Performance and heat transfer evaluation of convex lens solar water heater with serrated, triangular cut and perforated twist inserts.

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Abstract: This paper studies the performance and heat transfer analysis of Solar water heating systems incorporated by Convex lenses also with two types of twists CSPT(combined Serrated Perforated Twists) and CTPT(combined Triangular cut Perforated Twists) with twist ratios 3 and 6. Convex lenses are preferred to utilize the diffusible radiation and it focuses the solar rays in single point on the absorber plate. It helps the riser tube to get higher solar radiation at the instant. Nearly 45 lenses fixed over the glass and focusing radiations to 9 rows of riser tubes. Generally, twists give a swirling effect to the working fluid and it enables the water to catch up high heat from the riser tubes. In this case, CSPT and CTPT are introduced to examine the heat transfer characteristics. The experiments are carried out for plain and CTPT, CSPT collectors. Reynolds number and the Nusselt numbers are lying between 190 - 1266 and 4.104-16.7331. The friction factor is in the range of 0.035 to 0.1155. The implementation of convex lenses with the insertion of CSPT and CTPT helped to earn better heat transfer. CTPT with minimum twist ratio 3 has provided 1.9 times higher efficiency as compared to CSPT twist inserts. It enhances the overall efficiency by up to 9% than the conventional one.

Keywords: Convex lens, diffusible radiation, twist ratio, swirling effect, and Nusselt number

1.0 Introduction:

In the current scenario, solar energy has become widely used energy. Due to the depletion of fossil fuels now the world turns over toward the application of renewable energy. Renewable energy will play a huge role in the future. At present, the usage of renewable energy is growing rapidly. In this case, solar energy is one of the most important renewable energy worldwide. Solar energy contains a lot of benefits according to the usage. One of which is to convert the solar energy into thermal energy. It is the most effective and easy conversion process. Solar water heater works based on the above-said conversion process. This solar water heating system directly absorbs solar radiation and converts it into thermal energy for heating the water. Generally, solar water heater has been modified by many people according to design, placing of mirrors, construction of header, etc. those modifications have given better results. But in this paper, the convex lenses along with CTPT and CSPT swirl generators are used to boost the heat transfer in solar water heating system and the results are being discussed.
Kale et al. (1) investigated the performance of the convex lens CSP system for hot water and steam generation. They used six convex lenses with 0.0471m² area and copper receiver of 5mm internal dia. and 10mm of outer dia. The results were found that it attains a maximum temperature of 81°C at the mass flow rate of 1kg/hr and the efficiency obtained around 63-64%. He finalized that the presence of convex lenses will help to get the maximum result. Vinod Kumar Verma et al. (2) experimented to analyze the performance of convex lenses for heat transfer application. Six convex lenses and a copper receiver tube are used here. A two-axis manual tracking system is used to track the sun continuously. The results revealed that CSP by convex lenses is the best-suited one for solar water heating to get high heat transfer.

The above-said authors only published the articles according to the convex lens, but in this paper, the solar water heater with convex lenses is approached in different methods of design.

Twists are the best heat transfer improvement element in the heat augmentation technique. Murugan et al. (3) investigated the thermal performance of solar collectors using peripherally wing cut swirl generators (PSG). They used three types of swirl generators including PSG such as Triangular wings (Tri-PSG), Rectangular wings (Rec-PSG), Trapezoidal wings (Tra-PSG) in the solar water heater for enhancing heat transfer. Among the three types of wings the Trapezoidal wing cut swirl generator provided high thermal performance than the other two types. Hasanpour et al. (4), this paper explains the heat transfer and friction factor characteristics of double pipe heat exchanger with modified twisted tape such as perforated, V-cut, U-cut. The results were compared with the conventional heat exchanger. The results confirmed that the Nusselt number and friction factor for modified twists are higher than the typical twists except for the perforated twist. Kongaitpaiboon et al (5), introduced perforated conical ring (PCR) and analyzed the heat transfer characteristics of a heat exchanger. The results revealed that the heat transfer rate obtained in PCR increases 137% over the plain tube. Also, it was found that the PCR is more efficient than CR.

