Suez Canal Engineering Energy and Environmental Science Journal
Faculty of Engineering – Suez Canal University
2025, Vol. 3, NO. 1, Pages 1–5

The Optimal Tilt Angle of the Solar Fixed System of Parabolic Trough Collectors

Mohamed S. Mustafa[1*], Mohamed G. Mousa[2], Mohamed M. Dawood[3], Tamer M. Mansour[4], Tamer Nabil[4]

[1]Higher Technological Institute, Tenth of Ramadan city, Egypt
[2]Mechanical Engineering, Faculty of Engineering, Damietta University, Damietta, Egypt
[3]Mechanical Power Engineering, Faculty of Engineering, Damanhour University, Elbehira, Egypt
[4]Mechanical Engineering Department, Faculty of Engineering, Suez Canal University, Ismailia, Egypt

**Corresponding Author: Mohamed S. Mustafa, Email address: mohamed.saad@hti.edu.eg*
DOI: 10.21608/sceee.2024.293152.1026

Article Info:

Article History:
Received: 27\05\2024
Accepted: 03\07\2024
Published: 30\01\2025

DOI: 10.21608/sceee.2024.293152.1026

Abstract

Solar collectors are considered one of the most advanced methods for heating water or air. Their efficiency increases when the solar collectors are directed toward the sun. Based on the directional movement of the sun, there must be a sun tracking system, but this system is very expensive, especially in practical applications. In the current study, tests were conducted on the parabolic trough concentrators with different tilt angles (10^0, 20^0, 30^0, 40^0, 50^0), which is the angle at which solar rays fall on the solar collector perpendicularly, to reach the optimal tilt angle. It was found that the north-south direction of the solar concentrators is better than the east-west direction. The best heating performance of the solar collectors is at a tilt angle of 30^0. It is also noted that when the tilt angle exceeds 30^0, the percentage of solar radiation falling on the concentrators is lowered. The tilt angle of 30^0 is the optimal angle for solar collectors, as it achieved the highest average temperature of the water leaving of the solar collector by 18%.

Keywords: *Parabolic trough, tilt angle, solar radiation*

Suez Canal Engineering, Energy and Environmental Science Journal (2025), Vol. 3, No.1.

1. Introduction

Energy is critical to the growth and survival of humans, and one of its forms, solar energy, is a clean, green, and limitless energy source (Wang et al, 2015) , making it one of the most promising alternatives to fossil fuels today. In this context, the research focuses on concentrated solar energy systems, which collect sun rays in an intense and concentrated manner before converting them into thermal energy that can be used in a variety of other systems. Nowadays, one of the top concerns in the development of parabolic focus collectors is to increase their efficiency in a variety of ways, including improving the processing precision of reflective surfaces, producing highly reflective materials, and so on.

It is worth noting that good sun tracking modes can greatly improve the efficiency of parabolic through concentration, PTC, collectors. The tracking modes of PTC, collectors can be divided into two types based on the number of tracking axes with the primary optical axis in terms of direction (Peng L et al, 2010). Single-axis solar tracking uses either elevation angle or azimuth, which can be performed by ensuring that the incident light falls on the plane formed by the primary optical axis and focal line (Yu L et al, 2011). This type mainly includes the north-south tilt tracking mode, the north-south horizontal tracking mode and the east-west horizontal tracking mode. Recently, the literature on double-axis tracking modes has accounted for more than 41.58% of all research on tracking modes for parabolic trough concentrators, those conducted on single-axis modes account for approximately 42.57%. (Hafeza AZ et al, 2018).

