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FACTORS AFFECTING THE PERFORMANCE ENHANCEMENT OF A PARABOLIC TROUGH COLLECTOR UTILIZING MONO AND HYBRID NANOFLUIDS: A MINI REVIEW OF RECENT PROGRESS AND PROSPECTS

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ABSTRACT. Utilizing solar power has become more common in most regions among several renewable energy sources that are currently available, including geothermal, wind, biomass, and tidal etc. Hence, researchers are turning their attention to solar energy studies. Solar thermal collectors have the ability to capture solar energy. Various solar collectors have already been modelled, designed, built, and tested to perform in a variety of temperature ranges, including low temperature collectors (compound parabolic collectors 60-240°C, evacuated tube collectors 50-200°C, and flat plates 30-80°C), medium temperature collectors (parabolic trough 40-400°C, cylindrical trough collector 60-300°C, and linear Fresnel reflectors 60-250°C), and high temperature collectors (heliostat field collector 150–2000°C and parabolic dish reflector 100–1500°C). The parabolic trough collectors (PTCs) have been discovered to be the most popular between the various solar collectors in applications such as the steam generation, the delivery of process heat, and desalination. Since about three decades ago, various theoretical and experimental research studies have been carried out in order to improve the thermal and optical efficiency of the PTC system. This review studies the parameters influencing the PTC thermal performance and the enhancements to improve the design modification, optical, and thermal properties used in PTC.

KEYWORDS: Thermal performance; Parabolic trough collector; Nanofluid; Evacuated tubes; Mass flow rate.

1. INTRODUCTION

Since energy demand is dramatically growing and conventional energy supplies are shrinking. The energy shortage has been a worldwide challenge. Natural resources depletion, the rapid demand for the known types of energy resources, oil price fluctuations, the rising level of pollution, and greenhouse gas emissions are the most pressing obstacles for using an alternative clean and renewable energy resources [1]. Solar energy usage is important for sustainability and a variety of global climate change problems. Solar energy can be considered to be an important clean and renewable energy resource that's capable of accomplishing sustainability and solving a variety of problems, such as global climate change [2, 3]. Solar energy has the ability to be employed in multiple processes, such as useful heat generation, power generation, and different chemical processes [4, 5]. Among the most common methods for converting solar energy into electrical power, which are solar towers, linear Fresnel, and parabolic trough collectors (PTCs), PTCs are one of these techniques that is widely used and regarded to be stable, with capacities ranging from a few kilowatts to hundreds of Megawatts [6]. Throughout the use of solar concentrating collectors, the most advanced concentrated solar collector technique is the parabolic trough collector (PTC), which has a broad range of applications in concentrated solar power (CSP) plants and is used in more than 80% of all CSP plants around the world [7]. The use of PTC has the benefit of the solar energy can be maximized, and the temperature can easily reach 500°C [8]. Parabolic trough solar collectors (PTCs) are the most advanced techniques for concentrated collectors, and thus it got the majority of attention, and as consequence, a lot of research has been based on it [9]. The performance of PTC can be influenced by a variety of factors. It is vital to look into how these factors, which affect the heat transfer, the drop in the pressure, and the thermal efficiency of the collector. Hence, there have been a large number of studies done on PTC performance enhancements [10]. As a consequence, the thorough review could enhance our comprehension of the research of other scientists, enhance the PTCs' structure and design, and reduce thermal and optical loss. Hence, the objective of this research is to compile and evaluate the prior studies on PTC thermal performance enhancements. Additionally, a review of methods to enhance heat transfer in PTC systems is provided. Due to their significance in lowering energy loss in PTCs, design characteristics as well as heat transfer improvement techniques are taken into account in the current study. Furthermore, some recommendations for future works are provided based on the prior research.

2. HOW DO THE PARABOLIC TROUGH SOLAR COLLECTORS OPERATE?

In a few words, the parabolic trough collectors (PTCs) are "Concentrated Reorientation of the Solar Radiation" technologies. In their simplest design, the PTCs have two basic components: the parabolic reflector, which is a reflective sheet of a defined material bended into a parabolic shape, which is concerned with the process of concentrated reorientation of the solar radiation falling on it onto the heat collector (receiver), which represents the second part [11]. The receiver is a metal tube, often dark in color, designed to be placed at the parabolic reflector's focal line to receive the maximum possible radiation [12]. For the most benefit of the available solar radiation in the operating area, in advanced systems, some special techniques are used, and the two most common ones will be mentioned here.

