Al-Nahrain University, College of Engineering Journal (NUCEJ) Vol.18 No.2, 2015 pp.259 - 272

Heat Transfer Enhancement of Flat Plate Solar Collectors for Water Heating in Iraq Climatic Conditions

Braa Khalid Ameen
Water Deputy in Anbar

Mustafa B. Al-Hadithi
Mech. Eng. Dept
College of Engineering
University of Anbar

Obaid T. Fadhil
Mech. Eng. Dept
College of Engineering
University of Anbar

engbaraa86@gmail.com

Abstract.

This work presents an experimental and numerical study to investigate the heat transfer enhancement of flat plat collector (FPC) using three types of twisted tapes (single twisted tape (ST), double twisted tape (DT) and mixed twisted tape (SDT)) which are compared with plain tube with twist ratios (TR=2). The study are considered under fully developed turbulent flow with solar radiation heat gain are changing with time.

The designed FPC consists of four pipes with 1.25cm in diameter and 1mm thick are placed above the plate to act as a heat removal fluid passage ways. The system consists of two collectors, each one has (40cm x 160cm x 15cm) and connected to two tanks, each one is 20 liters. The amount of heat gain from solar radiation depends on many effective parameters are used; type of twisted tape are using, type of collectors plate metal (aluminum or copper), value of Reynolds number, amount of sun rays available at the site, number of glass covers and orientation of the collectors with respect to the south direction.

From the experimental results was obtained which are demonstrate that the DT are more efficient than ST and SDT, since the heat transfer enhancement which increases the output temperature of the working fluid.

The experimental study also show that the temperature of outlet water from mixed twisted tape collector is higher than the other type of plain tube collector by 10°C. The outlet water temperature of collector made from cupper is more than the collector made of aluminum about 6°C. The outlet water temperature from collector which has Reynolds number of 5000 less than 5°C for copper collector and less than 4°C for aluminum collector from the other with Re number is 10000. Increasing of the temperature of the outlet water in the collector which has two glass cover is about 4°C from one glass cover.

The numerical analysis was based on finite volume numerical techniques to solve the governing partial differential equations in three dimensions, using ANSYS FLUENT commercial CFD software, to study the effect of Reynolds number and twisted tape types on the heat transfer enhancement and friction factor. The comparison between the experimental and numerical results shows a high agreement, and the maximum error was 8.3% occurred with mixed twisted tape.

Introduction

The world now uses energy at a rate of approximately 4.1×10^{20} joules/yr, equivalent to a continuous power consumption of 13 trillion watts, or 13 terawatts (TW). Even with aggressive conservation and energy efficiency measures, an increase of the Earth's population to 9 billion people, accompanied by rapid technology development and economic growth world-wide, is projected to produce more than double the demand for energy (to 30 TW) by 2050, and more than triple the demand (to 46 TW) by the end of the century. The reserves of fossil fuels that currently power society will fall short of this demand over the long term, and their continued use produces harmful side effects such as pollution that threatens human health and greenhouse gases associated with climate change. Alternative renewable fuels are at present far from competitive with fossil fuels in cost and production capacity. Without viable options for supplying double or triple today's energy use, the world's economic, technological, and political horizons will be severely limited.[1]

A typical flat-plate solar collector is shown in figure (1). When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and transferred to the transport medium in the fluid tubes, to be carried away for storage tank. The bottom of the absorber plate and all the sides are insulated to reduce conduction losses. The tubes are welded to the absorbing plate and then are connected at both ends by large-diameter header tubes. The header and riser collector is the typical design for flat-plate collectors.

This collector does not present the potential problem of uneven flow distribution in the various riser tubes of the header and riser design, but serpentine collectors cannot work effectively in thermo siphon mode (natural circulation) and need a pump to circulate the heat transfer fluid.

The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector because the glass is transparent to the shortwave radiation received by the sun, but it is nearly opaque to long wave thermal radiation emitted by the absorber plate (greenhouse effect).

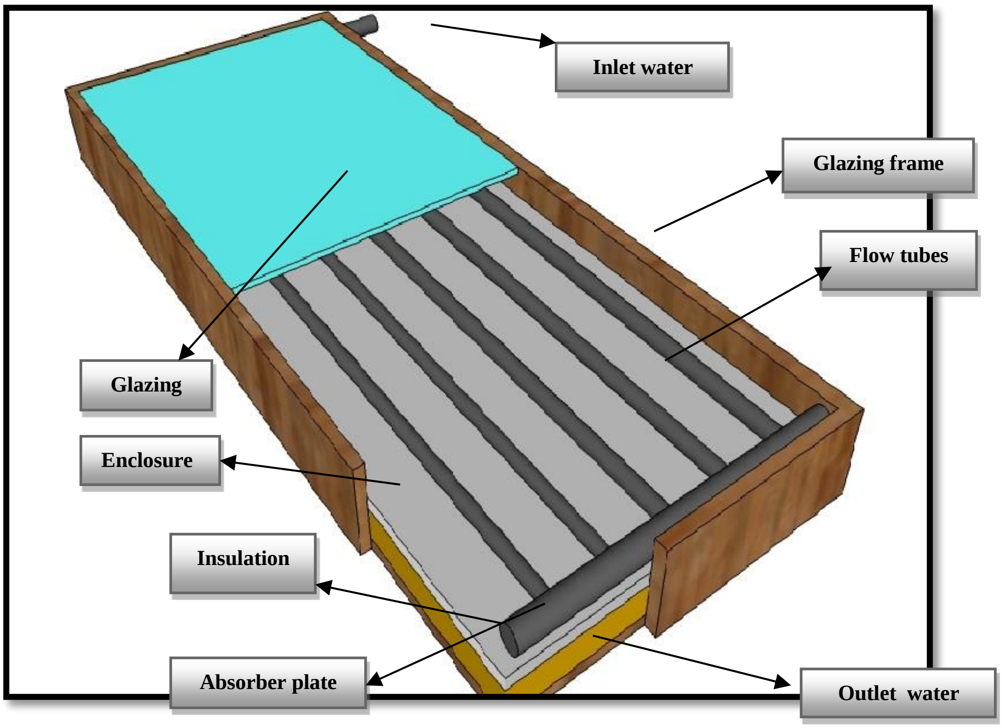


Figure 1: A flat-plate collector is an insulated, weatherproofed box containing a dark absorber plate. The plate heats up and transfers the heat to the fluid flowing through tubes in or near the absorber plate.

S. Eiamsa et al. (2010) [2] determined experimentally the influences of twin-counter/co-twisted tapes (counter/co-swirl tape) on heat transfer rate, friction factor and thermal enhancement index. The results also show that the CTs are more efficient than the CoTs for heat transfer enhancement. Chinaruk Thianpong et al. (2012) [3] investigated experimentally the twisted tape insert which was applied as a swirling flow generator for the passive heat transfer enhancement. The maximum heat transfer was obtained by utilizing the tape with s/w = 0.4, d/w = 0.17 and y/w = 3, which is higher than those obtained from the plain tube with and without typical twisted tape by around 27.4 and 86.7%, respectively**.** G. Iordanou et al. (2012) [4] presented theoretically and experimentally the enhancement of heat transfer to the working fluid a metal porous medium placed inside pipes. The metallic mesh inserted in the collector, provided a higher water temperature compared to the conventional collector and it is the presence of the aluminum mesh inside the channels that distributes heat more evenly. Muhannad Sahib Ali (2012) [5] investigated experimentally the design of flat-plate solar collector system. The production amount of hot water depends on the type and size of the system, the amount of sun rays available at the site, proper installation, and the tilt angle and orientation of the collectors with respect to the south direction. This study used aluminum as an absorber plate because its thermal conductivity is high more than copper and mild steel, its price is cheap. J. Ananth et al. (2013) [6] investigated experimentally the heat transfer and friction factor characteristics of thermosyphon solar water heater with full length helical twist of twist ratio 3, twist with rod and spacer of lengths 125, 250 and 500 mm has been studied. The experimental data for plain tube collector has been compared with fundamental equation falls within the acceptable limits

For Nusselt number and friction factor. Findings shows that the Nusselt number decreases with increase in rod and spacer length and the pressure drop increases with decrease in rod and spacer length when compared with full length twist. Benjamin Greening et al. (2014) [7] considered life cycle environmental sustainability of solar water heating systems in regions with low solar irradiation, such as the UK. The results suggest that flat plate collectors have slightly lower environmental impacts than evacuated tube designs. Reducing the current energy losses of 65% - 45% would reduce the impacts by around 35%. Compared to a gas boiler, solar thermal systems are a better option for only five out of 11 environmental impacts considered, with global warming and depletion of fossil resources being lower by 88% and 83%, respectively. Other impacts such as human and eco-toxicity are up to 85% higher.

