

PAPER • OPEN ACCESS

An Experimental Study on New Multistage Solar Parabolic Trough Collector

To cite this article: Vinous M Hameed and Maryam Ibrahim 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1094** 012103

View the [article online](#) for updates and enhancements.

You may also like

- [Optical, Energetic and Exergetic Analyses of Parabolic Trough Collectors](#)
Murat Öztürk, Nalan Çiçek Bezir and Nuri Özek
- [Experimental validation of energy parameters in parabolic trough collector with plain absorber and analysis of heat transfer enhancement techniques](#)
F R Bilal, U C Arunachala and H M Sandeep
- [Enhancing the thermal performance of solar collectors using nanofluids](#)
M I Omisanya, AK Hamzat, SA Adedayo et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

An Experimental Study on New Multistage Solar Parabolic Trough Collector

Vinous M Hameed and Maryam Ibrahim

Chemical Eng. Dept., Al-Nahrain University, Baghdad, Iraq

E-mail: Vinous.m.hameed@ced.nahrainuniv.edu.iq

Abstract. Solar parabolic collector is a clean a promising traditional technique due to the deficiency in energy resources. A new designed multistage solar parabolic trough collector was proposed and its thermal performance was investigated in this study. The collector width and length are 1m with a copper receiver tube outside and inside diameters of 2.54cm, 2.46cm, respectively. Four buses tube receiver were proposed inside the parabolic collector fitted in a thermocouple at the entrance and exit regions of each bus. A solar tracker with a solar sensor for maximum collecting incident sun rays from the sun rise to sun set. The test section is covered with a glass sheet for easy cleaning and to protect the system from losing heat to the surrounding. To evaluate the thermal performance of the new collector, several variables were studied which are: temperature difference between the fluid inlet and outlet regions, heat absorbed by the collector, convective heat transfer rate, and collector thermal efficiency. All the studied variables show that minimum water volumetric flow rates will give max temperature difference between the fluid inlet and outlet regions, heat absorbed by the collector, convective heat transfer rate, and collector thermal efficiency respectively.

Keywords. Solar collector, Solar tracker, Collector trough, Water heater, Parabola.

1. Introduction

Since 1970, interest in the search for renewable energy sources began to increase due to the increased energy demand, which had a great impact on the environment due to the burning of fossil fuels. Since solar energy makes up most of the renewable energy on Earth, one of the sources of bridging the demand for energy for the future has been Concentrated Solar Power (CSP) system [1]. Among all the (CSP) system technologies available so far, the parabolic trough collector is the best solution for power generation [2]. It is characterized by several advantages, including the high energy capacity, high efficiency, multiple uses, long life, and durability against moisture. It also has drawbacks such as the use of moving parts, the deformation of the receiver over time, the high maintenance cost of the tracking system, and the large required land area [3] [4]. The power produced from the sun light could be achieved by different techniques and parabolic solar collector was one of these methods. The desired performance can be achieved in a Parabolic Trough Collector (PTC) system depending on the system design, material selection, the available solar radiation and the Heat Transfer Fluids (HTF) [5]. Sagade, et al. (2013), [6] prototyped parabolic trough with a 0.86 reflector aperture region protected by Aluminum foil. This parabolic line-focusing trough was tested without and with glass cover, with a mild steel receiver coated with a black proxy film. With or without glass cover, instantaneous output of 51% and 39% was achieved, at 16, 42 ° N latitude, 74,13 ° W longitude. This paper focuses on parabolic trough that yields instantaneous efficiency of 60 % with top cover [6]. Jaramillo et al.



