

Thermal Analysis of Cylindrical Parabolic Trough Collector Using Particle Swarm Optimization

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Abstract: For about the first instance, a revolutionary Multi-objective Particle Swarm Optimization (PSO) method is applied to achieve a relatively close CPTC design for improving better thermal performance and output warmth. Optimized design of parabolic trough collectors serves an important part in today's marketplace and is a rising area of concern for experts and academics. Particle swarm optimization (PSO) is a unique approach for enhancing a solar power trough collector's heat transfer analysis. Nanofluid has received a lot of interest as a way to increase convective heat transfer. They surpassed the previously used fluid. The thermal conductivity and convection temperature transfer coefficients are increased by employing nanofluid as the heat transport fluid and changing the base fluid. Particle concentration, thermal dispersion consistency, and nanofluid dimension are the important parameters for enhancing thermal conductivity, according to a prior study. As a preliminary step, keep these points in mind. Except perhaps the concentration fluid intake velocity and pipe diameter, the optimal solution value is determined using the tested model characteristics and the Dimethyl Polysiloxane Molecular as a base fluid. The results are exhibited at different temperatures. To determine if the recommended solution approach is appropriate, the outcomes of two research publications are compared.

Keywords: Particle swarm optimization, Solar collector, nanofluid and CPTC

I. INTRODUCTION

Energy is the greatest basic component of our cosmos [1]. Energy is one of the most basic and necessary aspects of human life. It might be said that it is a basic requirement of modern civilisation. In the phase of economic, social, and industrial growth, energy is required. The use of power by mankind for their needs is used to determine a nation's stage of progress. There are several qualities of energy[1]. "Energy cannot be generated nor destroyed, but it may be converted from one type to another," as per the "rule of conservation of energy." The need for energy is growing day

by day as the population grows, industrialisation expands, and transportation expands, among other factors. Today's energy strategy has just a few options. One road goes to fossil fuels (a tough path), which implies going as we have for several years, i.e. emphasizing energy quantity by discovering additional fossil fuels and constructing increasingly larger power plants. The second approach is more straightforward, leading to energy alternatives that prioritize energy quality while also being renewable, adaptable, and environmentally benign. The second option is based mostly on renewable energy sources such as daylight, breeze biomass, tidal energy, and so on.

The energy sources available to humanity are divided into two groups.

Non-Renewable Sources of Energy, sometimes known as fossil fuels, include coal, petroleum, natural gas, natural fuels, and geothermal power.

ii. Renewable energy sources include wood, hydropower, wind power, solar power, and nuclear fusion, that have been accessible for millions of years.

Objectives of the study

- Using Syltherm800 as a nano fluid, investigate the thermal performance of a cylindrical parabolic trough collector (CPTC).
- To study the thermal characteristics of Aluminium oxide (nano particle) / Syltherm800 nanofluid in the CPTC's absorber.
- Using the particle swarm optimization (PSO) technique, improve the thermal performance of the CPTC.
- To create a CPTC computational formula for power generation.
- To investigate CPTC's performance by altering the system and operational parameters.

II. LITERATURE REVIEW

[2] Kushwaha et al. For the very first time, a novel Multi-objective Particle Swarm Optimization (PSO) is used to obtain a relatively close CPTC design for better thermal transfer improvement and outlet temperature. In today's competitive sector, efficient architecture of parabolic trough collectors plays a significant role and is a growing subject of interest for engineers and academics. Particle swarm optimization (PSO) is a novel way to thermal analysis optimization in solar power trough collectors.

Malana and colleagues The influence of many factors like sun geometry, rim ratio, apertures, geometrically concentration ratio, receivers shape, optical defects, secondary reflector, and incidence angle on the fluxes spread of PTSC is critically summarized in this study. Finally, numerical studies are suggested for further study in this field.

Chakrabortya and colleagues Internal helical twists are added to the PTC absorber tube. For Al₂O₃-H₂O with H₂O, three models with 15, 20, and 25 helical turns are examined. The volume fraction of Al₂O₃-H₂O is 0.09. For Al₂O₃-H₂O versus H₂O, the Nusselt number is increased by 4.54 percent to 36 percent. Thermodynamic efficiency and exergy both improve by 1% -10% and 0.2 percent -3.2 percent, respectively.