Li et al (6) depicted the heat transfer enhancement of triangular perforated fin by using CFD software and experimentally. The obtained results from the both are same while comparing. Finally, it is proved that the triangular perforated fin contributes to increase the heat transfer. Ammaralifarhan et al (7) experimented with three types of solar collectors. One has an absorber plate with perforation. The other two have a perforated absorber plate with 3 and 6mm holes. The results indicated that the solar collector of absorber plate with 3mm gained more energy than the absorber plate with 6mm perforation and the absorber plate of increasing number of holes with a small diameter is more efficient more than the absorber of decreasing number of holes with high diameter. Bodius Salam et al (8) researched heat transfer coefficient, friction factor, efficiency of water while twisted tape inserted into the tube of 26.6mm diameter. This twisted tape is having a rectangular cut of 8mm depth and 14mm width. The obtained heat transfer efficiencies vary from 1.9 to 2.3%. Eiamsaard et al. (9) investigated the performance of heat transfer, flow friction in tube assisted heat exchanger with oblique delta winglet twisted tape (O-DWT) and the results were compared with straight winglet twisted tape(S-DWT). Twist ratios of 3, 4 & 5 and wing cut ratios of 0.11, 0.21, and 0.32 were used. Results showed that the Nusselt number and friction factor increases with the decrease of twist ratio with the increase of depth of the wing cut ratio. O-DWT gives efficient results comparing with S-DWT.

Bhattacharya et al (10), analyzed the characteristics of friction factor and Nusselt number for laminar flow in a circular duct with the help of Integral transverse rib roughness along with Centre-cleared twisted tape. The results proved that the performance of circular duct with integral transverse rib roughness and Centre cleared twisted tape is more efficient than other enhancement techniques. Chang et al (11) studied the heat transfer in tube fitted with serrated twisted tape and smooth twisted tape. The Nusselt number and friction factor increases with the decrease of twisted ratio for both serrated and smooth twisted tape. The result of this experiment reveals that the heat transfer of water while using serrated twists is 1.2 or 1.3 times than the smooth twist. Sneha ponnada et al (12) conducted an experiment on the thermal performance of water in circular duct using with perforated twisted tape.
with alternate axis (PATT), perforated twisted tape (PTT), Regular twisted tape (RTT). The results found that the heat transfer rate in PATT, PTT, RTT is 48%, 43%, and 33%. Amar Raj Singh Suri et al (13) examined the heat transfer rate and friction in a heat exchanger using multiple square-cut twisted tapes. Results revealed that the heat transfer rate is considerably increased when using multiple square-cut twisted tape than without square-cut twisted tape. Eiamsa et al (14) carried out an experimental work about the serrated twisted tape on heat transfer enhancement against typical twisted tape (TT). Found out the results and the results showed that the use of serrated increases the heat transfer rate than the typical twist. Serrated twisted tape has a great influence on the enhancement of heat transfer rate.

Many research works had been conducted in heat exchangers by various authors in different geometry, but very few only have used different familiar shapes of twists in solar water heater. Hence, this research work has been carried out in a solar water heater with two different unworked geometries of twisted tapes such as CSPT and CTPT of two twist ratios of 3 and 6.

2.0 Experimental set up:

![Fig.1. Schematic diagram of the experimental setup.](image)