The objective of the present work is to evaluate the enhancement of flat plate collector which (FPC) inserts three types of twisted tape (single ST, mixed SDT and double DT) using twist ratios (TR= 2) and compared with another which has plain tube also using a different method to increase the thermal energy is used in water heating for Ramadi climatic conditions. All of the above tests were carried out under fully developed laminar and turbulent conditions a Quasi steady.

2. Mathematical Model

The mathematical model of solar collector consists of external energy balance of absorber plate and internal energy balance of absorber plate. Model solves the energy balance of solar collector under steady-state conditions were taken into considerations:

- The regular flow and in case stability in the pipeline.
- There is no energy stored in the glass cover and absorber plate.
- The neglect of the temperature difference through the glass cover.
- The properties of the fluid constant.

According to principles (Duffi & Beckman)[8] the useful energy output of collector can be represented as :

$q_u = \dot{m}\, C_p\, (T_o - T_i)$ ….. (1)

$Q_u = A_c\, [S - U_L\, (T_{pm} - T_\infty)]$ ….. (2)

$\Delta p = \gamma \times \Delta h \quad \left(\frac{N}{m^2}\right)$ ….. (3)

Δh = inclined reading from manometer × $\sin\theta$ ….. (4)

$\gamma_{water} = 9810\ N/m^3$

The conservation equations for continuity, momentum and energy equations for the turbulent model of these case studies are used [9] under the following assumptions:

1- Steady state.
2- Incompressible fluid.
3- Newtonian fluid.
4- Laminar and Turbulent flow (Re=1500-10000).

- Conservation of Mass (Continuity):

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{V}) = 0 \qquad \text{….. (5)}$$

- Navier - Stokes Equations (Momentum):

$$\nabla \cdot (\rho \vec{V}\vec{V}) = -\nabla p + \bar{\nabla} \cdot \bar{\tau} \qquad \text{….. (6)}$$

The stress tenser τ is given by:

$$\bar{\tau} = \mu\left[\left(\nabla\vec{V} + \nabla\vec{V}^{T}\right) - \frac{2}{3}\nabla \cdot \vec{V} I\right] \qquad \text{….. (7)}$$

Energy Equation:

$$\nabla \cdot (\vec{V}(\rho E)) = \nabla\left(k\nabla T - \rho C \vec{V} T'\right) \qquad \text{…. (8)}$$

3. Experimental setup

The schematic of the experimental setup is shown in the figure (2). Two sheet of glass used with 4mm thickness to cover solar collector above a plate of copper and aluminum (40cm x 160cm) coated with black to maximize the energy collection. Four pipes (1.25cm in diameter with 160cm long) placement above the plate to act as heat removal fluid passage ways. The (FPC) using three types of twisted tapes (ST), (DT) and (SDT)) to be compared with plain tube which was used with twist ratios (TR=2) as shown in the figure (3). The system consists of two collectors, each one has (40cm x 160cm x 15cm) and connected to two water tanks, each one is 20 liters. In order to minimize the heat loss from the back and sides of the collector, which are insulated by 7.5cm thickness of glass wool insulation. The case of wood used surrounds the aforementioned components and protects them from dust, moisture, and any external effects. The test loop consists of a water pumps, tanks, flow meter, solar meter, valve, PC computer, data logger, manometer, thermocouples, and FPC as depicted in figure (4).

