International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 6 (2015) pp. 14739-14754

http://www.ripublication.com

Heat Transfer Augmentation In A Solar Water Heater Using Cross and Twisted Tape Inserts

V. Pavendan[1], K. Muthukumar[2], N. Arivazhagan[2], K. Srithar[2,*]
[1] Department of Automobile Engineering, Fatima Michael College of Engineering and Technology, Madurai – 625020, Tamil Nadu, India.
[2] Department of Mechanical Engineering, Thiagarajar College of Engineering, Madurai – 625015, Tamil Nadu, India.
**Corresponding Author: ponsathya@hotmail.com*

Abstract

This work deals with the experimental studies on solar water heater system fitted with seven type of inserts cross type insert; twisted tape insert (i) with three different pitch ratio; (ii) with perforation; (iii) with fins; and (iv) alternative axis with fin. Experiments are carried out both in modified solar water heater and conventional solar water heater for the same operating conditions with Reynolds number ranging from 3000 to 9000. Plain twisted tape with PR = 3 gives better performance than cross type insert and other type of twisted tape due to high whirling effect. Over the range of experimental result, the Nusselt number, friction factor and thermal performance factor of solar water heater fitted with alternative axis of finned twisted tape insert for PR = 3 are respectively 1.43 – 1.2, 1.43 – 1.32, 1.27 – 1.11 times superior than plain twisted tape of PR = 3 due to better mixing flow with fin effect. Also type 7 insert attained average maximum temperature is around 60^{o}C, increases with increase in solar intensity.

Keywords: Solar water heater, Flat plate collectors, Heat transfer enhancement, Inserts, Thermal performance factor.

Introduction

Based on recent study, developed nation and developing nations, are mainly focused the research on renewable energy oriented, especially in solar energy. The solar energy is the primary source of all renewable resources and promising energy to sustain the present energy crises. Application of solar energy to civilization came in direct (Thermal production method) and indirect way (Electricity production method). Between two, the direct mode is commonly accepted as the simplest and least expensive techniques in many feasible applications. There are many applications with solar energy, solar air heater [1], solar water heater [2], solar desalination [3], solar dryer [4], solar cooker [5], solar refrigerator [6], solar photovoltaic system [7] and hybrid system [8]. The application of solar energy system mainly based upon the solar collector.

Solar collector fall into two types: flat plate collector and concentrator. Flat plate collector is simple in design, has no moving parts and less maintenance than concentrator collector [9]. Flat plate collector collects the solar energy by black coated absorber plate and it transfer to the working fluid. In order to improve the high heat transfer rate into the working fluid, the various insertions of insert is tried in working fluid passage like fin [10, 11], rib [12], wire coil [13, 14], wire mesh [15], conical ring or nozzle [16, 17], swirl generators [18] and twisted tape insert [19]. These are suitable techniques to be applied in flat plate solar collectors to lengthening the heat transfer area (residence time) and generating turbulence flow (convective heat transfer coefficient) in fluid passage [20]. Among the various inserts, fluid passage equipped with twisted tape is more popular method to produce turbulence and high heat transfer rate.

The twisted tape insert is a very simple and effective device to enhance the heat transfer in fluid passage by better twist mixing due to generating swirl or secondary flows, increasing the flow velocity due to the tube partitioning and blockage, and providing an effectively longer helical flow path to increase the residence time [19]. In the twisted tape concept, various experimental works was done with simple twisted tape, multiple twisted tapes [21], twisted tape with rod / spacer [22], twisted tape with nail [23], twisted tapes with different cuts / holes [24, 25] and twisted tape with different surface modifications [26].

In addition, few modified twisted tapes are attempted in flat – plate solar water heater application. The performance improvement on solar water heater equipped with twisted tape of various twist ratios (3 - 12) is studied experimentally [19]. The heat transfer augmentation of solar water heater attached with twisted tape insert gave better performance than conventional water heater in natural circulation mode [27] and forced circulation mode [28].

The available literatures shows that heat transfer increases in tube fitted with various geometrical shapes of swirl flow generators. However, there is no information about study the effect of perforated and finned twisted tape in solar water heater performance. Therefore, in the present study, effect of perforated and finned twisted tape on augmentation of heat transfer, friction factor and thermal performance factor of solar water heater was studied experimentally. The experiments are conducted by using cross and six different geometrical shapes of twisted tape inserts in modified solar water heater and then its performance compared with conventional.

Experimentation

The details of the overall experimental setup and procedure are explained as follows.

The schematic diagram of the experimental setup for conventional (without insert) water heater and modified solar water (with insert) heater are shown in Fig 1(a) and (b). The conventional and modified collectors are having same dimensions with a tilt angle of 10^o (latitude of Madurai) and facing towards south.

