulation so the isolated tank temperature be approximately same of Tout.

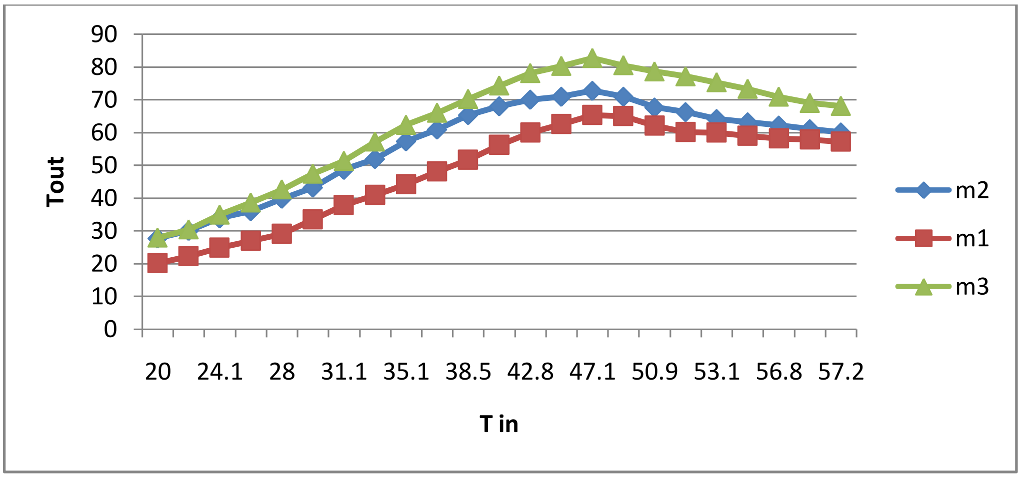

Figure (4) the relation between Tout (C◦) and Tin (C◦) for all tube models(m1 model 1, m2 model 2, m3 model 3)

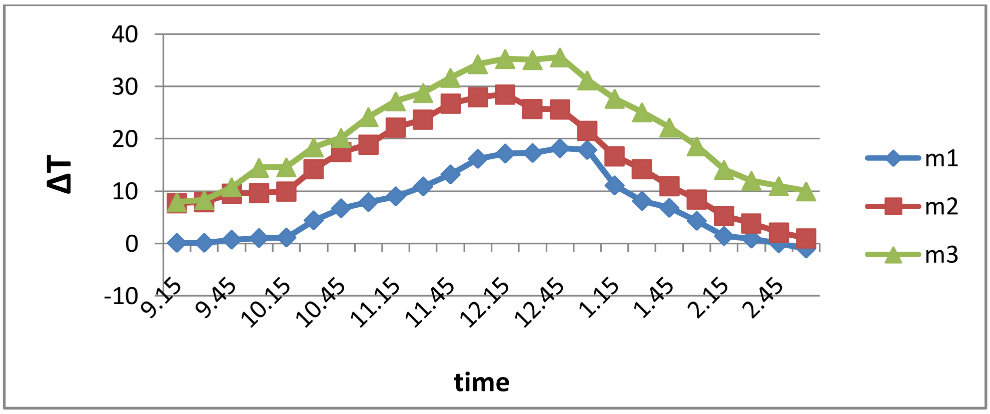

Figure (5) the relation between time (hr.) and ΔT (C◦) for all tube models (m1 model 1, m2 model 2, m3 model 3)

Thermal Efficiency,ηthThermal efficiency is found by equation (3) for each SC types to determine the thermal performance of the system for different temperature and mass flow rate. The figure (6) shows the relation between ηth and time. The results shown in figure (6) clearly indicated that the twisted tube fitted with twisted tap SC design leads to high thermal efficiency compared to the other models, followed by the twisted tube type and the lowest thermal efficiency value for the normal tube type, that due to the twisted path induced swirl flow and be more attach with the tube surface. From figure below we observe that the thermal efficiency rise slightly to reach the maximum value with increasing input temperature with increase the time to reach the peak value and decrease after that. The maximum efficiency recorded at the third type (TTTT) (0.81%) at time(11:30 hr), the second type twisted tube and less one normal tube type