Figure 2: flat plate solar collectors

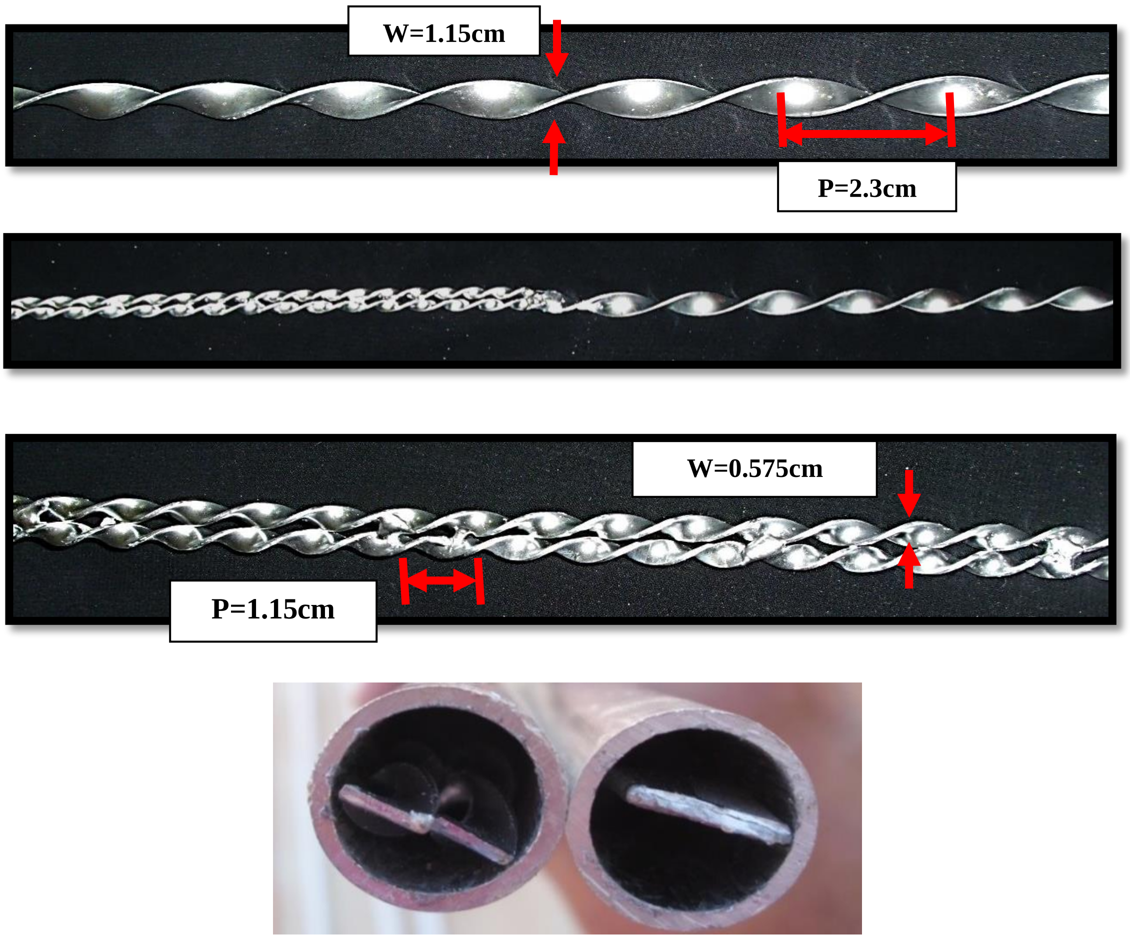


Figure 3: Twisted tape types inserted in the pipe

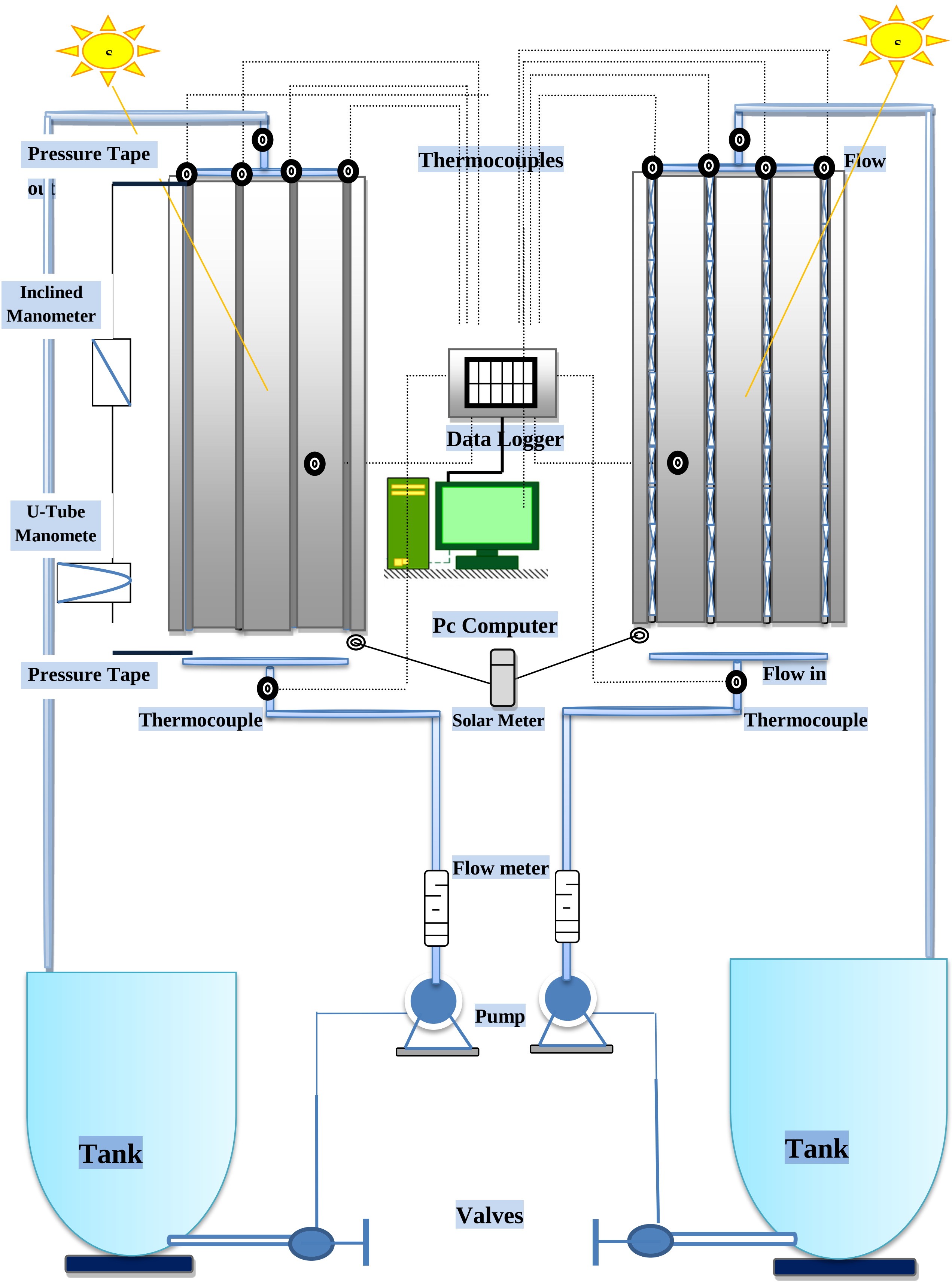


Figure 4: Schematic diagram of Experimental apparatus

4. Results and discussions

4.1 Experimental Results

Fig.(5) shows the variation of ambient conditions and solar radiation (measured every 15 minutes) in Ramadi city for selected clear days during the test period namely; (19/10/2014, 20/10/2014, 22/10/2014 and 23/10/2014). It can be shown that the ambient temperature follows the incident solar radiation magnitude from sunrise to solar noon, after that a considerable deviation in this behavior is indicated in October.

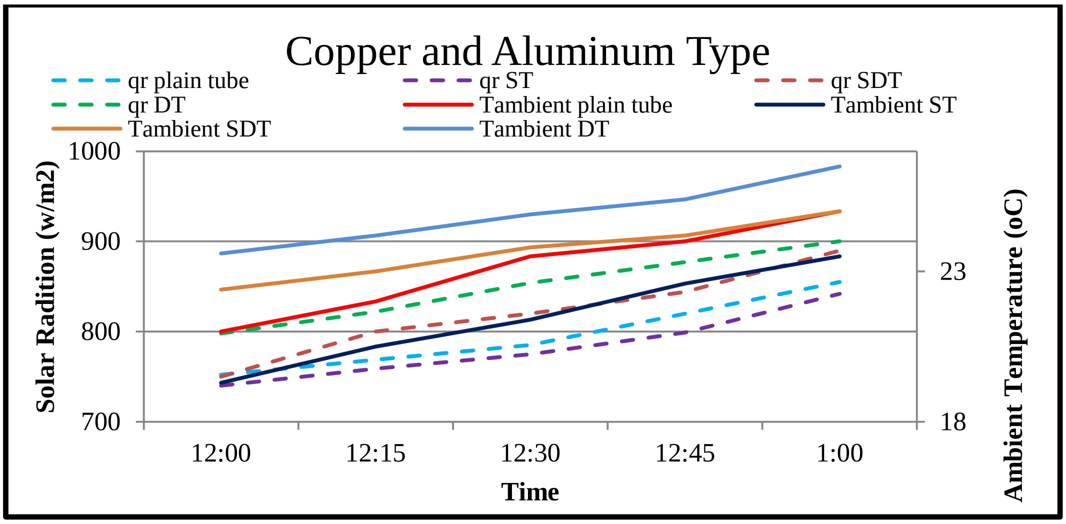


Figure 5: Hourly Variation of Solar Radiation and Ambient Temperature for (19, 20, 22, and 23/10/2014)

Fig. (6)) shows the effect of type of twisted tape on the value of outlet water temperature of the collector by comparing it with plain tube inserted in tube on flat plate collector made of Aluminum and Cupper which tilted at angle 45° and orientation of the collectors with respect to the south direction.

The results obtained from these figure, shows that the value of outlet water temperatures in double type twisted tape are higher than when compared with plain tube and high fraction factor. A single twisted tape type is less value and the mixed type of twisted tape is moderate. Also shows the effect of metal types on outlet results in which the copper collector is better than aluminum collector because the copper metal has high thermal conductivity.

All the above results are obtained with steady state (constant inlet water temperatures with time). The reading of outlet water temperatures are recorded each 15 minutes for one hour.