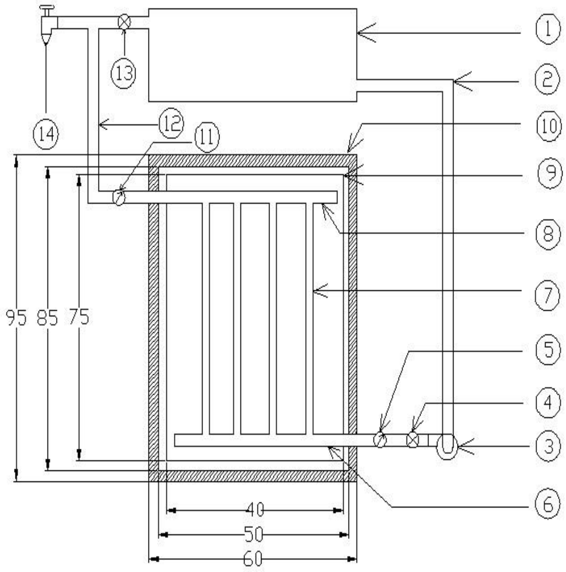


Figure 1 (a): Schematic diagram of the conventional

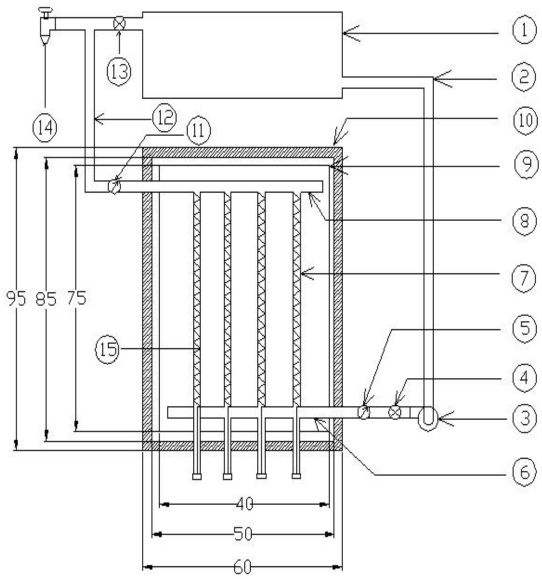


Figure 1 (B): Schematic Diagram of The Modified

1. Recirculation tank 2. Water inlet 3. Pump 4. Valve (V_1) 5. Inlet pressure gauge 6. Lower header 7. Riser tubes 8. Upper header 9. Absorber plate 10. Outer casing with insulation 11. Outlet pressure gauge 12. Water outlet 13. Valve (V_2) 14. Tap for measuring mass flow rate 15. Inserts

The experimental setup mainly consists of solar flat plate collector, recirculation tank and connecting pipes. Both conventional and modified solar collectors are made by galvanized iron sheet and are well insulated by using Polystyrene sheet to minimize the heat loss. The collector consists of glass, at top absorber plate integrated four parallel riser tubes with upper and lower header at bottom. A glass cover of 4 mm thickness transmits the solar energy to absorber plate. 750 x 400 mm of black coated steel absorber plate absorbs the solar energy as heat energy and it further transfer into water in pipe. Four riser tubes are parallel to each with 600 mm length, 19 mm internal diameter and 1.5 mm thickness and placed above the absorber plate. Lower header connected to the inlet pipe and upper header connected to outlet pipe of the recirculation tank of 40 liter capacity. The photographic views of the conventional and modified solar water heater are shown in Fig 2 (a) and (b).

Figure 2 (a): Photographic view of the conventional

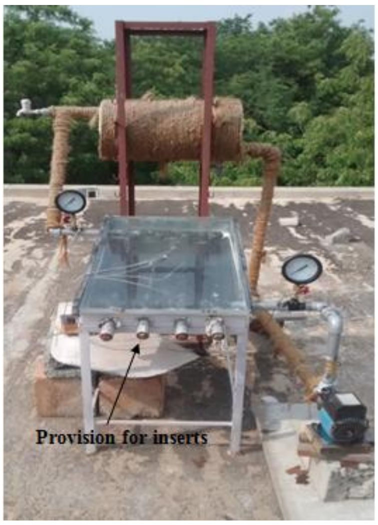


Figure 2 (b): Photographic view of modified solar water heater solar water heater

Five thermocouples are placed on various parts of collector setup such as two in absorber plate, two in riser tube wall and one in glass. Two more thermocouples wires are fixed at inlet and outlet pipe of the collector to measure the inlet and exit water temperature. Pressure gauges are located at the upstream and downstream of the collector to measure the pressure drop across it. Taping (14) is provided at water outlet pipe from the collector to measure the mass flow rate using measuring jar and stop watch. Solar radiation measured by solarimeter.