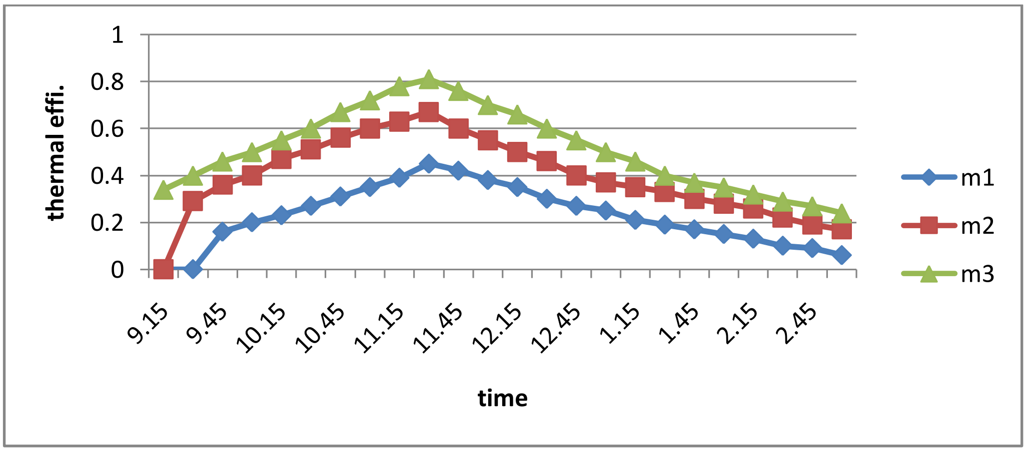

Figure (6) the relation between thermal efficiency ηth and time (hr) for the three models types (m1 model 1, m2 model 2, m3 model 3)

Exergetic Performance From The exergy efficiency was calculated from equation (6) for each SC model with different mass flow rates and ΔT. Figure (4.4) show the relation between the ηex and time (hr). From this figure the exergy performance takes a curve shape, that because it rose in the first part of the day and decrease slowly in the second part. The maximum value reach to it was 0.25% with third SC type (twisted tube with twisted tap), after that the second type and the last was the normal tube type.

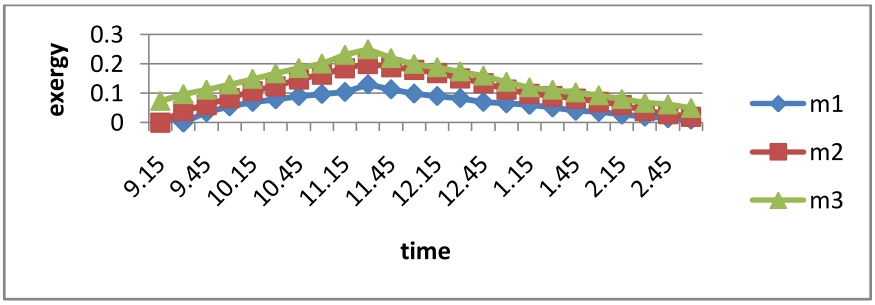

Figure (8) the relation between exergy efficiency ηex and time (hrFor the three models types (m1 model 1, m2 model 2, m3 model 3)

Nusselt Number's (Nu) Figure (9), which explains the relationship between the Nu with the time in different mass flow rate for all the models. The figure show that the Nu in the beginning start with zero due to no self-circulation started at this time, after that the circulation started and be increase so we note that Nusselt Number's increased in the first part to reach the maximum after that slowly decrease. 913.71 was the maximum value of Nu. Twisted tube with twisted tap reached to this value. The twisted 45tube records the second one and the last one which less value was the normal tube

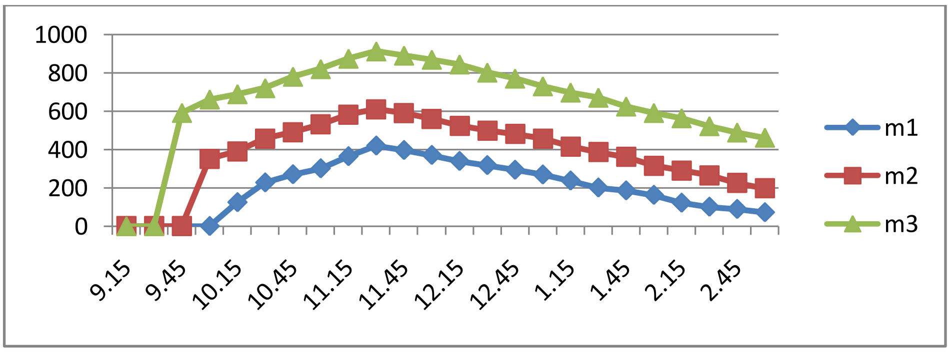

Figure (9) the relation between Nu and time (hr) for the three models types (m1 model 1, m2 model 2, m3 model 3)