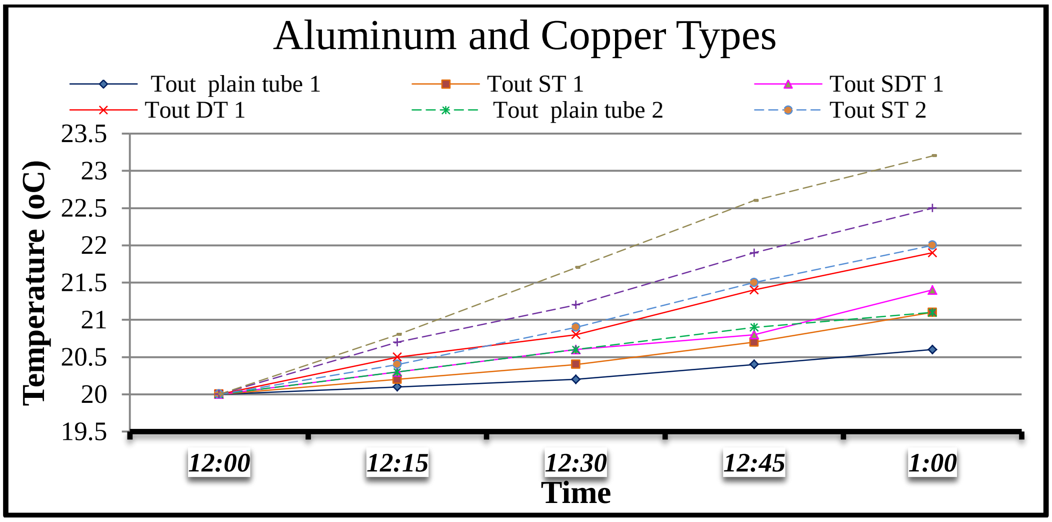


Figure 6: Comparison of outlet water temperature among collectors of aluminum and copper has plain tube; ST, SDT and DT twisted tape

Fig. (7) Shows the effects of mixed twisted tape SDT and the metal types on obtained results. The results show that the using of mixed twisted tape which increases the outlet temperature about 10°C more than plain tube. The maximum water temperature are obtained with mixed twisted tape has been 67.7°C and 61.4°C for copper and aluminum collector, receptively.

The mixed twisted tape SDT makes an increases in the values of outlet temperature in the same condition because of the interruption in the fluid flow and it makes decrease in the boundary layer thickness along the tube due to the exist of mixed twisted tape. Also the twisted tape generating the swirling flow inside the pipe therefor the coefficient of heat transfer will be increases and the heat gain from internal surface of tube will be more.

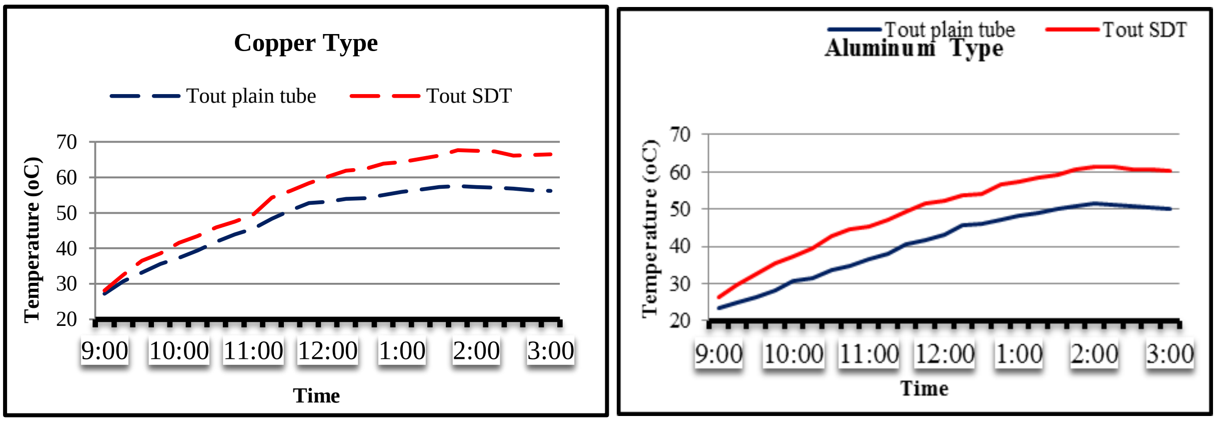


Figure 7: Comparison of outlet water temperature for SDT and plain tube collector

Fig. (8) shows the effect of the Reynolds number on outlet water temperature at Re=10000 and at Re=5000, since the water temperature of collector at Re=10000 is higher than at Re=5000 about 5°C, this is because the collector at Re=10000 is high flow rate of water and then leads to the interruption in the fluid flow and increases the number of rotation of water between tank and flat plate. These causes lead to divergent of results
.

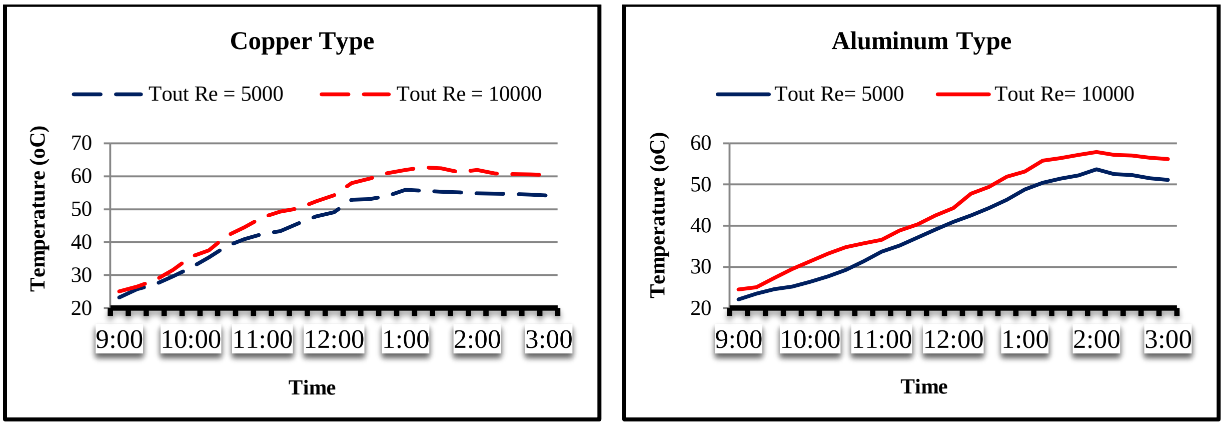


Figure 8: Comparison of outlet water temperature for SDT

From Fig. (9) clarify the effects of one and two glass covers on outlet water temperature. This parameter leads to an increase the outlet of water temperature about 4°C, this is because the glasses layer prevents the sun rays from reflecting to the atmosphere and reducing the energy losses by conduction and convection. From this results the use of two glasses layer is better than one glass layer.

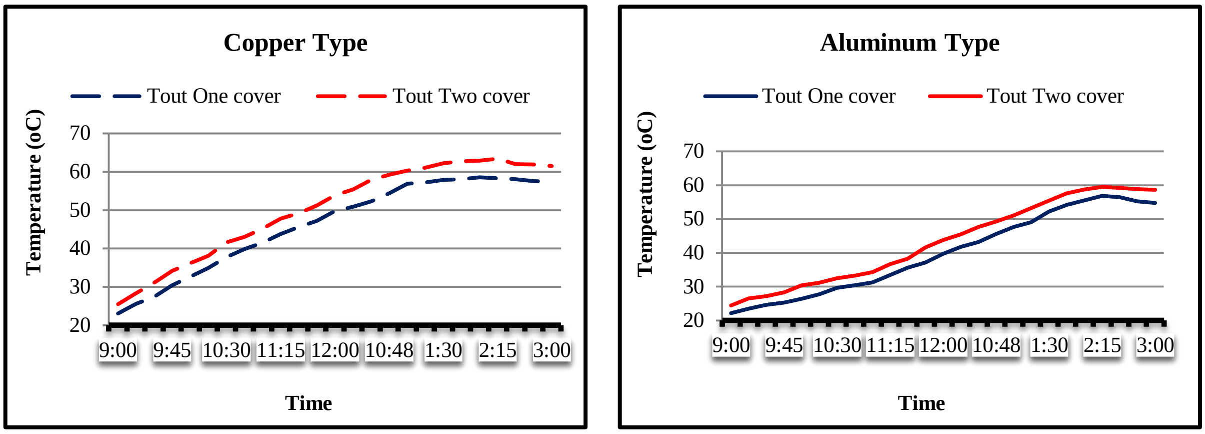


Figure 9: Comparison of outlet water temperature for SDT

Fig. (10) Shows the effect of metal from which the collector of cupper is better than the collector of aluminum because of the high thermal conductivity when compared at the same condition. The outlet water temperature for cupper collector is higher than 5°C of aluminum collector and the absorber plate temperatures for copper collector is higher than (10°C) aluminum collector. This due to absorbivite of copper is higher than aluminum material.