1. Water tank  
2. Collector box  
3. Riser tube  
4. Absorber plate  
5. Header  
6. Convex lens

2.1 Construction details:

The entire collector set up is made up of wood with dimensions of 1000mm*1000mm. This wooden collector plays an important role as it prevents heat loss from the system. Here nine riser tubes of internal diameter 11mm and external diameter of 13mm are connected in parallel with Upper and Lower headers. Each riser tube is of 1m length and connected with headers at each end. Header is a main fluid distributional element having the uniform cylindrical shape of 25.4mm diameter and 1000mm length placed across the nine riser tubes. Both headers and riser tubes are made of copper. Twists of CTPT and CSPT are inserted within the tubes to provide swirling effect to the water. Besides with riser tubes are covered by an absorber plate made up of a copper sheet of 1000mm*1000mm*0.3mm and it is coated with black paint. The entire assembly inside the collector is closed by a transparent glass plate with convex lenses are in uniform intervals. The glass plate is of 5mm thick and nearly 45 convex lenses are placed on the glass plate of 300 mm distance from the top.
and bottom of the edge of the transparent glass. The distance between each convex lens is 100mm and the focal length of the lens is 13mm. Convex lenses mainly contribute to focus the solar radiation at a single point of the riser tubes. A storage tank of 100 liter capacity is used to store the water, which is made up of stainless steel. Two tubes of inlet and outlet are connected with the bottom and top header to feed and extract the water. Thermocouples are pinned at 35 points of the set up to take the readings. Here K-type thermocouple is suggested as it can measure up to 1000°C. Solar radiation will be gotten more if the setup is oriented with the earth’s latitude. For the Nagapattinam region, 18° latitude is advisable to get maximum solar radiation.

![Experimental setup](image)

**Fig.2.** Experimental setup.

### 2.2 Concept of Convex lens:

Usually, the convex is used for focusing. Here it secures itself as a very predominant thing in this system. The focal length of 13mm lenses is used here. The structure of the lens enables itself for receiving the solar rays of different angle and it concentrates all the radiations at a single point on the riser tubes. It enables the riser tubes to get maximum solar radiation. Normal plain solar water heater does not have this feature as its efficiency is also less. The presence of convex lenses help the system to attain maximum efficiency.

![Top view of the solar water heater with convex lenses](image)

**Fig.3.** Top view of the solar water heater with convex lenses.
2.3 Concept of CTPT and CSPT:

Using twist inserts is an efficient augmentation method of heat transfer. The purpose of twists is for making swirl effect of water inside the tubes. It also reduces the flow speed of water as it stays a long time within the tubes. Hence the heat transfer rate between the riser tube and water will also be high. In this paper, we wish to give more heat transfer. So, we have introduced new modification twists such as CSPT (Combined Serrated Perforated Twists) and CTPT (Combined Triangular Perforated Twists). In CSPT, the combination of serrated and perforated has been made. In CTPT, the combination of a Triangular hole and perforated has been made. When water flows within the riser tubes, it will be allowed to flow along the helix of the twists and through the circular as well as triangular holes of the twist. It makes easier for the water particle to get collapse and mix with other particles. In this way, twists help the all water particle to carry an equal amount of heat along with itself. The inserting of CSPT and CTPT gives more swirl effect to the water than the existing twists.

![Fig.4. Pictorial view of CTPT (Combined serrated and perforated twist) and CSPT (Combined Triangular cut and perforated twist).](image)

3.0 Data Processing:

The Normalized Nusselt number (Nu/Nu), Normalised friction factor (f/f) and thermal performance factor (η/η) are evaluated for the uniform header solar water heating system with helical twisted tape inserts of ratio’s Y =3,4,5,6 and without twisted tape inserts.

3.1 Heat Transfer:

The Heat Transfer rate of the water in the single riser tube is estimated through the following basic equation (Liao Q, Xin MD, 2000) (15).

\[
Q = m c_p (T_{out} - T_{in}) = U_0 A_0 (T_{w0} - T_m)
\]

(1)

\[
\frac{1}{(U_0 A_0)} = \frac{1}{(h_i A_i)} + \frac{\ln(D_o/D_l)}{(2\pi k_w L)}
\]

(2)
The internal convective heat transfer co-efficient, \( h_i \) is determined by the equation (3). The experimental Nusselt Number is calculated using the following equation

\[
\text{Nu} = \frac{h_i D_i}{k}.
\]  

All the fluid thermophysical properties are determined at the bulk mean temperature, \( T_m \).

### 3.2 Pressure drop:

The differential pressure transducers are attached to the riser tubes through proper tapping for measuring the pressure drop of each riser tube over the length of the riser tube.

\[
f = \frac{\Delta P}{L} \left( \frac{\rho u_m^2}{\mu} \right)_{f}
\]

Where \( \Delta P \) is the pressure drop over the length \( L \).