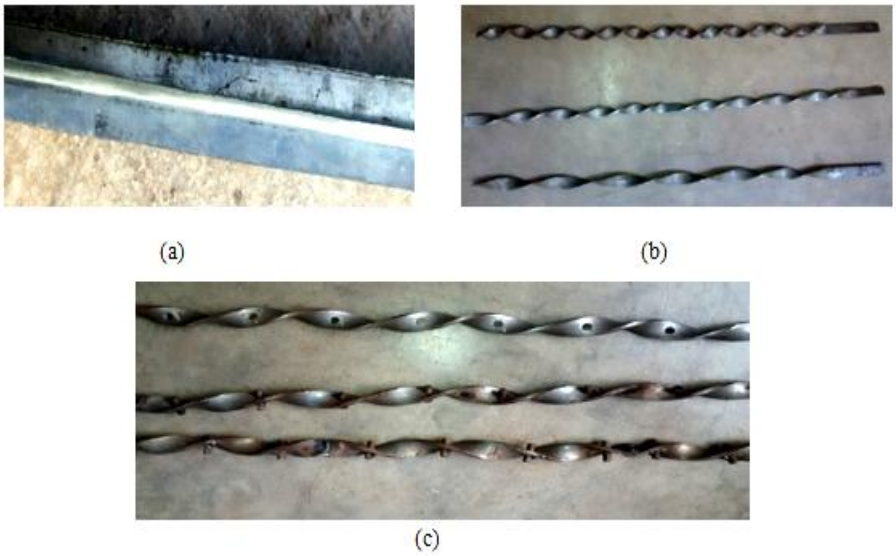
Two solar water heaters are used in the experimental study for comparison. The conventional is taken as reference. The experimentation is carried out from 09.00 to 05.00 pm. During the experimentation, water is pumped through the collector by means of the pump. The mass flow rate of the pumped water can be adjusted by the valve (V_1) and it measured by collection of water in measuring jar within a specified time. With steady mass flow rate, solar radiation, ambient temperature, temperature of the absorber plate, riser tubes wall and glass in collector and pressure drop are recorded an hourly basis during the month of June to November 2014. The experimental works are carried out at solar laboratory located at Thiagarajar College of Engineering, Madurai, Tamil Nadu, India.

Details of Insert

Seven types of inserts are used on modified solar water heater collector for comparison with conventional solar water heater is shown in Table. 1. For that, first experiments are carried out with cross type insert. Second, set of experiments are carried out with three plain twisted tape type inserts with various pitch ratio (PR = p/w = 3, 5 and 7). Third set involved with three modified twisted tape type inserts for best pitch ratio of 3 such as perforated twisted tape, twisted tape with fin and alternative axis of twisted tape with fin. They are made from thin, flat strips of mild steel with suitable length and width for insert into the riser tubes of modified solar water heater collector. The schematic diagrams and photographic views of the inserts are shown in Fig. 3.

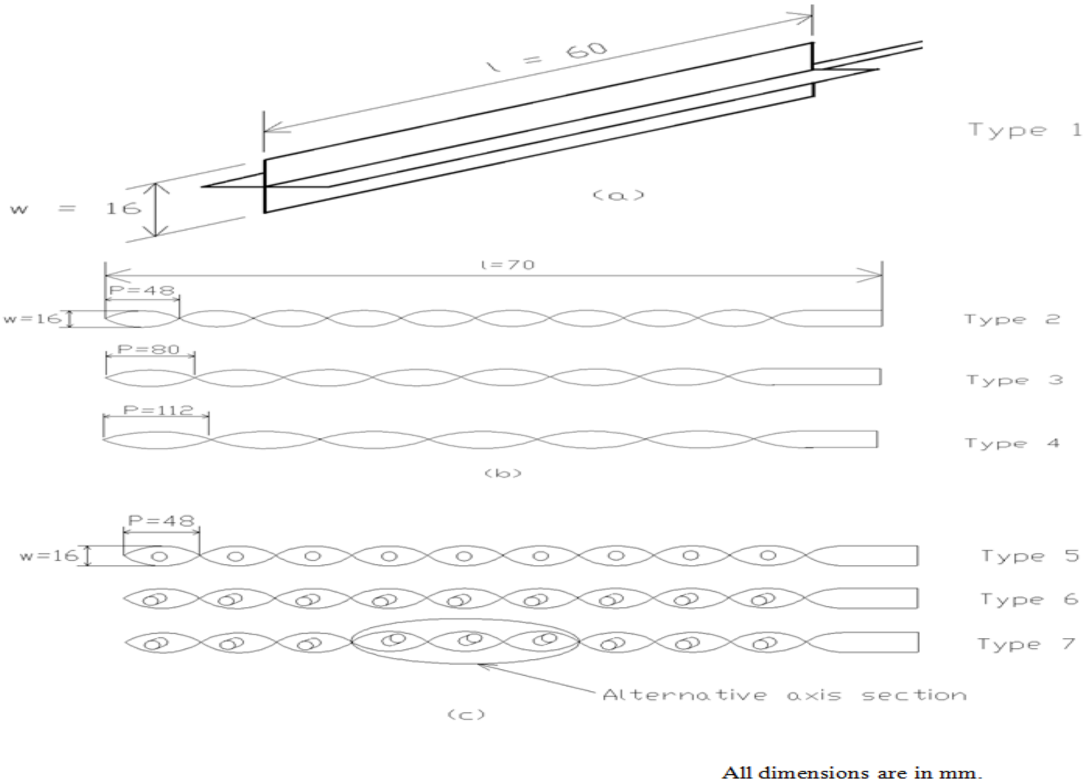
Table 1: Physical Dimensions of The Type of Inserts

S. No	Type of inserts	Specifications
(a) Cross shaped insert		
1	Type 1	Cross type insert
(b) Twisted tape		
2	Type 2	Twisted tape insert, PR = p/w = 3
3	Type 3	Twisted tape insert, PR = 5
4	Type 4	Twisted tape insert, PR = 7
(c) Modified twisted tape		
5	Type 5	Perforated twisted tape, PR = 3
6	Type 6	Twisted tape with fin, PR = 3
7	Type 7	Alternative axis twisted tape with fin PR = 3



(a) Cross shaped (b) Twisted tape for various pitch ratio (c) Modified twisted tape

Figure 3 (a): Photographic view of inserts



a) Cross shaped (b) Twisted tape for various pitch ratio (c) Modified twisted tape

Figure 3 (b): Schematic diagram of inserts

Data Reduction

The averaged experimental data were reduced to obtain the Nusselt number, friction factor and thermal performance factor are calculated as follows.