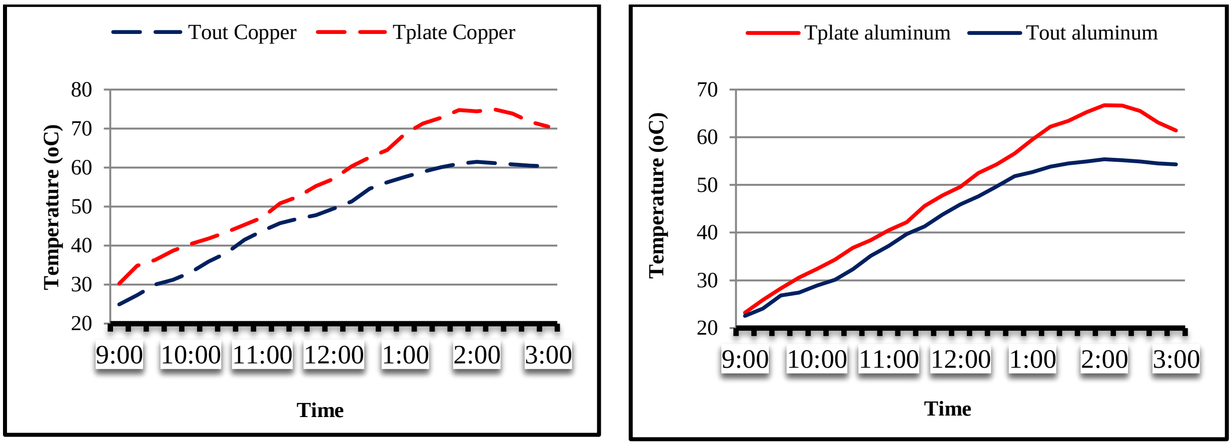


Figure 10: Comparison of outlet water temperature for SDT

Fig. (11) Shows the friction factor with published by Blasius [10], equation (10)

$$f = 0.316\, Re^{-0.25} \qquad \text{….. (10)}$$

Based on the practically measured pressure drop, Darcy friction factor can be calculated using the expression:

$$f = \frac{\left(\frac{\Delta p}{L}\right) D}{\frac{\rho v^2}{2}} \qquad \text{….. (11)}$$

Also the friction factor for three types of twisted tape (ST), (DT) and (SDT)) in hydro dynamically fully developed flow through a circular tube was measured to investigate the flow characteristics for the plain tube and tube with twisted tape for the twist ratio (TR = 2) at 45°.

The friction factor at the DT twisted tape is maximum and at ST twisted tape is minimum when compared with plain tube and the last type of twisted tape is SDT between them as shown in below figure.

Generally, the friction factor decreases when the Reynolds number increasing for the all range of Reynolds numbers and types of twisted tape. Finally the results approved that the SDT gives average friction factor and better outlet water temperature from collector.

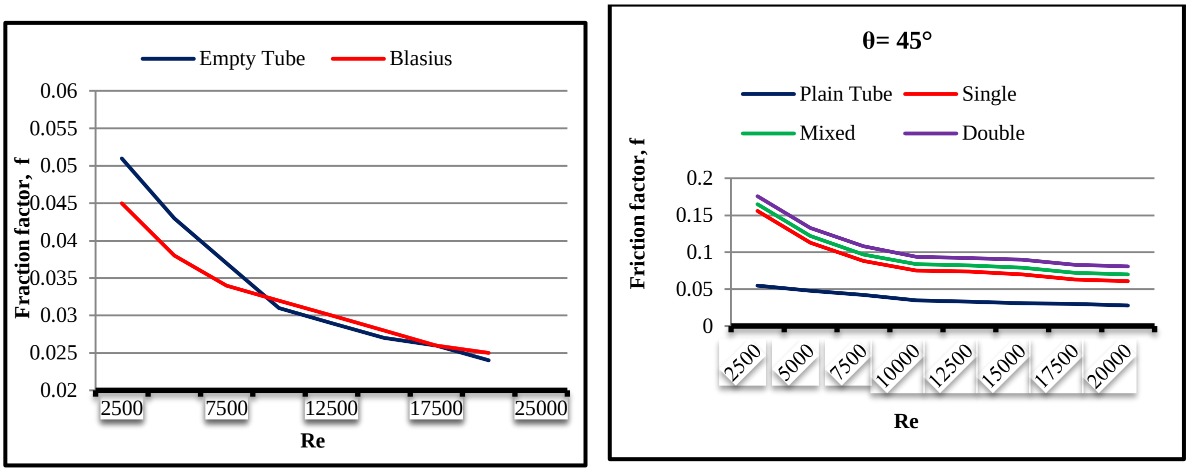


Figure 11: The effect of Reynolds number and different twist types on friction factor for water.

4.2 Numerical Results

Numerical Results were carried out by employing the finite volume method single-phase module by commercial CFD program (FLUENT) and for all the specified conditions of Reynolds number (Re = 1500 - 10000) and twist ratios (TR = 2) as shown in the figs. (12) and (13), while the heat fluxes applied to the flat plate collector were in the range of 740-900 (812) W/m^2.

The temperature of the water at the inlet is initially uniform at (20C). The temperature profiles shown are due to the assumption of hydrodynamic developed flow. The temperature contours of outlet water temperature from collectors for plain tube and three types of twisted tapes at (TR = 2), the temperature of water increases at the exit of collector and with change of twisted tape type as shown in the figs. (14) to (17) at different Reynolds number.

For all types of twisted tape, it is found that increases in outlet water temperature compression with plain tube and with increasing Reynolds number, the water outlet temperature will decrease.

The maximum and minimum temperature of water is in collector which has DT twisted tape and ST twisted tape, respectively. Comparisons with collector have plain tube. The collector temperature of water outlet inserted SDT twisted tape with good enhancement of temperature.

4.3 Comparison between the experimental and numerical results

The Comparison between the experimental and numerical result are shown in figs. (5), (6), (14), (15), (16) and (17) for three types of twisted tapes with twist ratio (TR=2) and plain tube. A high agreement between the results is noticed, and the maximum error was 8.3% occurred with mixed twisted tape