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Barakat et al. (Barakat B et al, 2001) discovered adopting dual-axis tracking modes can increase the efficiency of solar energy reflected by the solar collector by 20%. Furthermore, in their investigation of dual-axis modes, Fahim and Kang (Fahim U et al, 2018) observed that the optical efficiency of these modes can be as high as 0.813%, with an annual average 40.9% greater than that of North-South tracking modes. Backus (Bakos GC et al, 2006) employed a 40-degree tilt angle to track dual-axis solar radiation and found that solar energy incident on the tracking surface was 46.46% higher than incident radiation on the fixed surface. In the context of continuous improvement of the dual axis concentrated solar energy collector, Khalifa et al. (Khalifa AJ et al, 1998) found that utilizing a dual-axis tracking system can increase the solar collector's energy gain by 75%. Mao (Mao J et al, 2012) found through a study of uniaxial parabolic trough collectors that the thermal energy gained from the solar collector incident on the trough is higher when the tracking is placed between north-south, as well as when it is placed between east -west in summer and vice versa in winter, (Montes MJ et al, 2009, 679-689), (Montes MJ et al, 2009, 2165-2176). Zhou et al. (Qu WJ et al, 2017) tracked the Earth's north-south axis and the rotation axis as well. The daily efficiency of the concentrators was improved by 63% and 40% for 300 kW/h. PTC collectors. It is clear from the literature review presented above that dual-axis solar tracking modes collect more solar radiation. However, they are more complex to configure and higher in cost than others, and thus are essentially unreliable in practical applications compared to their single-axis counterpart. Many studies have been conducted on single-axis solar tracking modes for parabolic trough concentrators, but these studies have not settled on the optimal tilt angle according to the north-south or east-west tilt tracking modes. Therefore, improving the tracking mode for the PTC collectors was studied to reach the optimal tilt angle that achieves the highest efficiency for the PTC collectors and to use them in practical applications (solar stills). According to what was mentioned previously, the unidirectional tracking mode was applied from the north-south as the best. The modes of different tilt angles were also studied to obtain the best tilt tracking mode for the solar collectors.

2. Experimental work

The test experiment consists of a multi-solar parabolic collector, as shown in the figures (1). The parabolic trough concentrators used consist of three successive troughs in the form of a cylindrical parabolic concentrator; each trough is located at a sufficient distance from the other to ensure that there are no shadows on the adjacent troughs. The cylindrical parabolic concentrator is made of polished zinc-coated steel to resist rust, with a thickness of 3 mm, a length of 1.55 m, and a width of 0.915 m. With an aperture area of 1.4 m2 and a concentration ratio of 20:11. These troughs are mounted on a steel frame to maintain the position of the cylindrical parabolic concentrator with a rim angle of 62 degrees. On the other hand, the receiver tube installed at the focus of the parabolic trough consists of an evacuated tube to reduce heat loss by convection to the surroundings and is made of borosilicate glass, 1.8 m long, with an outer diameter of 57 mm and a wall thickness of 10 mm. A copper tube in the shape of a U rests inside the glass tube with a length of 4 m and a diameter of 15 mm. It is painted with black thermal paint and covered with aluminum strips in order to absorb the largest possible amount of solar radiation reflected on the tube through the parabolic trough. Moreover, the PTC was directed in the north-south direction with different tilt angles on the horizontal axis. Parabolic troughs derive the heat transfer fluid (tap water) passing through the copper pipe from a basic water tank with a capacity of 100 liters attached to the steel structure at a level higher than the level of the troughs so that the water flows successively into the copper tubes using its potential energy and is stored in another completely insulated tank.

2.1 Test procedure and measurements

The experimental tests were conducted under the summer climatic conditions on the campus of the Higher Technological Institute, 10th of Ramadan city, El-Sharqia, Egypt (latitude 30.3◦, longitude 31.7◦, and height 112 m). All tests were carried out from 08:00 until 22:00.

Six trials were conducted, and the constructed multi- PTC were investigated with different tilt angles (θ =10°, 20°, 30°, 40°, 50°,60°). This test's measured values were used as a benchmark to evaluate the effect of tilt angles on the performance of PTC in all tests. While running the experiment, waterproof temperature sensors were used to measure the entry and exit temperatures of the PTC and the solar power meter, which is a precision instrument for measuring light intensity. It is used in solar radiation measurement and contains several specifications and features shown in table (1).