The energy balance equation for solar collector is expressed as follows [2]

$$Q_u = Q_i - Q_o = I\tau\alpha A_c - U_l A_c (T_c - T_a) \quad (1)$$

The rate of useful energy gain extracted by working fluid in the riser tube of collector is calculated using the following equation [2, 27, 28]

$$Q_u = mc_p (T_{out} - T_{in}) = U_o A_o (T_{wo} - T_m) \quad (2)$$

The internal convective heat transfer coefficient is calculated as follows

$$h_i = \left[\left(\frac{1}{U_o A_o} - \frac{\ln(D_o / D_i)}{2\pi k_w L} \right) \times A_i \right]^{-1} \quad (3)$$

The internal convective heat transfer co-efficient, h_i is calculated by combining equation (1) and (2) to determine the Nusselt number following relation. [17, 27, 28]

$$Nu_p = \frac{h_i D_i}{k} \quad (4)$$

The firction factor can be determined by

$$f_p = \frac{\Delta p}{\left(\frac{L}{D_i}\right)\left(\frac{\rho u_m^2}{2}\right)} \quad (5)$$

The thermal performance factor of the solar water heater is the ratio between the convective heat transfer coefficient of the pipe with turbulators of modified water heater and that of plain tube heater. [17, 20, 25]

$$TPF = \frac{\left(\frac{Nu_t}{Nu_p}\right)}{\left(\frac{f_t}{f_p}\right)^{\frac{1}{3}}} \quad (6)$$

Thermal efficiency of the solar water heater is calculated by following fundamental equation [26, 27],

$$\eta = F_R (\tau\alpha) - F_R U_l \frac{T_{in} - T_a}{I} \quad (7)$$

Where heat removal factor (F_R) and heat loss coefficient (U_l) is calculated from following equations from Duffie and Beckman [13, 29].

$$U_l = \frac{Q_u - I_t(\tau\alpha)}{T_a - T_P} \tag{8}$$

$$F_R = \frac{Q_u}{I(\tau\alpha) - U_l(T_{in} - T_a)} \tag{9}$$

Result and Discussion

In the experimental study, effect on Nusselt numbe, friction factor and thermal performance factor characteristics of modified solar water heater using with various inserts are investigated. Also obtained result of modified solar water heater results are presented with conventional results for comparison.

Plain Tube Collector For Data Verification

The experimental values of Nusselt number and friction factor for plain tube collector are verified with fundamental equation for checking the acceptable limits of experimental values. The experimental values of Nusselt number fitted with Levenspiel equation [28] for the range of Reynolds number 2100 – 10000 (10).

$$Nu = 0.116\left(\mathrm{Re}^{2/3} - 125\right)\mathrm{Pr}^{1/3}\left(1 + \left(\frac{D_i}{L}\right)^{2/3}\right)\left(\frac{\mu}{\mu_w}\right)^{0.14} \tag{10}$$

Whereas experimental value of friction factor for plain tube collector is compared with available equation of Blasius (11) written below for the Re < 10^5

$$f = \frac{0.079}{\mathrm{Re}^{1/4}} \tag{11}$$

Fig. 4 indicates that the effect of Nusselt number and friction factor on Reynolds number for plain tube collector. Increment of Reynolds number makes the flow to be turbulent, which leads to high convection heat transfer. Increase in convection heat transfer is implying the increase in Nusselt number. So that Nusselt number increases with increase in Reynolds number for the entire range. The friction factor decreases with increases in Reynolds number and the values are between 0.008 – 0.011.