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

(2013), [7] used five connected parabolas designed and constructed to generate hot water and low enthalpy steam, three of which were at rim angle 90° and two were at 45° . They were manufactured from aluminum reflectors and copper receiver tube ($W = 0.84$ m, $L = 1.0$ m, $d_i = 0.022$ m, $d_o = 0.022$ m). It was operated by two systems, closed loop ($\dot{m} = 0.00721$ kg / s) and open loop ($\dot{m} = 0.00187$ kg / s). They were observed to have a closed loop thermal efficiency of 43% with temperature of ($T_i = 85$, $T_o = 108.5$) $^\circ\text{C}$ and an open loop type of PTC system of 29% with temperature of ($T_i =$, $T_o = 25$), with a the cost of 170\$ [7]. Zou et al. (2016), [8] conducted an experimental study carried out in cold surroundings to assess the performance of Parabolic Trough Collector PTC in small size ($W = 1$ m, $d_i = 0.023$ m, $d_o = 0.026$ m, with rating flow $= 0.5$ m³ / h, average DNI of 720 W / m², reflector mirror and aluminum receiver tube). They used two types of receiving tubes, one is coated double glazing evacuated tube, while the other is uncoated double glazing evacuated tube. They have noticed an average thermal efficiency of 33% in case of an uncoated double glazed evacuated tube and 30% in case of a coated double glazed evacuated tube [8]. Almanza, & Correa et al. (2000), [5] developed a first-surface solar mirrored parabolize with a curved form geometry over coated soda-lime lens. In order to cover all the surface of the concentrator, the size was 2.37 m of aperture. This material usually runs to 800°C with a lowest fracture when it has been installed and hardened. They were put in an oven up to 600°C for around 2 hours to settle powdered lenses. Sputters with planar magnetron have been used to build mirrors. About 86% had the specular reflection of the mirrors, 90% of reflection of solar beam radiation arrived on a simulated 1.14 m diameter pipe receiver, and 16 mirrors were made from 0.3 to 0.6 m and set up like a mosaic set [5]. Bellos (2016), [9] established that Nanofluids are one of the most promising strategies for improving efficiency in parabolic trough collectors. The goal of this study was to investigate the use and distribution into thermal oil (Syltherm 800) of various nanoparticles (Cu, CuO, Fe₂O₃, TiO₂). For flow rates of 50 to 300 L min⁻¹, for admission temperatures from 300 K to 650 K and for concentrations of nanoparticles up to 6 percent, a detailed parameter analysis was performed. The effect of the level of solar irradiation on thermal efficiency improvement was also examined. A new index was also developed for the assessment of working fluid in solar collectors. The analysis was conducted with a developed thermal model in Engineering Equation Solver (EES). According to the final results, the most efficient nanoparticle was the Cu [9]. The aim of the present study is to collect the maximum benefit from the incident sun light to get maximum water temperature. This is done by new designed solar water heater with a sun tracker to ensure maximum benefit from the incident sun light all over the day light in Baghdad city located at latitude $33^\circ 19'$ north, and at longitude $44^\circ 25'$ east.

2. Experimental work

The experimental work was done in two steps as shown below:

2.1. Design of the experimental test section

To investigate the performance of the proposed new solar trough, a system was designed and constructed consisting of the following parts and steps, which will be described below:

The designed PTC has the following shape, Figure 1:

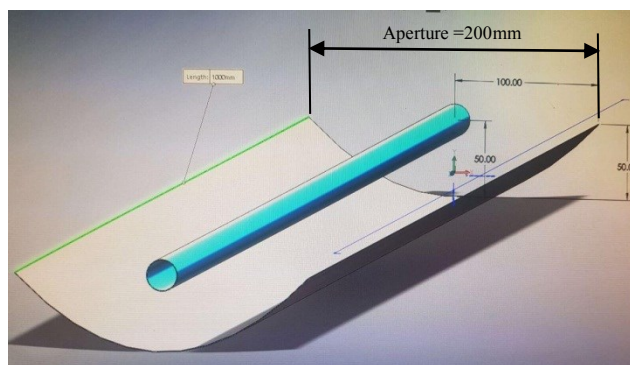


Figure 1. Schematic designed of PTC.

After designing single channel PTC which was a traditional method used as solar water collector heater. The modified PTC consists of five channels or buses PTC. The new reflective system consists of five parabola trough channels. Each channel has the same dimensions of the single channel. The total area parabola area will be (1) m². The parabolic trough plate is iron coated by chrome as glass mirror. The plate thickness was (1) mm and the dimensions of the parabola was (Parabola aperture=20cm, Focal distance=5cm, length=1m and weight =48.4kg). The new PTC water heater has the following shape, Figure 2:



Figure 2. New five channel PTC water heater.