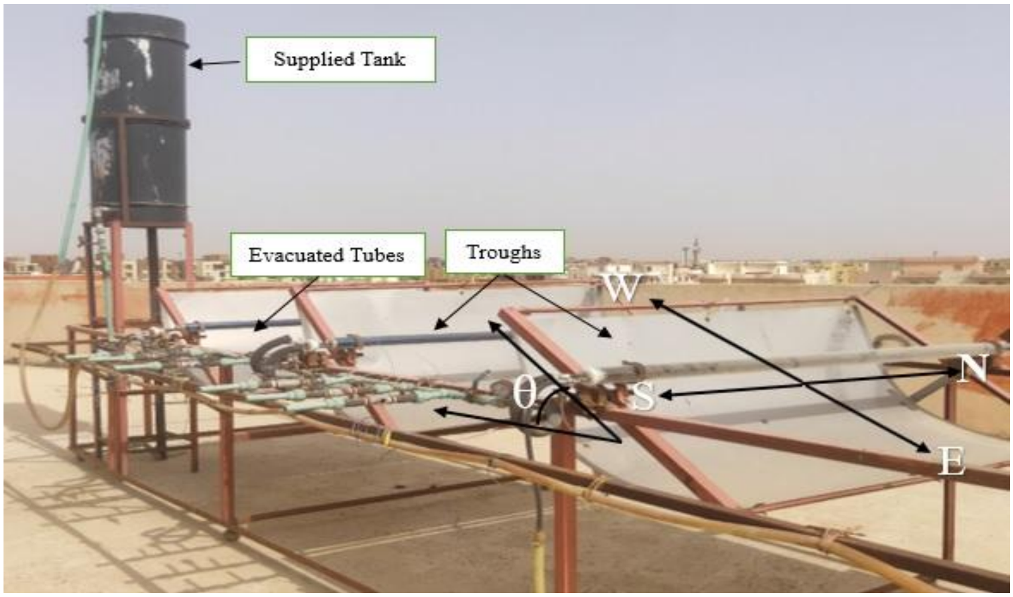

Figure 1: The Typical Image of parabolic Trough Concentrator System.

3. Results and Discussion

The operating conditions included the entry temperature of the PTC, the exit temperature of the PTC, the intensity of solar radiation, and the inclination angle of the solar concentrator. Temperatures and solar radiation were measured every hour from 8:00 to 20:00 during the summer of 2023. Figure (2) shows the variation in solar radiation intensity during the days of May 10, 11, 12, 13, and 14, 2023.

It should be noted that the variation in solar radiation during the five successive test days followed a similar general trend. The average solar radiation and average ambient temperature were 805 W/m2 and 30.3°C for 12 hours.

It is also clear from the figure that the peak of solar radiation during the days was at 12:00, which is 1227 w/m2. At the beginning of the experiment, the solar radiation has the lowest value, then increases with increasing hours of operation until the peak of the solar day, then decreases again until the end of the day. The ambient temperature curve indicates that the thermal energy response, which is affected by operating and ambient temperatures, is delayed by an hour.

Table 1:The Specifications of Solar Power Meter

	The specifications
Resolution	0.1W/m², 0.1 Btu/（ft²-h）
Error range	± (10%R+2dgts) R: readings
Temperature error	±0.38W/m² / ℃ [±0.12 Btu/（ft²-h）/℃] deviation at 25℃
Measuring range	0.1-1999.9 W/m², 0.1-1999.9 Btu/（ft²-h）
Wavelength range	340nm--1100nm, Incidence Angle normal direction less than ±45-degree， peak wavelength 900nm
Operation temperature and humidity	0°C to 40°C <80%RH
Storage temperature and humidity	-10°C to 50°C <70%RH Dimensions
Battery needed	9V battery

Figure (3) shows the variation between the exit temperature of the PTC during the test solar day and according to the different applicable tilt angles (θ =100, 200, 300, 400, and 500). Where T_θ1,T_θ2,T_θ3,T_θ4,T_θ5 show the exit temperatures from parabolic trough collectors with different tilt angles at 100, 200, 300, 400, and 500, respectively, and T_(a,ave)shows the average ambient temperature for all test days.

The modes of the parabolic troughs were studied in the north-south direction and at different tilt angles to clarify the extent of the effect of the different tilt angles on the temperatures of the water leaving the solar system and to know the optimal tilt angle according to the operating conditions.