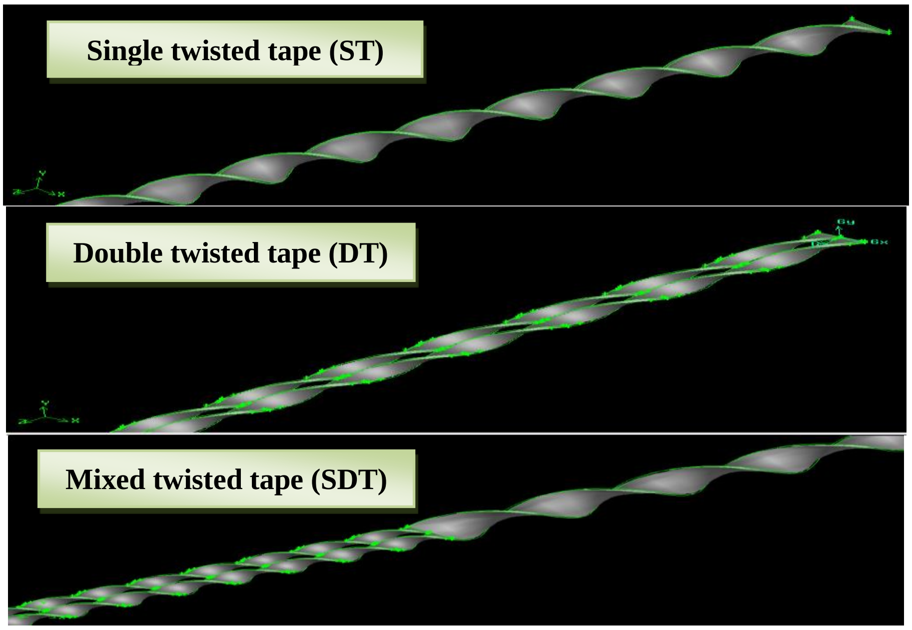


Figure 12: Shapes of different types of twisted tape

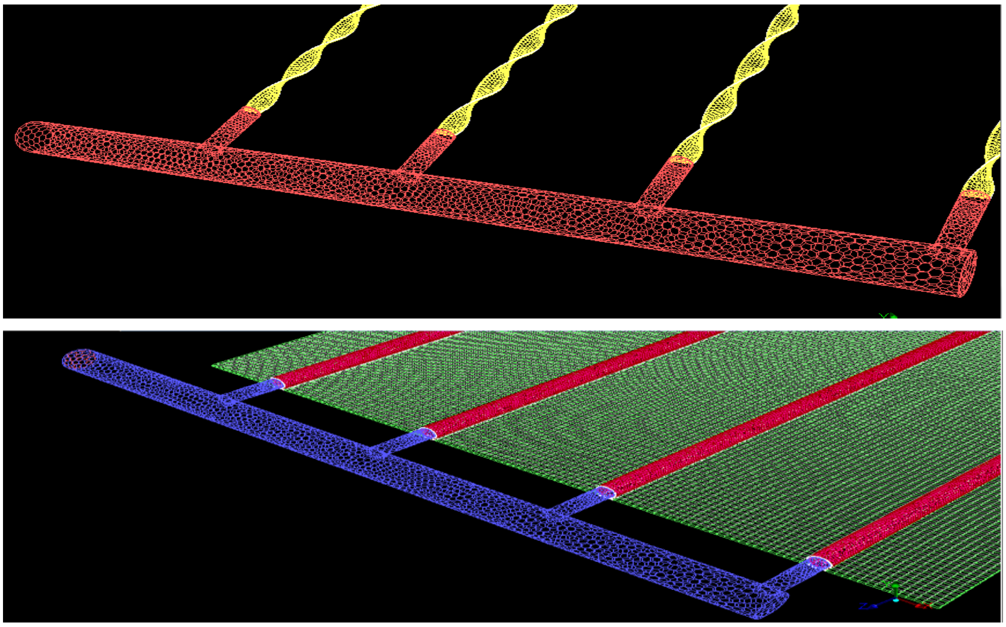
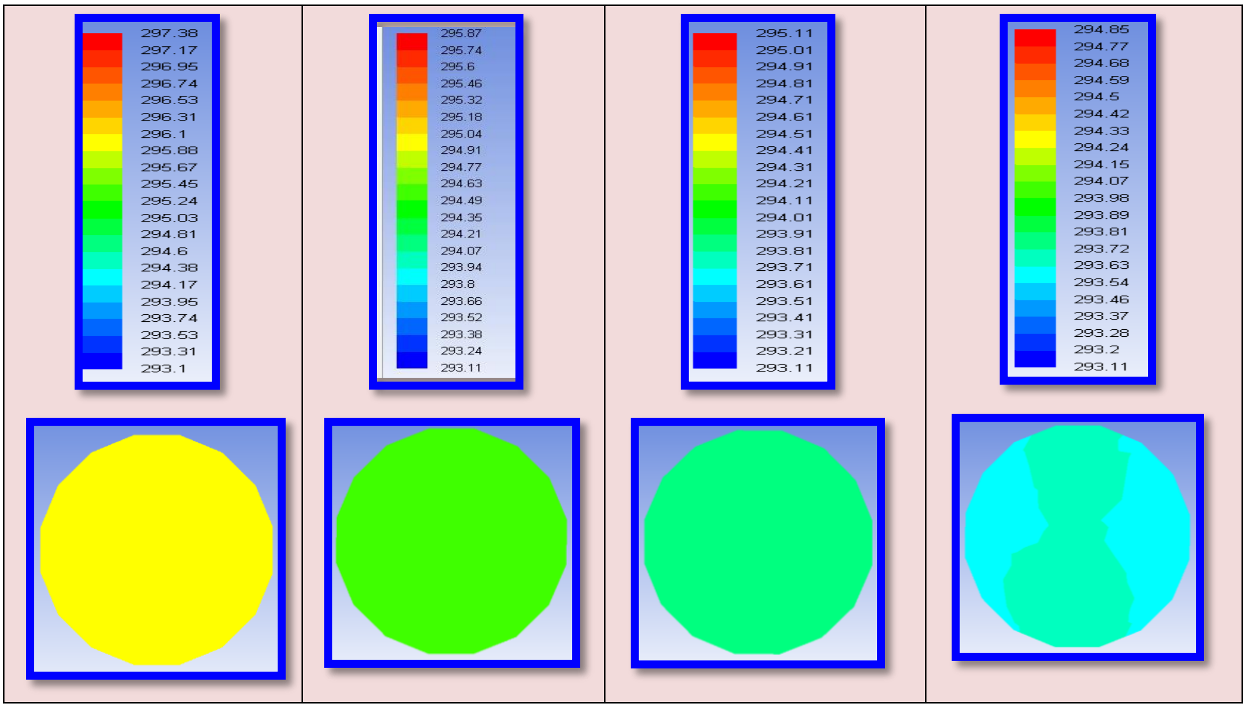
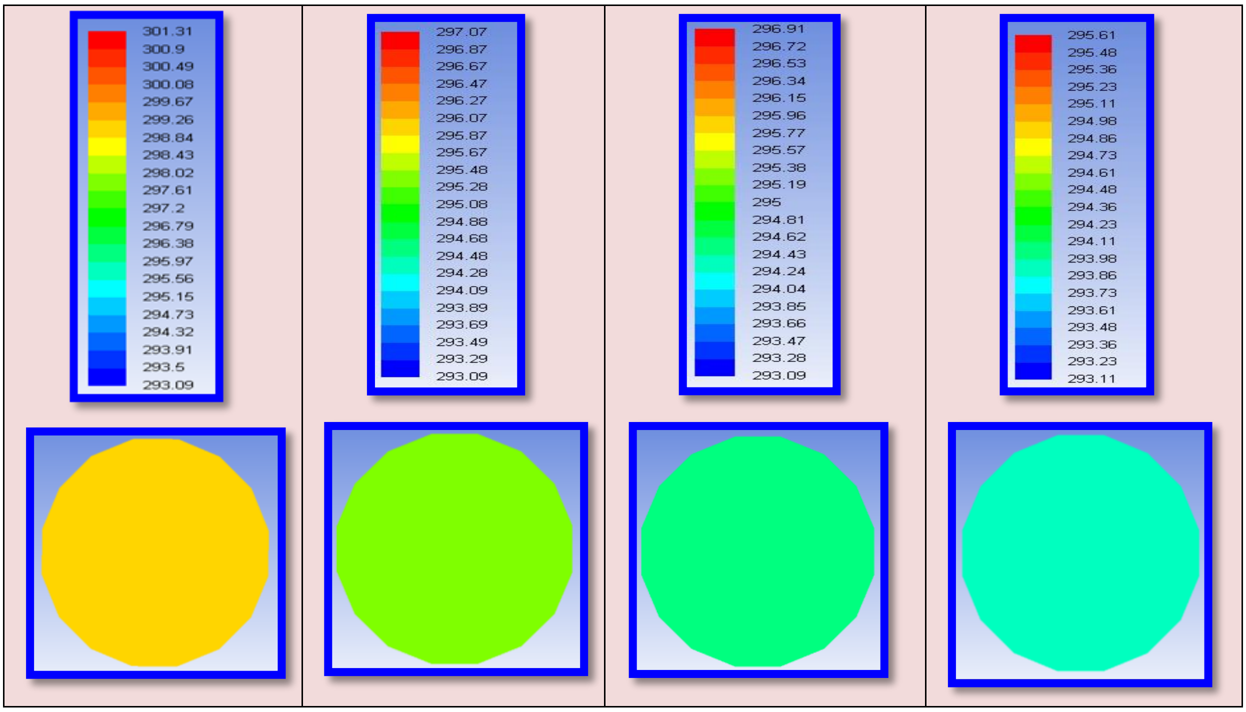