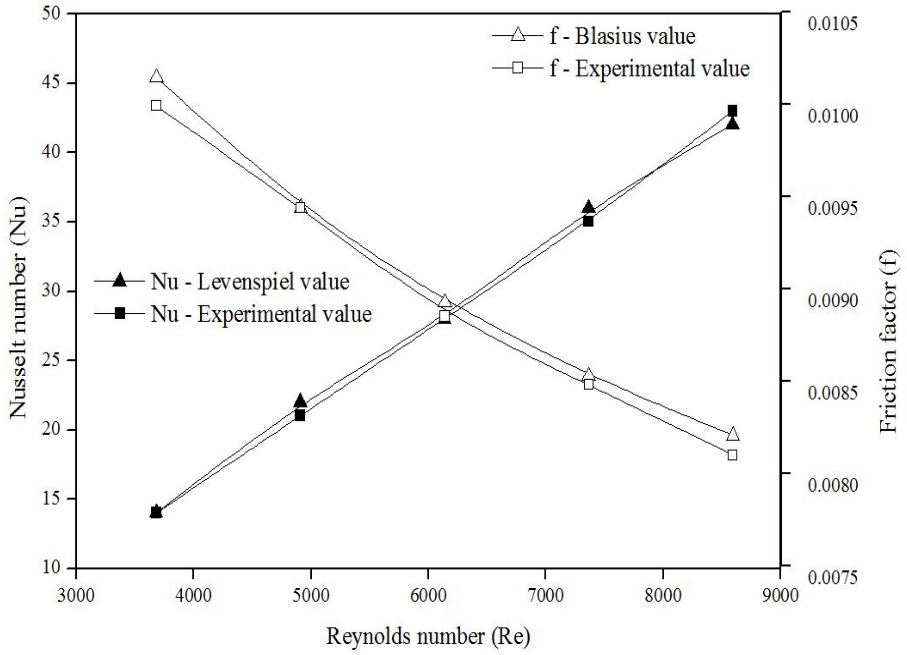


Figure 4: Data Verification For Plain Tube Collector

Effects of Nusselt Number and Friction Factor on Reynolds Number

Left part of the Fig 5 can be noticed that Nusselt number of modified solar water heater is higher than that of the conventional for the same environmental condition. It is due to insertion of insert in modified collector for the heat enhancement. The enhancement of cross shaped insert is lower than that of the twisted tape insert, due to absence of swirl flow effect. The plain twisted tape of PR = 3, 5 and 7 achieve the Nusselt number of 72, 68 and 65 respectively and it implies that as the pitch ratio decreases, the intensity of swirl flow increases which leading to higher heat transfer to the working fluid from the riser tube wall.

Left side of Fig. 6 compares the Nusselt number ration of the turbulator with conventional. It depicts that Nusselt number of type 7 and 3 insert is 2.85 and 1.78 higher than the conventional due to presence of swirl flow by twisted tape. Throughout the experimental result type 7 gives the best heat transfer than other types due to better fluid particle mixing by arrangement of fin with alternative axis type inserts.

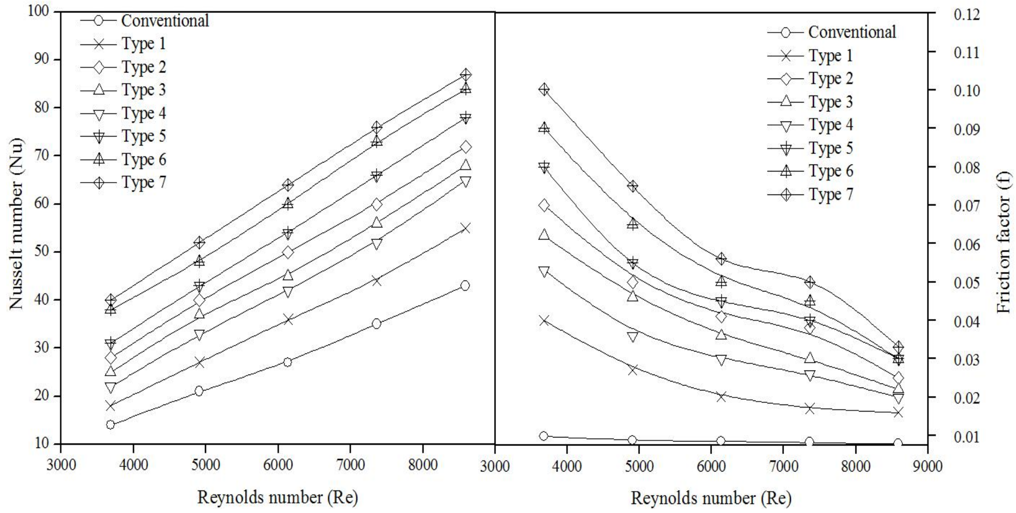


Figure 5: Effect of Nusselt number and friction factor with Reynolds number

Variations of friction factor with Reynolds number are shown in right part of the Fig. 5. From this figure, the friction factor decreases with increase in Reynolds number. Friction factor for plain tube is very much lower than modified collector due to effect of axial flow alone other than swirl flow. The range of friction factor for cross shaped insert is 0.016 – 0.04 and which is less than that of type 2 insert ranges that is 0.025 – 0.07 due to less disturbance effects. Friction factor of turbulator compared with respect to conventional ratio is represented in the right side of the Fig.6 It shows that the all inserts, friction factor of type 7 insert is high because of high disturbance in the flow field and is obtained maximum friction factor of.

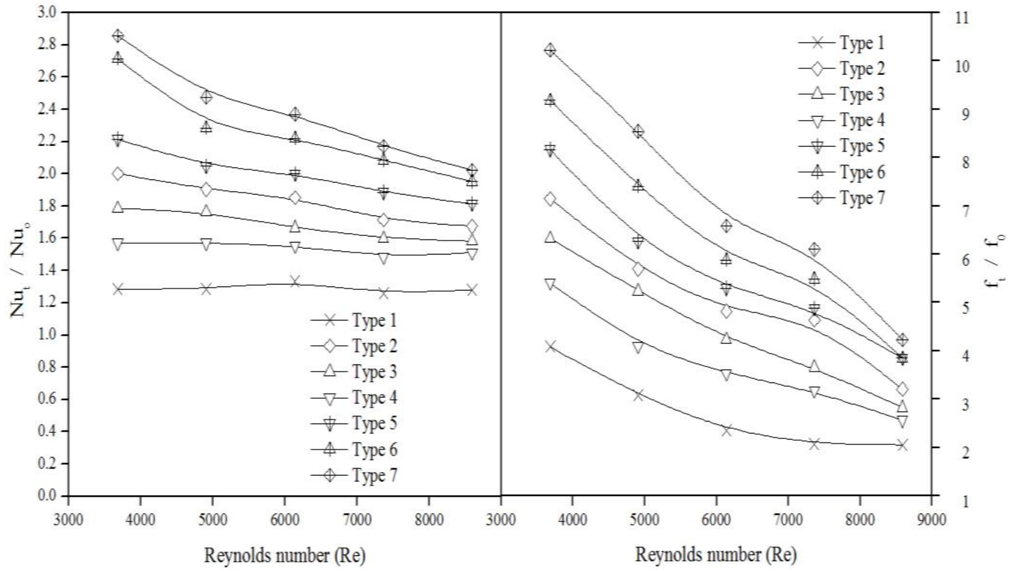


Figure 6: Effect of Nusselt number ratio and friction factor ratio with Reynolds number