Heat receivers are tubes that act as a receiver for sunlight rays absorbed directly and reflecting rays from the reflecting surface gathered in the focal point where tubes are located. The used pipes were made of copper which was considered a high temperature conductor with length (L) = 1m, d_o =2.54cm, and d_i =2.46cm. The parabola with pipes are located in an Aluminum box with 1m length and 1m width. The receiving tubes were covered with glass and insulated well to reduce the amount of heat lost to the surrounding and the dimensions of the glass were (110 ×110) cm and a thickness of (3) mm. The Dual Axis Solar tracking system was designed and connected to the structure support system of a PTC water heater. The tracking system consists of the following parts:

- a) Sunlight sensor
- b) Two servo motors (Super Jack), responsible for the movement of the reflector system (PTC) in (x, y) axes.

These are the main experimental parts of multistage PTC which at last has the following shape. The total PTC heating system is shown in the following picture, Figure 3.



Figure 3. Complete PTC main experimental parts.

2.2. PTC Operation

Two tanks are connected to the PTC system; one for cold water source and the other for the outlet collected hot water. A flow meter was connected to the inlet PTC tank to fit the amount of inlet water to the test section. Six k-type thermocouples are distributed on the test section. One thermocouple in the water inlet feeds another in the outlet water feed. The remaining four thermocouples were distributed at the end of each receiver tube bus. An automatic controller with a servo motor was connected to the foundation structure to move the test section according to the sunlight sensor signal.

A weather thermometer and air velocity were also added to the system readings. A glass sheet with 1m length and 1 m width was used to cover the multichannel solar collector. Four water flow rate values were selected to study the effect of changing Reynolds number on the PTC performance. According to the water flow meter range, four volumetric water flow rates were selected (3, 5, 7, and 9 l/min).

The experimental work was carried out for 15 operating days from (18_25/6/2020). In each day the experimental work was done over the day light at 8 a.m to 6 p.m. Each run was repeated two times or more to confirm the obtained collected data.

3. Theoretical used equations

$$(Ts) = \frac{Ts_1 + \dots + Ts_5}{5} \quad (1)$$

Where; Ts = average surface Temperature, Ts1, Ts2, ... = surface temperature at position 1, or 2 or, ..

Q° = Volumetric flow rate (m^3/sec)

$$Q^\circ = U \cdot A \quad (2)$$

Where; U= Water flow velocity (m / sec.), A= cross sectional Area (m^2)

$$A = (\pi/4) D_i^2 \quad (3)$$

$$\begin{aligned} D_o &= 1 \text{ (in)} = 2.54 \text{ cm} \\ &= 2.54 \times 10^{-2} \text{ m} \end{aligned}$$

$$D_i = D_o - 2P \quad (4)$$

P = thickness of tube (m)

$$P = 0.8 \text{ mm} = 0.8 \times 10^{-3} \text{ m}$$

Reynold's number [Re]

$$Re = \rho u d / \mu \quad (5)$$

$$\rho = \text{density of water (kg / m}^3\text{)} = 1000 \text{ (kg / m}^3\text{)}, \mu = 1.1 \times 10^{-3} \text{ kg / m s}$$

Internal Surface Area for heat transfer

$$A_i = \pi D_i L \quad (6)$$

Prantal number [Pr]

$$Pr = \frac{CP \mu}{K} \quad (7)$$

Where; CP= Heat Capacity, μ = Viscosity, K = Thermal Conductivity

Nusslet Number (NU):

$$Nu = 0.023(Re)^{4/5} \times (pr)^{1/3} \quad (8)$$

For $2500 > Re > 1.25 \times 10^5$

$$Nu = h_o D_o / K \quad (9)$$

$$h_i = q / A_i \times (T_o - T_i) \quad (10)$$

Area Surface for Heat transfer:

$$A_o = \pi D_o L \quad (11)$$

over all heat transfer Coefficient

$$AU = \frac{1}{\frac{1}{(A_o h_o)} + \frac{1}{A_i h_i} + \frac{\ln(D_o D_i)}{2 \pi K L}} \quad (12)$$

