Investigating Study of New Enhanced Parabolic Solar Collector Trough

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Abstract. Parabolic solar collector (PSC) was one of the most public used methods for heating purposes. This study modified PSC and increase its efficiency with minimum cost and space. A passive enhancement on PSC by adding fins on the outside tube surface was done. A copper tape was molded with a triangular fin shape around the copper receiver tube to increase the receiver tube's heat-absorbing surface area. This enhancement increases the PSC thermal performance. The solar parabola collector has a length of 1 m while its width was 0.2m. The tube receiver has a 1m length with inside and outside diameters of 2.46cm and 2.54cm, respectively. Each fin has a 1 cm base and 1 cm height. The total number of triangular fins around the receiver tube was 100, which significantly enhanced PSC's thermal performance. The readings were collected for fifteen days, with ten hours of continuous PSC automatic operation. The new SPC thermal performance was a promising technique with a low cost and efficient process compared to the traditional one with the same dimensions. The effect of volumetric flow rates was also studied where their values for 3, 5, 7, and 9 l/min. are 87.12%, 81.78%, 75.72%, and 58.53%, respectively.

Keywords. Solar collector trough, PSC.

1. Introduction
The deficiency in natural resources, especially fossil fuel, and increasing electrical power consumption and ozone depletion due to their pollution forced the researchers to find a new clean power source [1]. The primary objective function of the power generation system is steam generation. Parabolic Trough Collector (PTC) is usually used for steam generators using a parabolic trough farm reaching 300°C [2]. PTC is considered as a cheap, future, endless thermal energy source [3]. Solar energy is a freely available energy source globally, clean, green, and safe, and can be stored [3, 4]. SPC was widely used for domestic water heating [5, 6]. It is also used in the processing of heating pools and industrial applications [7, 8]. Many studies tried to enhance the thermal performance of PSC. These development techniques tried to modify them by passive and active techniques or numerically by modifying the applied design equations for calculation [9, 10]. Different passive enhancement methods could be applied to enhance thermal solar collector heat transfer. One of these applied methods was the enhancement of thermal energy by using nanofluid. Using nanofluid was the most promising method that could be applied in SPC. Evangelos Bellos (2016) investigated nanoparticle distribution for various nanoparticles (Cu, CuO, Fe2O3, TiO2). Different volumetric rates from 50 to 300 l/min and temperature range from 300 K to 650 K. The
nanoparticles concentrations up to 6 percent. The analysis is conducted with a developed thermal model in Engineering Equation Solver (EES). The final results show that the most efficient nanoparticles were Cu, with CuO$_2$, TiO$_2$, Al$_2$O$_3$, and SiO$_2$, respectively. Higher inlet temperatures and higher nanoparticle concentrations were the most preferred conditions for better thermal performance at low flow rates. The optical efficiency of the collector was 57.7% for the zero-incident angle. The optical efficiency of this collector was about 75.7%, with 96% receiver absorbance and 83% mirror reflectance. [11] Rabienataj Darzi et al. (2014) in this study helical corrugated tube with the specifications ($e/DH = 0.12, 0.15, 0.19, P/DH = 1, 0.8, 0.6$) with Al$_2$O$_3$/water nanofluid was used. The inlet and outlet water temperatures ranged between 15–20 °C and 40–50 °C, respectively. The pressure drops and the thermal performance at different flow rates were experimentally investigated. The enhancement amount of heat transfer was 3.2 times the smooth tube [12]. Wang et al. (2018) studied the pitch and roughness height ratios' effect on PSC thermal performance, ranging between 1 and 3 and between 0.05 and 0.1, respectively. The tube temperature was 603.15 K. The study showed that corrugated tubes were beneficial for roughness height to diameter ratio less than 0.1 and pitch ratio below 2 [13]. Another type of passive enhancement was the use of flow tabulators. These tabulators have different forms and shapes. Usually, turbo lasers with different types and shapes are not suitable for low fluid Reynolds numbers or flow rates. Garcia et al. (García et al., 2013) studied the coiled wire tabulator type effect on PSC's thermal efficiency. The rate range was from 0.011 kg/s to 0.047 kg/s. The thermal efficiency increased to 31%. The pressure dropped increased to 12%. [14]. Amani et al. (Amani et al., 2020) used a conical strip inserted in a PTC. The study proved that the PTC thermal performance factor varied from 0.679 to 1.107 [15]. Another passive method enhances heat transfer by surface roughness techniques (Webb et al., 1971) [16]. Gong et al. (2017) studied pin fin arrays inside the receiving tube, which enhanced heat receiving a tube in the parabolic trough. With the Finite Volume Method (FVM), they verified their results. A comparison between the numerical and experimental results was made. The results showed that a designed finned tube effectively increased the PTC's thermal efficiency, where the Nusselt number was increased to 9.0%. While the heat transfer efficiency factor up to 12.0%. [17] V. M. Hameed and B. M. Essa (2016) did the enhancement using triangular fins on a heat exchanger which enhanced the heat transfer and improved the heat exchanger performance [18]. Also the enhancement on the outside surface of the tube by triangular fins with a tabulator inside the heat exchanger tube was done by V.M. Hameed and M. A. Hussein (2017) which greatly enhanced the heat exchanger performance [19]. From the previous studies, this search tried to investigate the SPC thermal performance and by applying passive enhancement techniques on copper outside tube receiver. Triangular fins were added to the outside receiver tube surface by using a simple, cheap technique. A copper tape with a triangular finned end was molded and shaped around the tube receiver to increase the absorption surface area. The new finned SPC thermal performance was investigated and measured experimentally by constructing a complete SPC rig.