Firstly, the evacuated tube can be used instead of the absorber tube only to decrease the heat losses. As shown in Fig. 1, the traditional evacuated tube can be enhanced in many ways, such as by replacing it with a modified evacuated tube, which has been insulated partially by a solar transparent aerogel. In addition, its thickness has been adjusted with respect to the glass and absorber tube used dimensions till the optimum design has been reached, which provides more reduction of the heat loss from the absorber. This reduction results in a rise in the outlet fluid temperature, followed by a rise in efficiency [13]. Numerous productive studies have been conducted in recent years to successfully reduce the huge radiant heat loss of PTCs and enhance the solar energy conversion performance of the PTC system at high operating temperatures. One of the trendiest study areas is the fabrication of improved solar selective-absorbing coatings with low infrared emittance. Hence, many studied have been used mono and hybrid nanoparticles in coating the absorber tube to enhance its absorptivity.

Secondly, one of the most crucial modifications to improve the parabolic trough collector thermal and optical performance is solar tracking technique, which ensures a continuous focus of the solar irradiation on the focal axis of the PTC [14]. This radiation penetrates by using conduction from the tube's outside surface due to the temperature difference on its sides, to heat the heat transfer fluid that circulates through it, and then to the application to be fed [15]. Multiple types of fluid can be used, according to the application that will contribute to [16].

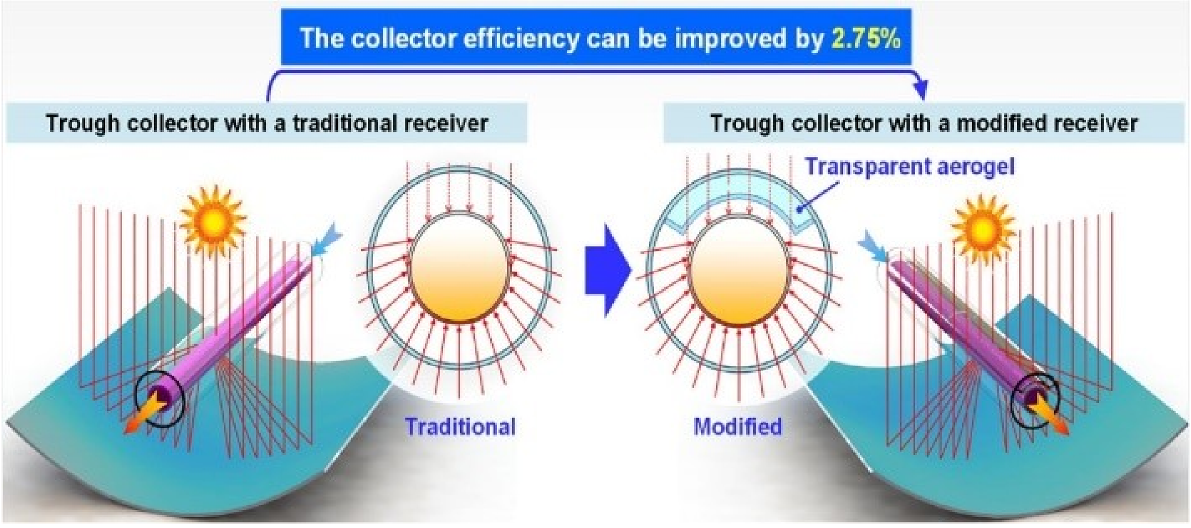

Fig. 1. The enhancing process for the traditional evacuated receiver [13].

3. FACTORS AFFECTING ON PARABOLIC TROUGH COLLECTOR

3.1. METEOROLOGICAL FACTORS

The meteorological factors affecting the performance of PTC can be divided in order of priority as follows: solar radiation, wind speed, dust, humidity, and air temperature. Countries on top of having the highest solar irradiation, such as Egypt, Mexico, India, and Spain, are statistically the most countries that use the PTC's technologies. This indicates that there is a close correlation between the amount of available solar radiation (especially the direct) and the PTC's performance [17]. For an 8.8° tilted PTC with 4800 ml/hr of feed water to be heated, the results of the solar irradiation variance on the collector efficiency are demonstrated in Fig. 2. The results demonstrate that the PTC's efficiency gradually increases directly until 12:00 pm with the rise of the solar irradiation, where after that it can be noticed that it also decreases gradually, due to the slow change in the solar radiation (increase/decrease) per day. Also, for the same previous conditions, as the ambient temperature increases, it is obtained that the PTC efficiency increases with a proportionally direct relationship, as shown in Fig. 3 [18].