Effect of Thermal Performance Factor

The efficiency of the solar water heater with solar radiation is shown in left side of the Fig. 6. Whereas its right side represents that the result of thermal performance factor with Reynolds number. Generally, increase in heat enhancement is increase the instantaneous efficiency of the collector. Heat enhancement of the modified collector is higher than the plain tube collector due to using passive heat enhancement techniques. Heat enhancement is increases with increase in incoming solar radiation from solar to collector. Among the all insert, type 7 is attained maximum efficiency about 51.11 % than plain tube and 19.29 %.

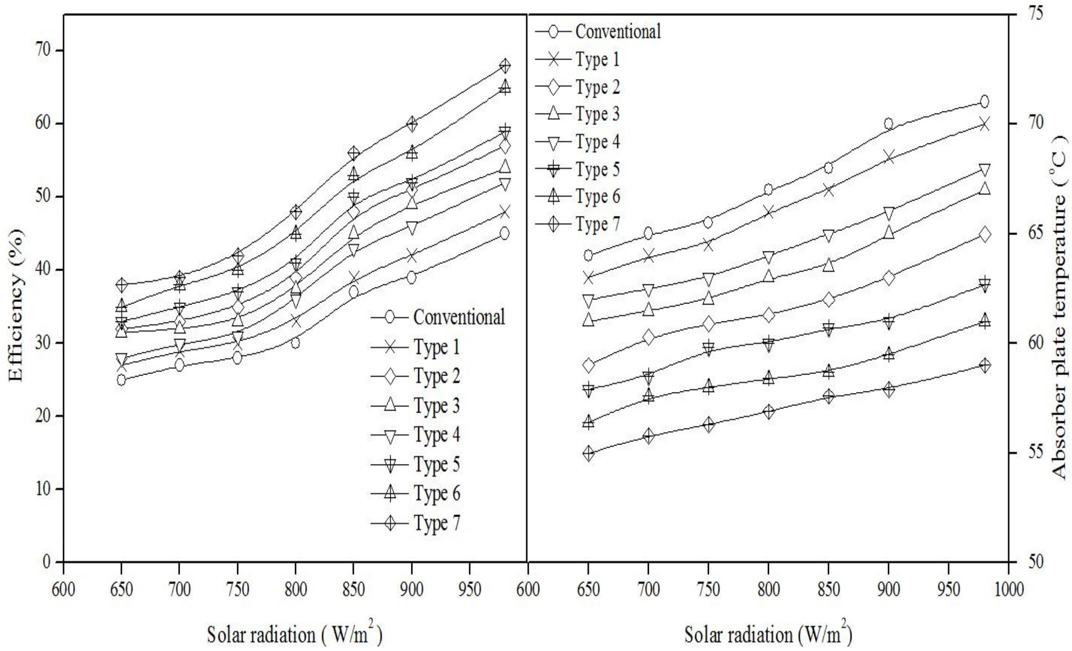


Figure 7: Effect of insert on efficiency and absorber plate temperature with solar radiation

The impact of solar radiation on absorber plate temperature is shown in right side of the Fig. 7. Observation of figure shows that temperature of the absorber plate is function of solar radiation. It found that the plain tube collector having high absorber plate temperature compared with all inserts due to minimum energy transfer to working fluid from riser tube wall surface. As the result of decrease in pitch ratio decrease the absorber plate temperature implying that maximize the energy transfer to the working fluid by consequence of high swirl flow generation and fin effect. The thermal performance factor for all type of inserts varies in the range from 0.8 – 1.31 and shown in Fig. 8.