### 3.3 Thermal Performance:

The thermal performance of the solar water heater is calculated by using the Hottel-Whillier-Bliss [16] equation as follows

\[
\eta = F_R (\tau\alpha) - F_R \frac{U_1 (T_m - T_a)}{H_i}
\]

The following equations are helped to calculate the heat loss Co-efficient \( (U_i) \), Transmittance – absorbance Product \( (\tau\alpha) \) and heat removal factor \( (F_R) \).

\[
Q = H_i (\tau\alpha) - U_1 (T_p - T_a) \\
U_1 = Q - H_i (\tau\alpha) / (T_m - T_p) \\
F_R = Q / H_i (\tau\alpha) - U_1 (T_m - T_a)
\]

Every 15 minutes once the Instantaneous thermal performance is calculated.

### 4.0 Results and Discussion:

#### 4.1 Verification of Nusselt number and Friction factor for convex lens plain collector:

The experimental Nusselt number and friction factor of the plain collector has validated with fundamental equations 9 & 10 and deviations fall within ±6.74 and ± 9.03% respectively. The increase of solar radiation increases the mass flow rate, Nusselt number and friction factor in Phase 1. In Phase 2 the decrease of solar radiation decreases the mass flow rate, Nusselt number and friction factor.

\[
\text{Nu} = 1.86 (GZ)^{1/3} \ (\mu / \mu w)^{0.14} \quad \text{for} \ GZ > 10.
\]

\[
f = 16/Re
\]
4.2 Effect of CTPT and CSPT twist inserts in heat transfer and Friction factor:

The combined triangular cut and circular perforation provided more impact and centrifugal forces radially towards the next helix than combined serrated and circular perforation geometry. In this research, CTPT-3 gives a higher Nusselt number and Friction factor for the twist ratio 3. Figure 5(a) and (b) shows the Nusselt number variations between CSPT-3 & 6, CTPT-3 & 6 and plain collector. Figure 6(a) and 6(b) shows the Friction factor variations for the above said, collectors. The results revealed that the Nusselt number and friction factor for CTPT-3 has 8.98% and 5.23% which is higher than CSPT-3 respectively.

![Figure 5](image1.png)

![Figure 6](image2.png)

Fig.5 (a & b) Nusselt number verification for CTPT and CSPT (Phase 1 & phase 2).
Fig. 6 (a & b) Frictional factor verification for CSPT & CTPT (Phase1 & phase2).

4.3 Effect of CTPT and CSPT in Thermal performance:

Fig. 7 shows the thermal performance characteristics of CTPT, CSPT, and plain collectors. The efficiency of the collectors increases with increase of solar intensity in phase1 and it reduces with decrease of solar intensity in phase2. The results confirmed that the CTPT with minimum twist ratio 3 exerts optimum thermal performance than CSPT with twist ratio 3 and 6 and is 1.9%.

Fig. 7. Relationship between Time and Efficiency.
5.0 Conclusion:

The results of the Convex lens solar water heating system operated with CSPT and CTPT of twist ratio 3 & 6 are experimentally evaluated and compared with each other.

The average Nusselt no obtained from CSPT-6, CTPT-6, CSPT-3, and CTPT-3 and plain are 9.46, 10.74, 12.866, 14.13 and 4.70 respectively. The mass flow rate attained at CSPT-6, CTPT-6, CSPT-3, CTPT-3 are 0.0361, 0.0363, 0.037, 0.0379 kg/s respectively.

In addition with the mean efficiency achieved by CSPT-6, CTPT-6, CSPT-3 & CTPT-3 are 49.77, 53.47, 59.8 & 61.03% respectively.

From the above results, it is confirmed that the CTPT with minimum twist ratio 3 provides higher efficiency in all parameters than the other twist.

The convex lens collector inserted with CTPT of twist ratio 3 has achieved 1.9 times higher efficiency than the CSPT collector.

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