The limbs darkened effect is used to offer a linked flux dispersion and temperature analysis of a large aperture PTSC in this work. With an accessible absorbers diameter of 70, 80, 90, and 110 mm, the fluxes dispersion for larger apertures PTSC like 700, 800, 900, and 10000 cm has also been investigated. To optimize the productivity of the larger apertures PTSC with existing receiver sizes, better manufacturing standards must be implemented.

Merafati and colleagues Four cities in Iran with varying weather circumstances were picked as case studies to test the PTC's performance. Concentration ratio, incidence angle correction factor, and collectors mass flow rate are all important metrics to consider. The major goal of this research is to assess the solar energy capacity of cities with various climates using PTC. The analysis is numerically modelled using the MATLAB program. Shiraz, with an average yearly heating value of 13.91 percent and annual usable energy of 2213 kWh/m², is the best place for solar concentrator systems, according to simulation data.

Mateo and his colleagues This paper proposes a method for simulating the day-to-day warming of a solar collector. The collector in question is component of a solar absorption refrigerator, and it's used to replenish the activated carbon within a cylindrical receiver (absorber) that sits in the central axis of a parabolic trough concentrator.

Padilla et al. [38] used a PTCS to perform a one-dimensional numerical heat transfer study. By separating the reception and the enclosure into many parts and assigning mass and power balance to each segment, the finite element approach was applied. Improvements to convection and radiant heat transfer relationships were also demonstrated. The model was compared to Sandia National Laboratory (SNL) experimental data as well as other models. The simulation findings reveal that the provided model, when compared to previous models, gives a superior agreement with experimental data in respect to efficacy, heat, and thermal losses.

With warming fluids of water and nitrogen, Li and Wang [39] investigated the heating value and warmth of two kinds of solar evaporated pipe parabolic trough solar collectors (N₂). With moisture as the heating fluid, the experimental findings showed that two evacuated tubes provided excellent heat transmission. So when mass circulation rate is little than 0.0045 kg/s, the heating efficiency varies from 70 to 80 percent, but the water boils quickly. The heating efficiency of Nitrogen, on the other hand, is roughly 45%, and the gas heat reaches 320-460 °C. To better understand the vacated tube heated by the solar trough concentrate system, a model was created, and the findings revealed that the model accords with observed measurements with an accuracy of 5.2 percent. **METHODOLOGY**

The parabolic trough concentrator tested at Sandia National Laboratory by Dudely et al. [57] was selected for analysis, as a basic simulation

A schematic diagram of the solar collector and absorber tube is shown in Fig-1 and the geometric characteristic of the collector are shown in Table-1 The absorber tube is 7.8m long and 0.07m in diameter. Syltherm 800 liquid has been used as the heat transfer fluid (HTF) in the collector field. The thermo physical properties of the fluid including density, viscosity thermal conductivity k and specific heat C_p are strongly dependent on the operational temperature. The thermo-physical properties of Syltherm800 for different temperatures are given in Table-2

Heat transfer inflatement is the process of improving the performance of heat transfer system by increasing heat transfer co-efficient. The heat transfer augmentation techniques are generally used in areas such as process industries, heating and cooling evaporators, thermal power plants, air conditioning equipment's, refrigerators, radiators for space vehicles and automobiles, etc.

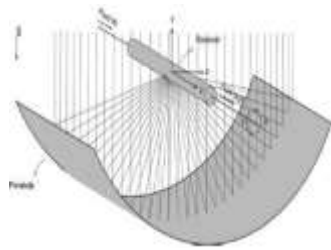


Fig. 1 Schematic diagram of the parabolic trough collector and absorber tube

$$Z = Nu / \left(\frac{\delta p}{\rho + V^2} \right) \tag{3.1}$$

Subjected to:

$$Re_{\min} \leq Re \leq Re_{\max} \tag{3.2}$$

$$Ri_{\min} \leq Ri \leq Ri_{\max} \tag{3.3}$$

where,

- Nu_{nf} Nusselt Number
- P Pressure drop(N/m²)
- ρ_{nf} Density of Nanofluid(kg/m³)
- V_i Fluid inlet velocity(m/s)
- Re Reynolds number
- Re_{\min} Minimum value of Reynolds number
- Re_{\max} Maximum value of Reynolds number
- Ri Richardson number
- Ri_{\min} Minimum value of Richardson number
- Ri_{\max} Maximum value of Richardson number