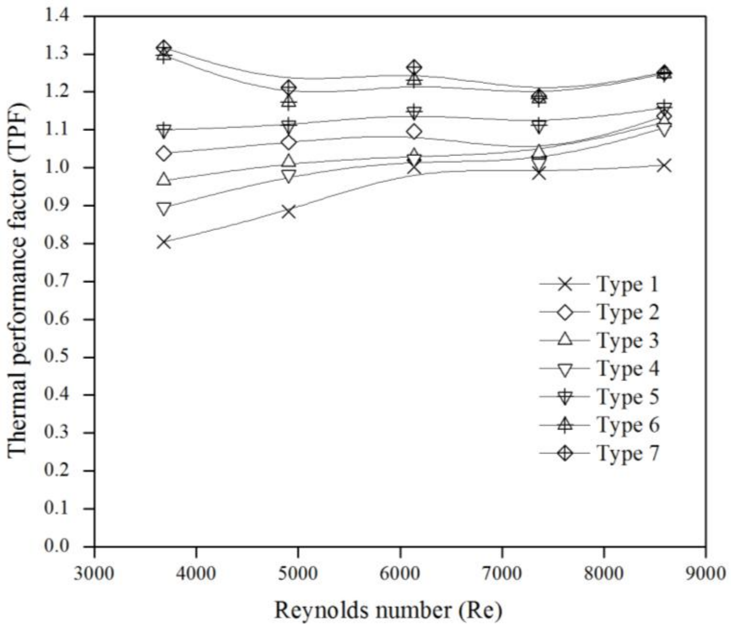


Figure 8: Effect of insert on thermal performance factor

Conclusion

The experimental investigation have been conducted to study the effect of different insert on heat transfer, friction factor and thermal performance characteristics of the solar water heater and presented. The obtained experimental data were compared with conventional and following conclusion were drawn based on experimental and theoretical investigation. The verification of experimental value of the plain tube collector was acceptable range with fundamental equation. The augmentation of heat transfer by the insert is better than the conventional collector. Cross shaped insert promoted less significance with efficiency of the collector than plain tube collector due to domination of axial flow direction than tangential flow direction. Effect of bi-directional flow of the twisted tape insert gives better performance than plain and cross shaped insert. Nusselt number increases with the decrease of pitch ratio and friction factor also increases with decreases with pitch ratio. Pitch ratio 3 gives the better performance than other ratio of 5 and 7. Perforated twisted tape insert gives the high heat enhancement than minimum pitch ratio of normal twisted tape due to better mixing of fluid particles by collision of axial and tangential flow of fluid particles. Among the all tested insert, efficiency of the modified twisted tape of alternative axis finned twisted tape is 51.11 % superior than other conventional and 41.66 % than cross shaped insert due to high disturbance of fluid with fin effect in core region.

Nomenclatures

A_c collector aperture area, m^2

A_i inside surface area of the riser tube, m^2

A_o	outside surface area of the riser tube, m^2
C_p	specific heat kJ/kg ^oC
D_i	inside diameter of riser tube, m
D_o	outside diameter of riser tube , m
f_p	friction factor for plain tube collector, (dimensionless)
f_t	friction factor for turbulator tube collector, (dimensionless)
F_R	collector heat removal factor, (dimensionless)
h_i	average convective heat transfer coefficient ($W/m^2\ ^oC$)
I	intensity of solar radiation, W/m^2
k	thermal conductivity of water, W/ m ^oC
k_w	thermal conductivity of the riser tube wall, W/ m ^oC
L	length of the riser tube, m
m	mass flow rate, kg/s
Nu_p	Nusselt number for plain riser tube (dimensionless)
Nu_t	Nusselt number for turbulator riser tube (dimensionless)
p	pitch length of one twist, m
Pr	Prandtl number (dimensionless $\Pr = C_p \mu / k$)
PR	pitch ratio = p / w, (dimensionless)
Q_i	rate of input heat energy, W
Q_o	rate of output heat energy loss, W
Q_u	rate of useful heat energy gain, W
Re	Reynolds number (dimensionless)
T_a	ambient temperature, ^oC
T_c	collector average temperature, ^oC
T_m	bulk mean temperature of fluid in the riser tube, ^oC $(T_{in} + T_{out})/2$
T_{in}	average inlet temperature of water, ^oC
T_{out}	average outlet temperature of water, ^oC
T_p	absorber plate temperature, ^oC
T_{wo}	average outside wall surface temperature of riser tube, ^oC
u_m	bulk average water velocity (m/s)
U_i	overall inside heat transfer coefficient ($W/m^2\ ^oC$)
U_o	overall outside heat transfer coefficient ($W/m^2\ ^oC$)
U_l	overall heat loss coefficient ($W/m^2\ ^oC$)
w	width of twisted tape, m

Greek letters

η	collector efficiency
ρ	density of water (kg/m^3)
μ	dynamic viscosity of water at bulk mean temperature (Ns/m^2)
μ_w	dynamic viscosity at wall temperature (Ns/m^2)
∇P	pressure drop of water (N/m^2)
$\tau\alpha$	transmittance – absorptance product

References

[1]. Sunil Chamoli, Ranchan Chauhana, Thakur, N. S., Saini, J. S., 2012, "A review of the performance of double pass solar air heater," Renewable and Sustainable Energy Reviews, 16, pp 481–492.

[2]. Hossain, M. S., Saidur, R., Fayaz, H., Rahim, N. A., Islam, M. R., Ahamed, J. U. Rahman, M. M., 2011, "Review on solar water heater collector and thermal energy performance of circulating pipe," Renewable and Sustainable Energy Reviews, 15, pp 3801–3812.

[3]. Velmurugan, V., Srithar, K., 2011, "Performance analysis of solar stills based on various factors affecting the productivity—A review," Renewable and Sustainable Energy Reviews, 15, pp 1294–1304.

[4]. Mustayen, A. G. M. B., Mekhilef, S., Saidur, R., 2014, "Performance study of different solar dryers: A review," Renewable and Sustainable Energy Reviews, 34, pp 463–470.

[5]. Muthusivagami, R. M., Velraj, R., Sethumadhavan, R., 2010 "Solar cookers with and without thermal storage—A review," Renewable and Sustainable Energy Reviews, 14, pp 691–701.