Figure 13: Mesh of the fluid domain in a tube with twisted tape



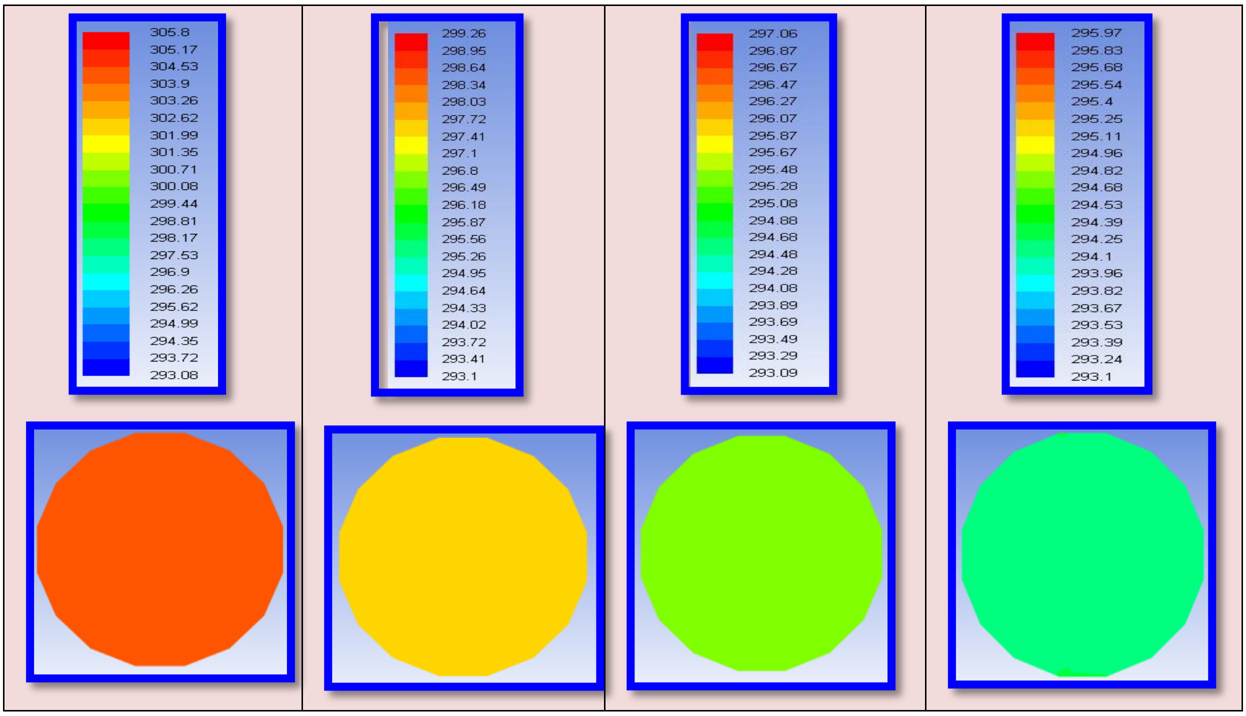
Re=1500 Re=2500 Re=5000
Re=10000

Figure 14: Static temperature contours obtained from the CFD model of the water in outlet collector without twisted tape (plain tube) at 12 Am



Re=1500 **Re=2500** **Re=5000** **Re=10000**

Figure 15: Static temperature contours obtained from the CFD model of the water in pipe for the collector single twisted tape at 12 Am



Re=1500 **Re=2500** **Re=5000** **Re=10000**

Figure 16: Static temperature contours obtained from the CFD model of the water in pipe for the collector mixed twisted tape at 12 Am

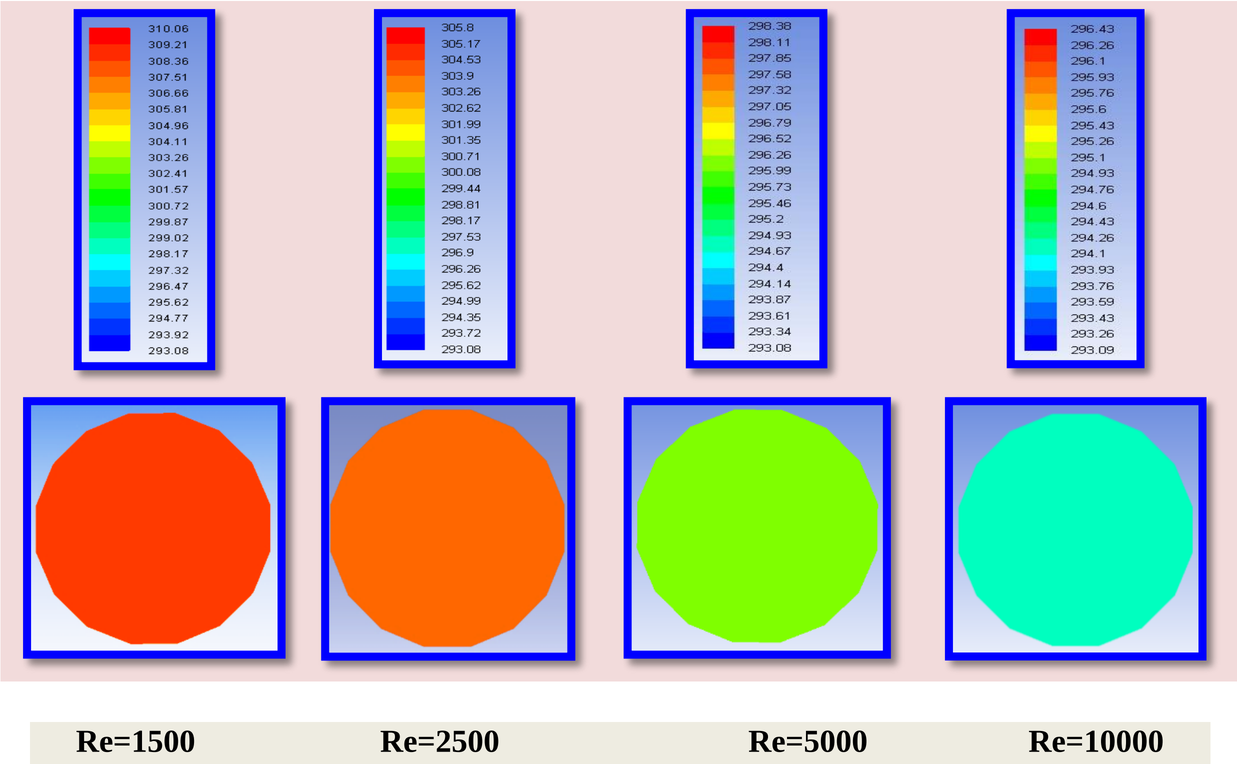


Figure 17: Static temperature contours obtained from the CFD model of the water in pipe for the collector double twisted tape at 12 Am

5. Conclusion

From the experimental investigation of the flat plate collector in Iraq climate conditions, the following conclusions can be extracted:

1) The use of twisted tape increases the outlet temperature of water, the double type gives higher outlet temperature of water and fraction factor compared to the other types.
2) The insertion of SDT type in pipe of the collector increases the outlet temperature of water which is 10°C .
3) The comparison between the copper and aluminum collector increases the outlet temperature of water about 6°C.
4) The outlet temperature of water increases 5°C by increasing the Reynolds number from 5000 to 10000.
5) The decreasing of heat loss from top of collector by using two glass covers increases the outlet temperature of water about 4°C compared with one cover.
6) The high value of the outlet temperature of water and fraction factor is double, mix and single twisted tape type, respectively.
7) The use of finite volume method single-phase model in ANSYS FLUENT commercial CFD software generally gives numerical results in good agreement compared with the experimental results, and it is suitable for predicting the pipe flow with twisted tape.