Table -1 Specification of the parabolic trough collector

S.No.	Parameters	Specification
1	Module size	7.8m*5m
2	Aperture area	39.2 m ²
3	Focal length	1.84 m
4	Concentration ratio	22.74
5	Absorber inner diameter	0.066 m
6	Absorber outer diameter	0.07 m
7	Glass tube inner diameter	0.109 m
8	Glass tube outer diameter	0.115 m
9	Transmittance of glass cover	0.95
10	Absorptivity of absorber tube	0.96

Table 2 Thermo physical properties of the Syltherm800[65]

S. No.	Parameter	Unit	Temperature(K)			
			300	400	500	600
1	Density ($\rho_{(bf)}$)	Kg /m ³	981.09715	939.5622	898.02725	856.4923
2	Specific Heat ($C_p(bf)$)	J / Kg °K	1620.198	1790.998	1961.798	2132.598
3	Thermal Conductivity ($K_{(bf)}$)	W/m °K	0.13371	0.11492	0.09611	0.0773
4	Viscosity ($\mu_{(bf)}$)	PaS	0.0081816	0.002171	0.0008276	0.0003903

Problem Formulation

The cross-section provides the mathematical [9] problem formulation for generating optimal design values for amplify heat transfer characteristics and outlet temperature of the CPTC. The combined objective function is expressed as below:

Maximize

In the above problem formulation equation (3.1) represents the optimization problem, equations (3.2) and (3.3) represent the upper & lower bound values of the Reynolds number and Richardson number respectively. The objective function is transformed into the form consisting

(3.4) and (3.5).

The Nusselt number is formed with the help of Re and Prandtl number

$$Nu_{nf} = 0.023(Re)^{0.4} (Pr)^{0.4} \tag{3.4}$$

Similarly, the pressure drop can be expressed as:

$$\Delta p = \frac{f L \rho V^2}{2D} \tag{3.5}$$

where,

- f Friction factor
- L Length of absorber tube m

In the present work, Re and Pr are evaluated based on SPTC physical model.

Cylindrical Parabolic Trough Collector (CPTC) Physical Model

The impacts of concentration of nanoparticles on the combined convective heat transfer coefficient of the nanofluid in a full turbulent flow are examined in the chosen model, which emphasizes section modeling of CPTC. On the outside area of the inner absorbers tube, a homogeneous heat flux is assumed. The working fluid in this project is Al₂O₃ (nanoparticles) – Syltherm800 (base fluid), and the volume, viscous, thermal conductivity, and specific heat vary as the temperature changes. The other parameters are 7.8 m, 0.07 m, and 10 nm for the absorber tube, diameter, and nanoparticle size, respectively. In one scenario,

Al₂O₃/Syltherm800 was employed as the HTF in the collector field, and the nanofluid flow was treated as a single phase flow with a mass flow rate of 0.91 kg/s. The operational temperature has a strong influence on the thermo-physical characteristics of the basefluid and nanoparticles, such as density, viscosity, thermal conductivity, and specific heat.

Table 3 Properties of nano fluid

S. No.	Properties	Unit	Formula
1	Density(ρ)	Kg/m ³	$\rho_{(nf)} = (1-\phi)\rho_{(bf)} + \phi\rho_{(np)}$
2	Specific Heat (Cp)	J/Kg.K	$Cp_{(nf)} = (1-\phi)Cp_{(bf)} + \phi Cp_{(np)}$
3	Viscosity μ	Pa.s	$\mu_{(nf)} = (1+2.5\phi)\mu_{(bf)}$
4	Thermal Conduc (K)	W/m ²	$K(nf) = \frac{K(np) + 2K(bf) - 2(1+\beta)2\phi K(bf) - K(np)}{K(np) + 2K(bf) + (1+\beta)3(K(bf) - K(np))\phi}$
5	Prandtl number(Pr)	-	$\frac{\mu Cp}{K}$

Solution Methodology

The mathematical expressions for the PSO algorithm are as follows:

Let the position vector of the j^{th} particle in a X -dimensional space is represented as $x_j = (x_{j,1}, x_{j,2}, \dots, x_{j,d})$. Similarly the velocity vector in a X -dimensional space is represented as $V_j = (V_{j1}, V_{j2}, \dots, V_{jd})$. The best position of the j th particle is set down and represented as $P_{best} = (P_{best1}, P_{best2}, \dots, P_{bestd})$. The index of the best particle among all the particle in the group is global best, represented as g_{bestd} . The judged position and velocity of the each particle can be evaluated using the current velocity and the distance from P_{bestd} to g_{bestd} as shown in the following equation:

$$V_{j,d}(t+1) - V_{j,d}(t) = C1r1(P_{bestj,d} - X(t)) + C2r2(g_{bestd} - X_{j,d}(t)) \tag{3.6}$$

$$X_{j,d}(t) = X_{j,d}(t) + V_{j,d}(t+1) \tag{3.7}$$

Where,

- $C1, C2$ Non negative acceleration constant
- $r1, r2$ Random number between 0 and 1
- w Inertia weight factor

In the given work the value of non-negative acceleration constant is taken as 1.2 according to past experiences. The

equity between the global and local exploration capabilities of the particles is revealed by introducing inertia weight factors. As originally developed, ‘w’ often decreases linearly from about 0.9 to 0.4 at the time of run. Generally, the inertia weight w is set according to the following equation:

$$W = W_{max} - \frac{W_{max} - W_{min}}{Iter_{max}} \times iter. \tag{3.8}$$

Where,

- $Iter_{max}$ Maximum iteration count
- W_{max} 0.9 and W_{min} 0.4

Generally, PSO algorithm is used for minimization of the fitness value function. Hence, the function Z is changed to J as shown below:

$$Z = \frac{K}{1+Z} \tag{3.9}$$

where,

K A positive integer valued 100

To the next hand, PSO is a useful technique locating the global optimum values within less number of iterations.

Validation

Our numerical analysis was validated in several steps. Result compared for receiver with a plain absorber tube, with experimental data from Y. K. Nayak et al. [58] for collector efficiency & a receiver’s temperature gain to ensure that our receiver model is accurate.

Table 4 Comparison of present numerical results with Y. K. Nayak et al. [58]

S. No.	Design Variable	Case A T=400K (model)	Case A T=400K (test)	Case B T=500K (model)	Case B T=500K (test)
1	Fluid input velocity	0.7469	0.2378	0.8024	0.2160
2	Concentration ratio nano-particles	0.044	0.03680	0.0534	0.04
3	Diameter of the ir receiver tube	0.1395	0.0696	0.1499	0.0699

Hence, after simulation its outlet results are compared with Y. K. Nayak experimental results. The comparison shows the reasonable agreement together. Because of this good agreement, the numerical solving method is validated. Table 4 shows the demonstration of validation.

III. ANALYSIS AND RESULTS

The results of the proposed approach for the cases A, B and C are shown in Table 5. The convergence plots of the suggested approach for different case studies in Fig-2

Table-5 Optimum value of design variable and objective function for case A, case B and case C.

S.No.	Design Variables	Optimal value			Objective function
		400 K	500 K	600 K	
1	Fluid input velocity (m/s)	0.2378	0.2160	0.2385	0.1947
2	Concentration ratio of nanoparticles	0.03680	0.04	0.0511	0.5256
3	Diameter of the inner receiver tube (m)	0.0696	0.0699	0.0658	0.4479

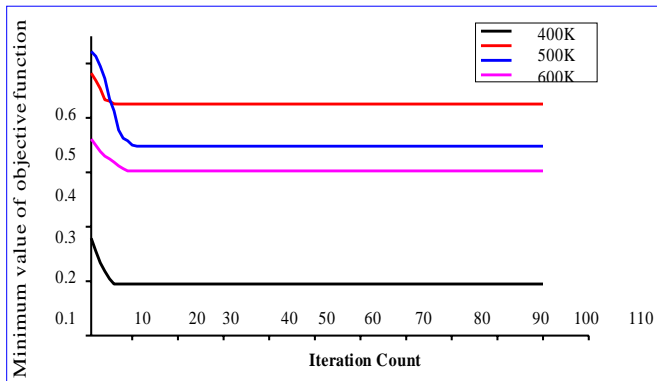


Fig.2 Convergence curve

IV. CONCLUSIONS

The accompanying conclusions may be formed based on the collected results:

- CPTC design plays an essential effect in thermal performance.
- The Nusselt and pressure loss are important factors to improve heat transmission and output temperature.
- Using the PSO method, the optimal value of the objective function is 0.4027 when the input temperature of the CPTC absorber tube is used as a design variable.
- The findings show that the suggested work has exceptional qualities in resolving challenges related to thermal assessment in CPTC.

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