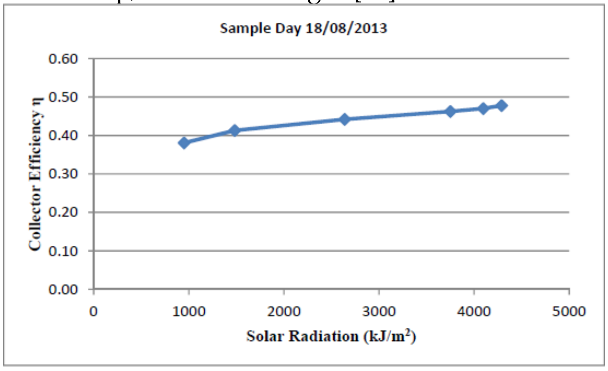

Fig. 2. PTC efficiency versus solar beem radiation.

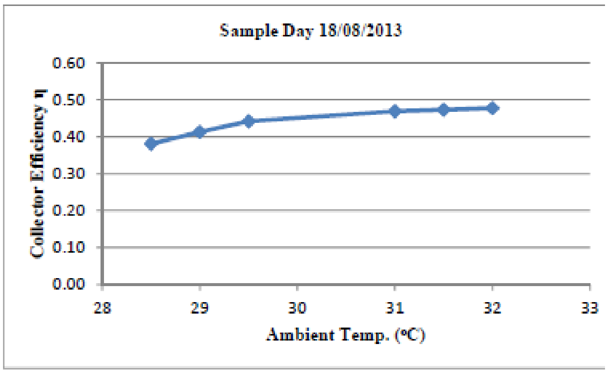

Fig. 3. PTC efficiency versus ambient temperature.

Tracking the steps followed within the broad contributions to enhance the solar collectors' efficiency in general, especially the PTC. It is noticed that there is a severe lack of data explaining the relationship between the efficiency of the PTC and the effect of dust accumulation on it. An experiment has been conducted in Isfahan, Iran, for the purpose of studying the factors closely related to the accumulation of dust, and the consequences of its effect on the glass transmission coefficient related to the system performance have been investigated. Four main factors clarified by the experiment showed a direct correlation between the density of accumulated dust and its effect on the decrease of the coefficient of transmission by 25%, for dust density ranged between [4.059-10.313] (g/m^2) within 70 days of testing as shown in Fig. 4. These factors are the decrease in the tilt of the installation (reducing the effect of gravity on removing accumulated dust), the prevailing wind direction and speed (two different effects depending on how the plates are oriented with relation to the direction of the wind. For windward plates, some dust has been shoveled away from the surface, meanwhile on the plates facing away from the wind, more dust has been accumulated), the timing of placing samples within the ambience , and the azimuth angle [19].

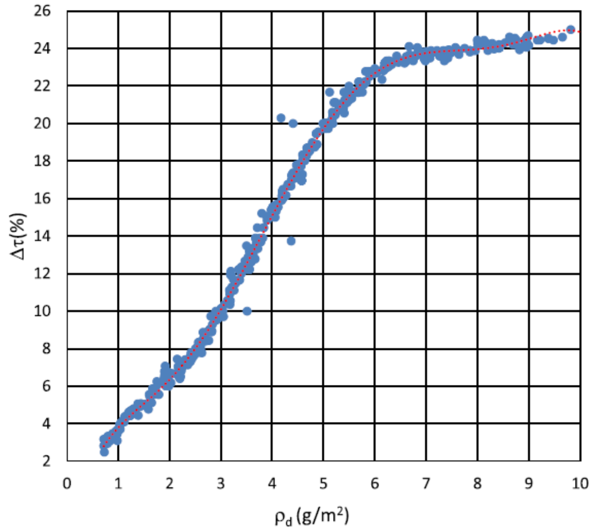

Fig. 4. Reduction % of transmission coefficient verse dust density on the all plates surface.