6. References

[1]Nathan S. Lewis and George Crabtree;(2005) ;"**Basic research needs for solar energy utilization**"; Report on the Basic Energy Sciences Workshop on Solar Energy Utilization.

[2]S. Eiamsa, C. Thianpong and P. Eiamsa;(2010) ;"**Turbulent heat transfer enhancement by counter/co-swirling flow in a tube fitted with twin twisted tapes**"; Experimental Thermal and Fluid Science,V.34,PP. 53–62.

[3]Chinaruk Thianpong, Petpices Eiamsa and Smith Eiamsa; (2012) ;"**Heat transfer and thermal performance characteristics of heat exchanger tube fitted with perforated twisted-tapes**"; International Communications in Heat and Mass Transfer, V.48,pp. 881–892.

[4]G. Iordanou; (2012) ;"**Experimental Investigations using partial Porous Medium inside the Channels of Flat Plate Solar Water Collectors** "; Journal of Engineering Science and Technology Review, V.5,No.1, pp. 30-33.

[5]Muhannad Sahib Ali; (2012) ;" **Experimental Study of Solar Hot Water System Design**"; Thi-Qar University Journal for Engineering Sciences, Vol. 3, No. 1,pp. 1–14.

[6]J. Ananth a, S. Jaisankar; (2013) ;" **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, V.73, pp. 207–213.
[7]Benjamin Greening and Adisa Azapagic; (2014) ;"**Domestic solar thermal water heating: A sustainable option for the UK?** "; Renewable Energy, V.63, pp. 23–36.
[8]John A. duffe and willem A. Beckman; (2006) ;" **solar engineering of thermal processes**"; third Edition, John wiley and sons, Inc.
[9]ANSYS FLUENT, Version 14.5, ANSYS Inc. 2013, "Fluent 14.5 User's.
[10]Incropera, Dewitt, Bergman and Lavine ;(2006) ;" **Fundamental of heat and mass transfer**"; (six edition).

7. Nomenclature

A_c Area, m2
h convection heat transfer coefficient, W m^{-2} K^{-1}
k conductivity W m^{-1} K^{-1}
N number of glass cover
L length of pipes, m
Q Energy, W
T Temperature, °C
Tfi Inlet water temperature tor solar collector °C
$T_{f,o}$ Outlet water temperature from solar collector °C
$T_{p,m}$ absorber plate mean temperature °C
D Diameter of perforated
s Spaced-pitch length of perforated, mm
w Twisted tape width
y Twisted tape pitch
t Thickness, m
E Total energy (J)
U_L Coefficient of thermal losses from solar collector W/m2.□C
Δp Pressure drop (Pa)
Cp Specific heat (J/kg. K)
f Friction factor
Δ Difference
$\dot{m}$ Mass flow rate (kg/s)
v Velocity (m/s)
$\vec{V}$ Velocity vector (m/s)

Abbreviations

FPC Flat plate collector
ST Single twisted tape
DT Double twisted tape
SDT Mixed twisted tape
CTs twin counter twisted tapes
CoTs twin co-twisted tapes
CFD Computational Fluid Dynamics
TR Twist ratio
S.R. Solar radiation (W/m2)

Greek symbols

ε Emissivity
β Collector tilt angle
τ Viscous stress tensor (N/m2)

Sub scripts

∞ ambient
g glass cover
o out
i in

Table 1: Specification of flat plate solar collector**.**

Items	Dimensions and specifications
Glass cover	Commercial glass cover Permeability coefficient: 0.860 The number of covers (N) = 2 Thickness: 4 mm Air space between covers = 2.5cm Air space between inner cover and absorber plate = 4cm
Absorber collector	Copper and Aluminum plate absorber Coefficient of thermal conductivity ˚C: 386 & 217 W/m.K Absorptive coefficient: 0.94 Inner tube diameter: 1.15 cm Outer tube diameter: 1.25 cm The number of rises tubes (n)=4
Insulation	glass wool insulation Coefficient of thermal conductivity: 0.038 W/m. Thickness of the insulating material (C): 7.5 cm
collector system	$A_c = 0.64\ m^2$ Collector system tiled at an angle (β) within the range of latitude 45° south direction to Ramadi city climatic conditions Number of collector: 2

تحسين انتقال الحرارة في خلية طاقة شمسية مسطحة لتسخين المياه في الظروف المناخية في العراق

براء خالد امين
دائرة ماء الانبار

مصطفى برزان عبد الغفور
جامعة الانبار/كلية الهندسة

عبيد طلك فاضل
جامعة الانبار/كلية الهندسة

الخلاصة:

هذا العمل تم دراسته عمليا' وعدديا' لتقصي تحسين انتقال الحرارة في مجمع شمسي ذو صفيحة مستوية تستخدم ثلاث انواع من الاشرطة الملتوية (المفرد, المزدوج, المختلط) بواسطة المقارنة مع انبوب فارغ وكانت نسبة الالتواء اثنان. الدراسة تركزت تحت جريان مضطرب مع تغير في الإشعاع الحراري مع الزمن.

المجمع الشمسي ذو الصفيحة المستوية المصمم يتكون من اربعة انابيب (قطر=1.25 سم وبسمك 1 ملم) وضعت على الصفيحة لنقل الحرارة الممتصة الى المائع. المنظومة تتكون من مجمعان شمسيان كل واحد يمتلك ابعاد (40 سم x160 سم x 15 سم) وربطت الى خزانان من الماء حجم كل واحد 20 لتر. كمية الحرارة المكتسبة من الاشعاع الشمسي يعتمد على فعالية متغيرات عديدة مستخدمة: احتوائه على الشريط الملتوي, نوع المعدن (المنيوم والنحاس), قيمة رقم رينولد, كمية اشعة الشمس الساقطة في الموقع, عدد طبقات الزجاج, زاوية المجمع الشمسي واتجاه المجمع المحاذي الى الاتجاه الجنوبي .

بينت النتائج العملية بأن الشريط الملتوي المزدوج اكثر كفاءة لتحسين انتقال الحرارة من الشريط الملتوي المفرد والمختلط التي تزيد درجة حرارة المائع الخارج من المجمع الشمسي واكثر معامل احتكاك.

تبين ايضا في الدراسة العملية بأن الزيادة في درجات حرارة الماء في مجمع شمسي يحتوي على شريط ملتوي مختلط واخر خالي اكثر من 10°م. درجة حرارة الماء الخارج من المجمع الشمسي مصنوع من النحاس اكثر بحوالي 6°م من مجمع مصنوع من الالمنيوم. درجة حرارة الماء الخارج من المجمع الشمسي يمتلك رقم رينولد 5000 اقل من 5°م من مجمع يمتلك 10000. الزيادة في درجة حرارة الماء الخارج من مجمع يحتوي على طبقتين من الزجاج بحوالي 4°م من مجمع يحتوي طبقة زجاج واحدة.

استخدام طريقة الحجوم المحددة لنموذج الطور واحد في برنامج فلونت انسس التجاري عادة تعطي النتائج العددية تقارب جيد بالمقارنة مع النتائج العملية وتعطي توقعات مناسبة للأنبوب مع الشريط الملتوي.