2. Experimental work

2.1. SPC design

The SPC was designed based on two steps:

1. Parabola design [20]. Based on the parabola length dimensions (1 m) and aperture width (0.2 m). The receiver tube distance far from the parabola was calculated based on the following set of equations was 0.05m

\[
y = \frac{d}{(0.5xW)^2} x^2
\]

(1)

\[
f = \frac{W^2}{16\pi d}
\]

(2)
Where; \( d \) is the collector depth (m); \( W \) is the collector width (m); \( f \) is the parabola focus. The studies conducted by Banas [21], Reuter and Allred [22], and Duffle and Beckman [23] declared the essential requirement for the designed implementation of SPC are [24]:

1. Constant reflector optical shape of the reflective surface.
2. The shape deviation should be within an acceptable range through the operation.
3. Severe conditions should not affect the system.
4. Should be able to operate for an extended time.

All these design requirements were taking into consideration in the new design of the finned tube collector.

2. **Receiver tube design**. A tube receiver with an outside diameter of 2.54cm and an inside diameter of 2.46cm was used. This study is concerned with developing a new type of tube receiver by adopting a passive enhancement on the tube receiver. The enhancement was done by adding triangular fins on the copper receiver tube's outside surface, Figure 1.

![Figure 1](image1.png)

**Figure 1.** Copper tape with triangular fins.

The triangular fin has a 1 cm base and 1 cm height. A copper tape with a thickness of 0.002 m. The triangle fins were molded and shaped around the copper tube to have the following shape, Figure 2.

![Figure 2](image2.png)

**Figure 2.** A new manufactured finned receiver tube.

The complete SPC test section, which consists of the reflected parabola section and finned tube receiver, will have the following shape after adding a glass sheet to make the cleaning process easy, Figure 3.

![Figure 3](image3.png)

**Figure 3.** The manufactured test section of SPC.
3. **Supporting system.** It is essential to ensure a good supporting SPC structure against severe environmental conditions. The selection of PTC material should be suitable for the system weight and durability against the change in conditions during the day and the year seasons. The other important constriction factor was its cost.

4. **Tracking system.** Many studies enhanced SPC's thermal performance using a single or dual sun tracker system [24, 11]. SPC connected to a controller with a servo motor move in two-directional axes. This controller tried to follow the incident sun ray all over the day efficiently. The tracking system is located on the solar parabola edges with a controller system that transmits signals to the servo motor located on the supporting construction. This complete process was used to move the SPC unit in the best position to incident sunray. The solar tracker block diagram can be shown in the figure 4.

![Figure 4. Schematic diagram of the used parabolic solar tracker](image)

The used sensor has the following shape, Figure 5:

![Figure 5. Sunlight solar sensor.](image)
2.2. Experimental procedure for SPC operation

After a complete design of SPC was finished, construct a complete SPC system by adding the auxiliary parts to the test section. Two water tanks were connected to the test section. One for the inlet cold water source that enters the SPC after connected to a flow meter controls the input water feed. The other tank was the outlet water tank, which collects the outlet SPC hot water. Two k-type thermocouples at the water entrance and SPC exit regions. The weather temperature and airspeed were also measured. The experimental flow process has the following shape, Figure 6:

![Figure 6. Schematic diagram of the experimental flow diagram of the SPC system.](image)

A controller kit (sensor and motor) directs the SPC to the best position for the incident sun rays. The system temperatures were collected continuously during the operating hours. The experimental work was carried out in June; four selected water volumetric flow rates were selected (3, 5, 7, and 9 l/min). The steady-state operation takes around 20 min after each run. The experimental work was held for more than fifteen days. For each day, 10 hrs of continuous rig operation. So, for each selected flow rate value, the SPC thermal performance was taken over more than fifteen days to ensure all the weather conditions are included through the operations as much as possible. Each day, the experimental test rig was operated for ten hours. The automatic controller follows the sun rays from the sunrise.