ConclusionsIn this experimental test of the (normal tube, twisted tube, twisted tube with twisted tap), the result show that the twisted tube fitted with twisted tap (TTTT) model is record the best enhancement in the result of (ΔT, circulation, Nu,ηth and ηex) with HTF (water). From this, we realized the enhancement by using twisted path to circulate through the tube in the spiral path and enhancing mix properties. In this way, the largest number of particles will be in contact with the surface of the heated tube so heated the HTF more than the other types. The analysis was carried out by estimating the temperature difference of the HTF (ΔT), circulation ($\dot{m}$),the pressure difference of the HTF (ΔP), thermal efficiency (ηth), exergy efficiency (ηex) , and Nussult number (Nu).The operational parameters and environmental of the investigated setup were measured during a day.From results, the normal tube has (Nu= 420.5),(ηex=0.13%) ,($\eta th = 0.45\%$) .The twisted tube type recorded result (Nu= 610.43),(ηex=0.20%) ,($\eta th = 0.67\%$) So, we can concluded that the twisted tube fitted with twisted tap (TTTT) owns the greatest value of thermal performance compared with the other shapes (Nu= 913.71),(ηex=0.25%) ,($\eta th = 0.81\%$). The accuracy of this test was ± 3.12%, ± 3.01%, ± 2.23%, ± 2.46% and 3.61 for ΔT,ΔP,exergy performance, energy performance and Nu respectively.

References

[1] L. Guo, J. Han, and A. W. Otieno, "Design and simulation of a sun tracking solar power system," 120th ASEE Annu. Conf. & Exhibition, Jun. 2013.

[2] [2]. R. S. Zulkafli, A. S. Bawazir, N. A. M. Amin, M. S. M. Hashim, M. S. A. Majid, and N. F. M. Nasir, "Dual axis solar tracking system in Perlis, Malaysia," J. of Telecommun., Electron. and Comput. Eng., vol. 10, pp. 91-94, 2018

[3]"Energy Sources: Solar". Department of Energy. Archived from the original on 14 April 2011. Retrieved 19 April 2011.

[4] S. Suman, M.K. Khan, M. Pathak, Performance enhancement of solar collectors—a 598Q8 review, Renew. Sust. Energ. Rev. 49 (2015) 192–210

[5] L.W. Florschuetz, Extension of the Hottel–Whillier model to the analysis of com776 bined photovoltaic/thermal flat plate collectors, Sol. Energy 22 (1979) 361–366

[6] Rommel M, Moock W. Collector efficiency factor F0 for absorbers with rectangular fluid ducts contacting the entire surface. Solar Energy 1997;60:199e207

[7] A. Soteris, Kalogirou solar thermal collectors and applications, Prog. Energy 640 Combust. Sci. 30 (2004) 231–295

[8] Duffie, J. A., and W. A. Beckman, Solar Engineering of Thermal Processes, John Wiley and Sons, New York, 1991.

[9] Fan J, Shah LJ, Furbo S. Evaluation of Test Method for Solar Collector Efficiency, Proceedings of Eurosun 2006, Glasgow, UK, ISES-Europe

[10] Fan J, Shah LJ, Furbo S. The Effect of the Volume Flow rate on the Efficiency of a Solar Collector, Proceedings of EurosunGlasgow, UK, ISES-Europe(2006)

[11]Ananth, J., and S. Jaisankar. "Experimental studies on heat transfer and friction factor characteristics of thermosyphon solar water heating system fitted with regularly spaced twisted tape with rod and spacer." *Energy Conversion and Management* 73 (2013): 207-213.

[12Jaisankar, S., T. K. Radhakrishnan, and K. N. Sheeba. "Experimental studies on heat transfer and thermal performance characteristics of thermosyphon solar water heating system with helical and left–right twisted tapes." *Energy Conversion and Management* 52.5 (2011): 2048-2055.

[13]Jaisankar, S., Radhakrishnan, T. K., Sheeba, K. N., & Suresh, S. Experimental investigation of heat transfer and friction factor characteristics of thermosyphon solar water heater system fitted with spacer at the trailing edge of Left–Right twisted tapes. *Energy Conversion and Management*, *50*(10)(2009), 2638-2649.

[14]Jaisankar, S., Radhakrishnan, T. K., &Sheeba, K. N.. Studies on heat transfer and friction factor characteristics of thermosyphon solar water heating system with helical twisted tapes. *Energy*, *34*(9) (2009), 1054-1064.

[15]Sarada, S. N., Raju, A. S. R., Radha, K. K., & Sunder, L. S.. Enhancement of heat transfer using varying width twisted tape inserts. *International Journal of Engineering, Science and Technology*, *2*(6). (2010)

[16]Al Dulaimi, Ra'ad K. Mohammed. "Experimental investigation of the receiver of a solar thermal dish collector with a dual layer, staggered tube arrangement, and multiscale diameter." *Energy Exploration & Exploitation* 38.4 (2020): 1212-1227.

[17]Petela R. Exergy of heat radiation. ASME Journal of Heat Transfer 1964;86:187– 92.

[18]Yogesh Hole et al 2019 J. Phys.: Conf. Ser. 1362 012121