Convection Heat transfer q_c :

$$q_c = AU \cdot A_o (T_s - T_{inf}) \quad (13)$$

Total Heat transfer:

$$q_t = q + q_c \quad (14)$$

Efficiency

$$\eta = (Q_{act} / Q_{max}) \times 100\% \quad (15)$$

$$Q_{act} = m^{\circ} CP (T_o - T_i) \quad (16)$$

4. Results and discussion

The experimental work was done by measuring the temperature distribution along the new PTC by using six thermocouples distributed on the test section. Several factors and variables were studied to calculate the thermal performance of the multichannel PTC unit. An open operation system mode of pumped water was done on the PTC and the following results were obtained and shown in the following figure 4:

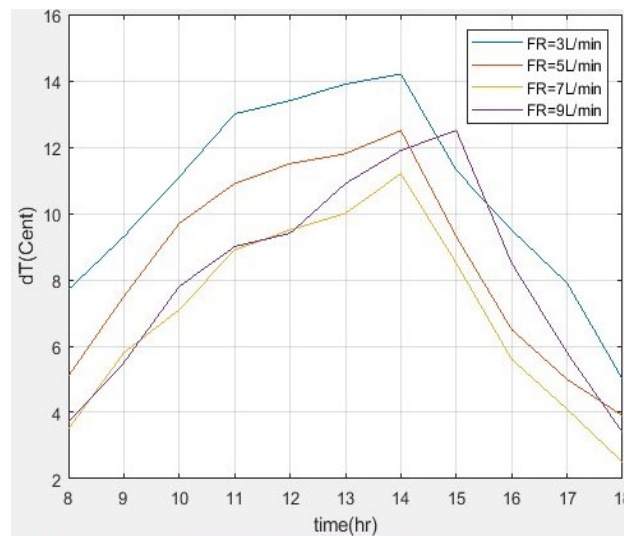


Figure 4. The temperature difference of multichannel PTC all over the day light operation for volumetric flow rates 3, 5, 7, and 9 l/min.

The figure shows that the temperature distribution of the gain temperatures increased in the middle of the day gradually to its initial position because the sunlight intensity increases then and decrease gradually till the night. The outlet water temperature from the collector has the same behavior of the previous figure behavior. Since the collector gains much heat; its temperature will be higher. This fact will be shown in the following figure 5:

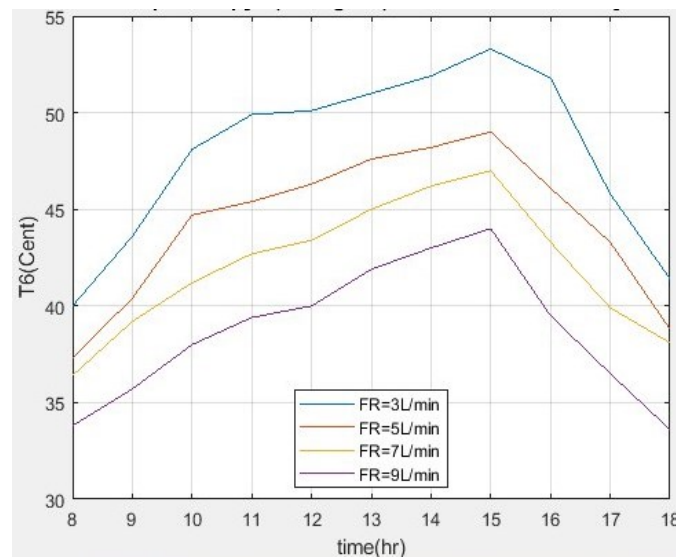


Figure 5. The outlet water temperature at different volumetric flow rates.