The experiment begins at 8:00 with an average solar radiation intensity of 756 W/m2 for all test days with different tilt angles for the parabolic troughs. The temperature of the water leaving the solar system at this time reached 280, a difference of three degrees from the system's supplied water. The intensity of solar radiation increases over time, and the temperature of the water leaving the system increases with it until it reaches the peak at 13:00, at which point the radiation intensity records a relatively lower value than the previous value (12:00), which is 1168 W/m2, which is less than the maximum value by 5%, and the temperature of the water leaving the solar system reached 57.20, with an increase of 104% over its initial value. After that, the exit temperatures decrease to reduce the intensity of solar radiation until it reaches the end of the experiment at 8:00.

The same trend is repeated for the curves with different tilt angles (200, 300, 400, and 500), as mentioned previously, and the figure indicates that the maximum temperature of water leaving the solar system was 61.2 at a tilt angle of 300, with an increase of 7%, 6.4%, 9%, and 12% over the exit temperatures of the solar system at angles of inclination (100, 200, 400, and 500), respectively. It also achieved an increase than the ambient temperature of 63 %. Furthermore, the temperatures of water leaving the solar system at tilt angles less than 30 are substantially higher than at other tilt angles.

This indicates that some solar radiation falls outside the range of the parabolic troughs, particularly after the peak of solar radiation (12:00), when the sun moves toward the west. It is worth noting that the previous analyses are summarized in the following figure, which shows the relationship between the different tilt angles and the average temperatures of the water leaving the parabolic trough concentrator. It was found that a tilt angle of 300 is the optimal angle for solar collectors, as it achieved the highest average temperature of the water leaving the solar collector by 18%.