3.2. DESIGN AND OPERATIONS FACTORS

3.2.1. REFLECTOR MATERIAL

As a solar thermal energy collector, the parabolic trough reflector is used as a long reflective parabolic mirror that is coated in a reflective silver, or composed of polished aluminum, or employs mirrors that linearly extend into the trough shape [8].

The aluminum composite reflector provides a maximum temperature of 87^{o}C because of its high reflectivity. The chrome plate reflector with a glass cover produces a temperature of 98°C while it is 82°C without a glass cover [20]. The low-cost PTC is made of an acrylic sheet and a copper receiver pipe and has a 45° rim angle and a 2.14 m^2 aperture area. The maximum thermal efficiency obtained is 52.3% and the water temperature obtained is 80°C [21]. PTC reflectors made of stainless steel have a thermal efficiency that is more than 16% higher than PTC reflectors made of acrylic mirror sheets [22].

The efficiency evaluation of PTC as a reflector for heating water combined with a manual tracking system was analyzed with an aluminum sheet in winter, and the results showed that this is a better choice since it lowers water heating costs [21].

3.2.2. TUBE ABSORBER CONFIGURATION

The absorber tube's configuration significantly affects how much heat from the solar source is captured. There are two main types of the absorber tubes: the single absorber tube or an adjusted absorber tube. The non-adjusted tube has an efficiency of about 26.7%, meanwhile, the adjusted tube efficiency goes up to 42.1% [23]. There are many configurations of adjusted tubes used, and one of the most common adjusted absorber tubes consists of an absorber tube with a twisted tape inserted inside, as shown in Fig. 5 [24]. With a twisting ratio equal to 2, while the tape is immersed in Al_2O_3 with water as the base fluid, the efficiency significantly increases to hit 64% [25].

3.3. WORKING FLUID

3.3.1. INDUSTRIAL THERMAL OIL

One of the key elements impacting the effectiveness of any solar energy collector using an absorbing tube is the heat transfer fluid. Thermal oils such as Therminol D-12, Dowtherm A, and Therminol VP-1 can be utilized to provide high thermal energy storage[26],[27]. Industrial thermal oil has been widely used, but the maximum temperature that can be achieved while its usage doesn’t go beyond 400 °C, at higher temperatures, hydrogen gas starts to get released as a consequence of breaking hydrocarbon chemical bonds. The overall efficiency of heat transfer gets influenced by this limit and goes down [28].

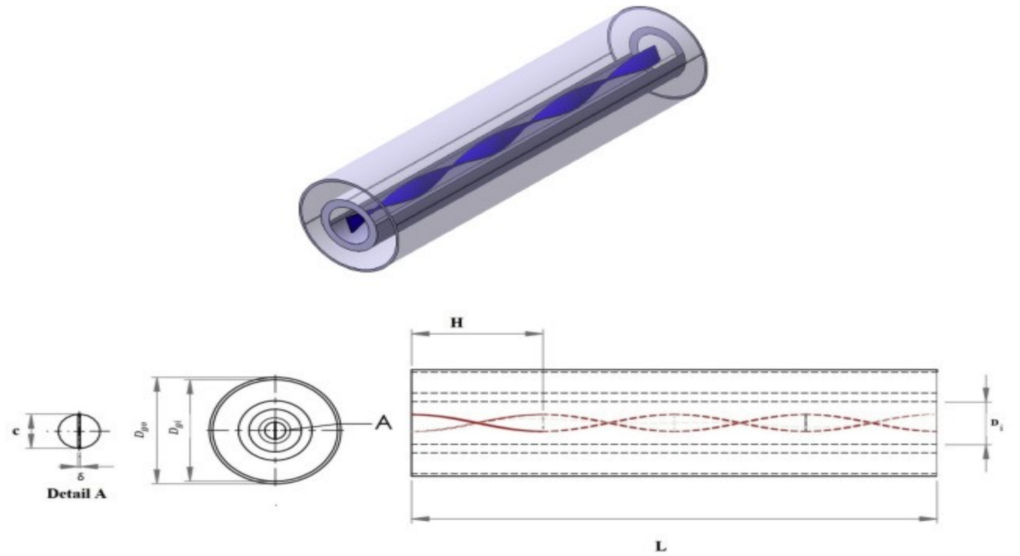

Fig. 5. An absorber tube with a twisted tape inserted inside [24].