3. New SPC performance calculation

The best subject of this study was to investigate the thermal performance of SPC. According to the required calculated variables to estimate the SPC performance, the following set of equations were used:

To calculate the amount of heat absorbed by the working fluid, the following equation was used [18, 19]:

\[ Q = m \cdot Cp \cdot A_x \cdot (T_{out} - T_{in}) \]  

Where; \( Q \) = amount of heat absorbed by the working fluid (W), \( m \) = mass flow rate of working fluid (kg/sec), \( Cp \) = heat capacity (J/K), \( A_x \) = tube inside cross-sectional area (m²), To calculate the total outside surface area of the tube and, \( A = \) surface area of the tube + surface area of fins. The copper tape was molded around the copper tube (receiver) at an angle 23° with the horizontal. The area of a single fin could be calculated with the help of the figure 7.
Figure 7. Single triangular fin with dimensions definition.

\[(A_f) = \{2 + 0.5 (b_f + L_f)\} + (2 L_f) \cos(2\alpha)\]  \hspace{1cm} (4)

So,

\[A = \pi d L + N (A_f)\]  \hspace{1cm} (5)

Where; \(N\) = number of fins around the receiver tube. To calculate the new SPC efficiency, the new finned parabola solar collector's thermal performance was compared to the thermal performance of the unfinned one. The parabola solar collector efficiency was calculated from the following equation [20, 24].

\[\eta = \frac{Q_{\text{with fins}} - Q_{\text{without fins}}}{Q_{\text{with fins}}} \times 100\%\]  \hspace{1cm} (6)

4. Results and discussion

For continuous operation, the daylight (from 8 a.m to 6 p.m) for two cases with and without fins. Each hour the readings of the thermocouples were taken. The data which were collected for 15 operation days have the following behavior, as shown in the figures 8 to 11:

Figure 8. Comparison between new finned and unfinned PSC tube receiver at 3 l/min water flow rate.
Figure 9. Comparison between new finned and unfinned PSC tube receiver at 5 l/min water flow rate.

Figure 10. Comparison between new finned and unfinned PSC tube receiver at 7 l/min water flow rate.

Figure 11. Comparison between new finned and unfinned PSC tube receiver at 9 l/min water flow rate.
Figures (5, 6, 7, and 8) show the amount of temperature enhancement due to the proposed finned techniques on the receiver tube of SPC. The enhanced receiver tube has a new 100 triangular fins around the tube receiver, which enlarge the area which absorbed the sunray heat. The thermal enhancement was due to the fins foundation cause a passive enhancement of heat transfer rate. The outlet water temperature was unequally increased for all the selected water flowrates values, as shown in Figure 12:

![Figure 12](image_url)

**Figure 12.** Different water flow rates for new SPC finned triangular tube receiver.

This figure shows the effect of increasing the water flow rates on the heat gain value or SPC thermal performance. When fluid velocity increased, the amount of temperature gain will decrease due to the decrease in the contact time between the flowing fluid and receiver tube surface. The maximum temperature increase will be obtained for the low water flow rate, which was 3 l/min in this study. In contrast, the minimum water increase was for high water flow rate, which was 9 l/min in this study. The system thermal performance calculated at the four volumetric water flow rate, as shown in the figure 13:

![Figure 13](image_url)

**Figure 13.** New finned tube receiver SPC efficiency.
The new SPC finned receiver tube's thermal performance increased with the fluid velocity decrease because of the temperature difference value increase. The uncertainty of data depends on the measuring device uncertainty, and it is less than ±0.01 K. The use of motor sun tracker also increase the thermal efficiency of the SPC in the two cases (with and without fins), and this truth was supported by Mageshwaran et al. 2018 [26]. The SPC was covered by a glass cover to overcome the cleaning problem. Also, the glass cover prevents losing heat to the environment, moving around the tube receiver [2, 27]. The finned SPC was covered by a glass sheet to reduce the convection heat loss to the surrounding air, which moves around the collector [2]. Also, the glass sheet help in easy clean the collector fro dust and other environmental effects. The used SPC finned receiver tube was the most promising technique compared to the conventional SPC receiver tube. The proposed new SPC now tube receiver reduces the size and required cost for the same SPC thermal performance. Passive enhancement usually has the same unequal effect for cost and performance requirements [10].

5. Conclusion
1. The new proposed finned tube receiver was a promising technique compared to the traditional one.
2. Finned receiver tube SPC has a low cost for construction and fabrication with high efficiency
3. The proposed new SPC are easy to clean and has durability against different environmental conditions
4. It needs a small space with a promised efficiency compared to traditional SPC with the same efficiency
5. Could be used for industrial and domestic purposes
6. The use of an automatic sun tracker helps to increase the thermal performance of the new SPC.
7. When the water flow rate decreased, the SPC performance increased

| Abbreviation | Description |
|--------------|-------------|
| SPC          | Solar Parabolic Collector |
| PTC          | Parabolic Trough collector |
| EES          | Engineering Equation Solver |
| PTC          | Parabolic Trough Collector |
| FVM          | Finite Volume Method |

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