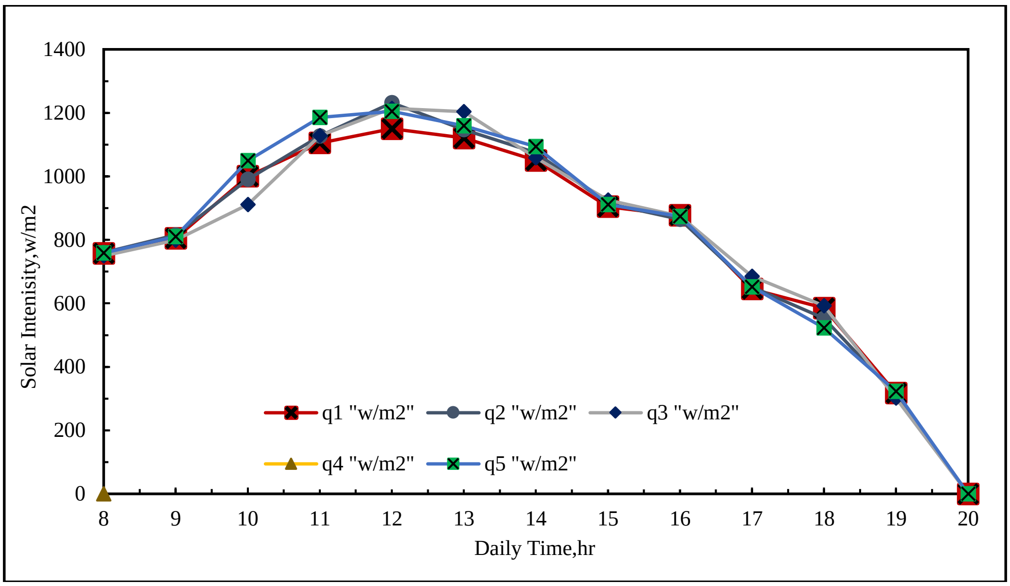

Figure 2: The Variation of Solar Radiation for Test Days

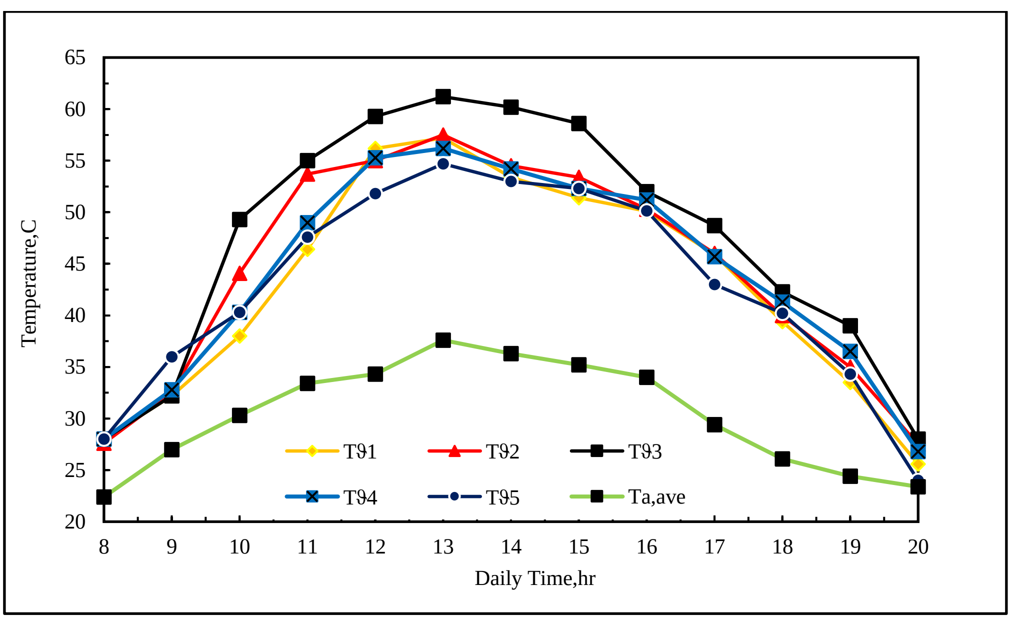

Figure 3: The effect of different tilt angles (θ=100, 200, 300, 400, and 500) on the temperatures of the water leaving the PTC.

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4. Conclusion

The current work provides the influence of the different tilt angles of the parabolic troughs on water leaving the solar system and the optimal tilt angle that can be used to achieve the highest efficiency of the system, where the following is evident:

1. The efficiency of the mode of the parabolic trough concentrators in the north-south direction is better than the east-west direction.
2. The mode of parabolic troughs at a tilt angle of 300 is the most efficient among others.
3. Water leaving temperatures from the solar system for tilt angles less than 30 degrees are greater than for other angles (400, 500).
4. The optimal efficiency of the system will be at the angle of a tendency close to the latitude angle for the location of the experiment.

5. References

Wang JP, Wang J, Feng W et al. Development and application of suntracking control system for parabolic trough solar collector. Trans Chinese\ Soc Agric Eng 2015;31:45–52.

Peng L, Liao J, Lanlan C et al. A study on motion control law of biaxial sun tracking system. Mech Manuf 2010;48:23–6.

Yu L, Wang J, Wang X et al. Comparative analysis of different uniaxial tracking modes. J Sol Energy 2011;32:426–32.

Hafeza AZ, Yousefa AM, Harag NM. Solar tracking systems: technologies and trackers drive types—a review. Renew Sustain Energy Rev 2018;91:754–82.

Barakat B, Rahab H, Mohmedi B et al. Design of a tracking system to be used with photovoltaic panels. In: Proceedings of the Fourth Jordanian International Mechanical Engineers Conference (JIMEC), 2001, 471–88.

Fahim U, Kang M. Performance evaluation of dual-axis tracking system of parabolic trough solar collector. In Proceedings of Materials Science and Engineering Conference Series, 2018, 012166.

Bakos GC. Design and construction of a two-axis sun tracking system for parabolic trough collector (PTC) efficiency improvement. Renew Energy 2006;31:2411–5.

Khalifa AJ, Al-Mutawalli SS. Effect of two-axis sun tracking on the performance of compound parabolic concentrators. Energ Conver Manage 1998;39:1073–9.

Chin C, Babu A,McBride W. Design,modeling and testing of a standalone single axis active solar tracker using MATLAB/Simulink. Renew Energy 2011;36:3075–90.

Mao J. Modeling and thermal performance analysis of parabolic trough solar field with single-axis tracked. Adv Mat Res 2012;101:512–5.

Montes MJ, Abanades A. Performance of a direct steam generation solar thermal power plant for electricity production as a function of the solar multiple. Sol Energy 2009;83:679–89.

Montes MJ, Abanades A. Solar multiple optimization for a solar-only thermal power plant, using oil as heat transfer fluid in the parabolic trough collectors. Sol Energy 2009;83:2165–76.

Qu WJ. Test of a solar parabolic trough collector with rotatable axis tracking. Appl Energy 2017;207:7–17.

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