The amount of heat for each flow rate can be shown in the following figure 6;

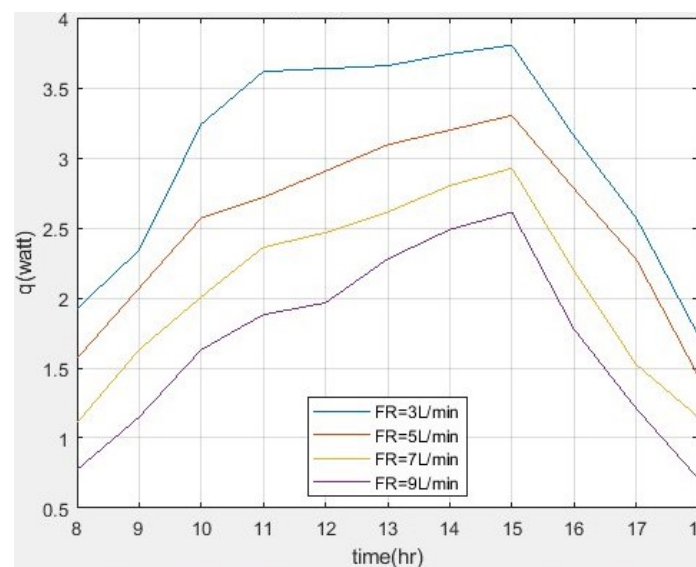


Figure 6. relation of heat gain by multistage SPC over a day light at different volumetric water flow rates.

Minimum liquid flow rate will have the maximum heat. All the selected flow rates values will have a concave down shape due to the heat intensity change over the day light. The minimum water flow rates will have maximum heat amount and vice versa. The heat transfer coefficient also was calculated by using suitable pointed equations as in the following shape, Figure 7:

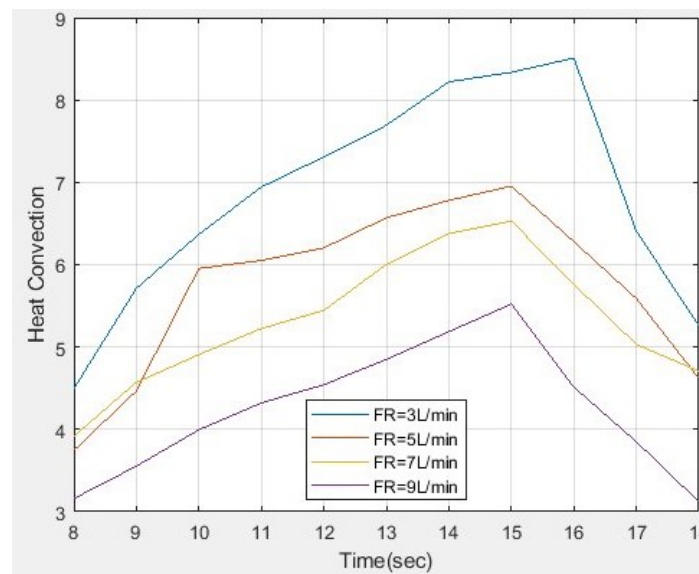


Figure 7. convective heat transfer vs. time for different volumetric water flow rates.

When the PTC efficiency for different volumetric water flow rates were calculated, the following figure is obtained, Figure 8:

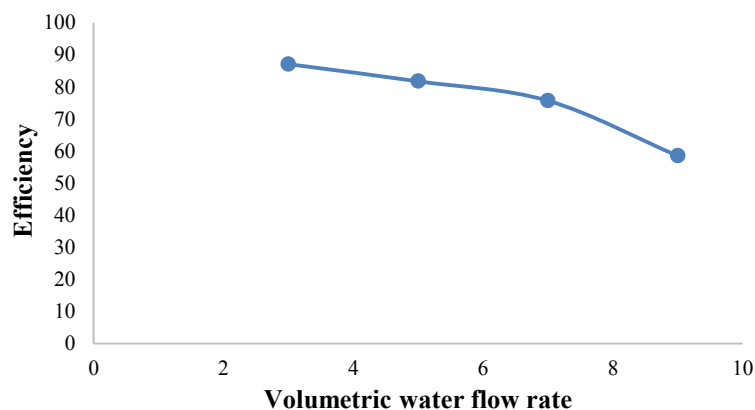


Figure 8. Multistage PTC at different volumetric water flow rates.