[6]. Hassan, H. Z., Mohamad, A. A., 2012, "A review on solar cold production through absorption technology," Renewable and Sustainable Energy Reviews, 16, pp 5331–5348.

[7]. Rakesh Kumar, Rosen, M. A., 2011, "A critical review of photovoltaic–thermal solar collectors for air heating," Applied Energy, 88, pp 3603–3614.

[8]. Xingxing Zhang, Xudong Zhao, Stefan Smith, Jihuan Xu, Xiaotong Yu, 2012, "Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies," Renewable and Sustainable Energy Reviews, 16, pp 599–617.

[9]. Sukhatme, S. P., Nayak, J. K., 2008, "Solar energy" Tata McGraw Hill Education Private Limited.

[10]. Jacek Kasperski, Magdalena Nems, 2013, "Investigation of thermo-hydraulic performance of concentrated solar air-heater with internal multiple-fin array," Applied Thermal Engineering, 58, pp 411 – 419.

[11]. Ho, C.D. , Chen, T. C. , 2008, "Collector efficiency improvement of recyclic double-pass sheet-and-tube solar water heaters with internal fins attached," Renewable Energy, 33, pp 655–664.

[12]. Paisarn Naphon, Manachai Nuchjapo, Jutarat Kurujareon, 2006, "Tube side heat transfer coefficient and friction factor characteristics of horizontal tubes with helical rib," Energy Conversion and Management, 47, pp 3031–3044.

[13]. Herrero Martin, R., Garcia, J. P., Garcia, A., Garcia-Soto, F.J., Galiana, E. L., 2011, "Simulation of an enhanced flat-plate solar liquid collector with wire-coil insert devices," Solar Energy, 85, pp 455–469.

[14]. Alberto Garcia, Ruth Herrero Martin, Jose Perez-Garcia, 2013, "Experimental study of heat transfer enhancement in a flat-plate solar

water collector with wire-coil inserts," Applied Thermal Engineering, 61, pp 461 - 468.

[15]. Gurveer Sandhu, Kamran Siddiqui, Alberto Garcia, 2014, "Experimental study on the combined effects of inclination angle and insert devices on the performance of a flat-plate solar collector," International Journal of Heat and Mass Transfer, 71, pp 251–263.

[16]. Alireza Hobbi, Kamran Siddiqui, 2009, "Experimental study on the effect of heat transfer enhancement devices in flat-plate solar collectors," International Journal of Heat and Mass Transfer, 52, pp 4650–4658.

[17]. Muthusamy, C., Vivar, M., Skryabin, I., Srithar, K., 2013, "Effect of conical cut-out turbulators with internal fins in a circular tube on heat transfer and friction factor," International Communications in Heat and Mass Transfer, 44, pp 64–68.

[18]. Smith Eiamsa-ard, Sarawut Rattanawong, Pongjet Promvonge, 2009, "Turbulent convection in round tube equipped with propeller type swirl generators," International Communications in Heat and Mass Transfer, 36, pp 357–364.

[19]. Kumar, A., Prasad, B. N., 2009, "Investigation of twisted tape inserted solar water heaters - heat transfer, friction factor and thermal performance results," Renewable Energy, 19, pp 379 - 398.

[20]. Liu, S., Sakr, M., 2013, "A comprehensive review on passive heat transfer enhancements in pipe exchangers," Renewable and Sustainable Energy Reviews, 19, pp 64 – 81.

[21]. Eiamsa-ard, S., 2010, "Study on thermal and fluid flow characteristics in turbulent channel flows with multiple twisted tape vortex generators," International Communications in Heat and Mass Transfer, 31, pp 644–651.

[22]. Ananth, J. , Jaisankar, S. , 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, 73, pp 207–213.

[23]. Murugesan, P., Mayilsamy, K., Suresh, S., 2010, "Heat Transfer and Friction Factor Studies in a Circular Tube Fitted with Twisted Tape Consisting of Wire-nails," Chinese Journal of Chemical Engineering, 18 (6), pp 1038—1042.

[24]. Murugesan, P., Mayilsamy, K., Suresh, S., Srinivasan, P. S. S., 2011, "Heat transfer and pressure drop characteristics in a circular tube fitted with and without V-cut twisted tape insert," International Communications in Heat and Mass Transfer, 38, pp 329–334.

[25]. Bhuiya, M. M. K., Chowdhury, M. S. U., Saha, M., Islam, M. T., 2013, "Heat transfer and friction factor characteristics in turbulent flow through a tube fitted with perforated twisted tape inserts," International Communications in Heat and Mass Transfer, 46, pp 49 – 57.

[26]. Eiamsa-ard, S., Promvonge, P., 2010, "Thermal characteristics in round tube fitted with serrated twisted tape," Applied Thermal Engineering 30, pp 1673 – 1682.

[27]. 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, pp 1054 –1064.

[28]. Jaisankar, S., Radhakrishnan, T. K., Sheeba, K. N., 2009, "Experimental studies on heat transfer and friction factor characteristics of forced circulation solar water heater system fitted with helical twisted tapes," Solar Energy 83, pp 1943–1952.

[29]. Duffie, J., Beckham, W., 2006, "Solar engineering of thermal processes," John Wiley & Sons.