Maximum efficiency for the multistage PTC was obtained for low system flow rates. While it increases gradually until reaching maximum at very low volumetric flow rates value. When the liquid water flow rate was low, the contact time between the copper tube surface and water increased. This leads to increasing the heat transfer rate between the receiver tube and water. This phenomena resulted in a better PTC thermal performance and efficiency. The amount of enhancement over a single channel PTC will be more than 70% for all selected volumetric flow rate values. The addition of the solar tracker on the solar collector foundation maximizes the daily collecting of incident sun rays on parabola surface from sun rise to sun set. The addition of glass sheet over the multistage parabola collector will enhance the heat transfer rate and prevent losing heat to the environment and move air around the receiver tube. Also the addition of glass sheet help in easily cleaning the system. The results show a promising designed solar collector with lower cost compared to the traditional one where the foundation cost of four collectors were reduced to one. Minimum required spacing for multistage PTC was compared to the traditional used one.

5. Conclusion

This study concluded the following:

1. The new designed solar collector will have a promising thermal performance compared to the traditional used solar collector.
2. The amount of temperature absorbed by the collector increased.
3. The proposed multistage solar collector has low cost since in its construction, the four parabolic collectors are reduced to one.
4. Minimum required space for operation makes it suitable for domestic and industrial operation.
5. Easy to clean and has a durability against the change in environmental conditions.
6. Addition of sun tracker decreases the amount of heat through the day operation.
7. Many variables were studied to investigate the thermal performance of PTC like (temperature, heat gain, heat transfer coefficient, and parabolic solar efficiency).

6. References

- [1] Z D Cheng, Y L He, F Q Cui, R J Xu and Y B Tao 2012 *Numerical Simulation of a Parabolic Trough Solar Collector with Nonuniform Solar Flux Conditions by Coupling FVM and MCRT Method* (Solar Energy) vol 86 pp 1770-1784
- [2] Omar Behara, Abdallah Khellaf and Kamal Mohammedi 2015 *A Novel Parabolic Trough Solar Collector Model-Validation with Experimental Data and Comparison to Engineering Equation Solver (EES)* (Energy Conversion and Management) vol 106 pp 268-281
- [3] Kaygusuz K 2009 *Environmental Impacts of the Solar Energy Systems* (Energy Sources, Part A: Recovery, Utilization, and Environmental Effects) vol 31 no 15 pp 1376-1386
- [4] Hafez A Z, A M Attia, H S Eltwab, A O ElKousy, A A Afifi, A G Abd El-Hamid and A N Abd Elqader 2018 *Design Analysis of Solar Parabolic Trough Thermal Collectors* (Renewable and Sustainable Energy Reviews) vol 82 pp 1215-1260
- [5] Almanza R and Martmhnez I 2000 *Parabolic Trough Reflector Manufactured with Aluminum First Surface Mirrors Thermally Sagged* (South Africa Journal of Educational Technology) vol 64 no 96 pp 1-10
- [6] Sagade Atul A, Satish Aher and Nilkanth N Shinde 2013 *Performance Evaluation of Low-Cost FRP Parabolic Trough Reflector with Mild Steel Receiver* (International Journal of Energy and Environmental Engineering) vol 4 no 1 pp 1-8
- [7] Jaramillo O A, E Venegas-Reyes, J O Aguilar, R Castrejón-García and F Sosa-Montemayor 2013 *Parabolic Trough Concentrators for Low Enthalpy Processes* (Renewable Energy) vol 60 pp 529-539
- [8] Zou Bin, Jiankai Dong, Yang Yao and Yiqiang Jiang 2016 *An Experimental Investigation on a Small-Sized Parabolic Trough Solar Collector for Water Heating in Cold Areas* (Applied Energy) vol 163 pp 396-407
- [9] Bellos E, C Tzivanidis and K A Antonopoulos 2016 *A Detailed Working Fluid Investigation for Solar Parabolic Trough Collectors* (Applied Thermal Engineering) vol 14 pp 374-386