3.3.2. MOLTEN SALT

Cost reduction is still an essential feature in the production of potential HTFs for PTC applications. Consequently, many experiments are ongoing to produce an advanced fluid that can run at a very high operating temperature, which eventually improves productivity without the costs of other essential parameters and variables[29].

While using the molten salt as HTF, the temperature increases by about 150°C to reach 500°C [30]. One of the limitations of using molten salt is its freezing temperature, as it may cause severe damage during maintenance [31].

3.3.3. STEAM (H2O)

Besides the highest temperature of HTF, which is the vital factor affecting the efficiency, there are some parameters that need to be obtained to increase the overall efficiency. These factors are low cost, minimum toxicity, and the ease of storage. All of that can be accomplished by using water as HTF in the absorber tube in PTC applications [32]. Steam can be generated at 103°C that happens when the heat gained equals 1500 W and the thermal efficiency is 83% [21].

3.3.4. NANOFLUIDS

The relative thermal conductivity of HTFs like industrial thermal oil, molten salt, and steam is quite low. In order to increase it, nanofluids are used as HTF. The nanofluid particles' size ranges from 1 to 100 nm [33]. The most known nanoparticles are Al_2O_3, SiO_2, TiO_2, CuO, and Fe_2O_3 [34, 35]. When employing a metal foam with 0.1% of CuO-water volume, thermal efficiency has improved from 55.65 to 79.29% [36].

Khakrah et al. [37] analyzed numerically the influence of Al_2O_3-synthetic oil nanofluid with a variation in nanoparticle concentration between (0-5 %) by volume associated with the HTF's inlet temperature on the typical PTC's thermal and exergy efficiency. It has been found that there is a rise in thermal efficiency with the gradual rise and decrease of the NP concentration and the inlet temperature, respectively. As illustrated in Fig. 6, with constant inlet temperature at its lowest value, the maximum improvement in the thermal efficiency is 10% with the highest NP concentration of 5%, and the minimum one is 3% for pure base fluid. In addition to the above, an improvement in exergy efficiency was noticed by rising each of the previous employees. It reached about 19% at a concentration of 5% for NP.

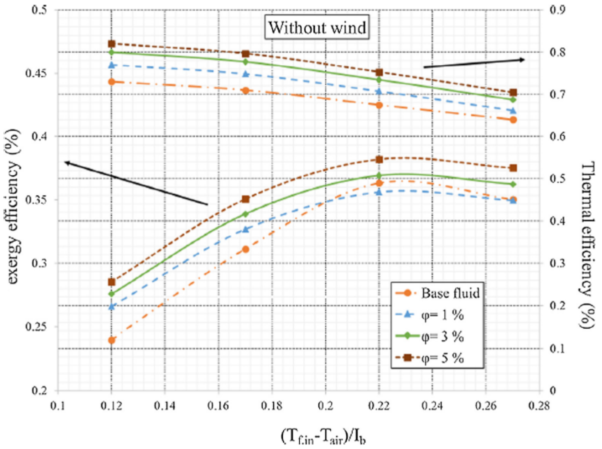

Fig. 6. Enhancement percentage of the thermal and exergy efficiencies with different concentrations of Al_2O_3 associated with HTF inlet temperature [37].

Cocci et al. [38-40] have presented a numerical study for the estimation of the annual production of a low-enthalpy PTC. Six water-based nanofluids each with various weight concentrations have been tested numerically and experimentally to boost the thermal efficiency: TiO_2 (1, 10, 20 and 35 wt. %), SiO_2 (1, 5 and 25 wt.%), Fe_2O_3 (5, 10 and 20 wt.%), Al2O3 (0.1, 1 and 2 wt.%), Au (0.01 wt. %), and ZnO (1, 5 and 10 wt.%). Two models of PTC were set up in Ancona (central Italy) [38-40]. A dedicated device was utilized to evaluate the nanofluids' thermal transfer coefficient in the evacuated-tube absorber. As demonstrated in Table 1, this analysis indicates that there are only very limited changes in the overall thermal efficiency in Al_2O_3, ZnO, TiO_2 and Au nanofluids at lower concentrations, although an increase in nanoparticles' concentrations reveals a change in the thermal transfer performance [38-40].

Khullar et al. [41] selected Al nanoparticles in Thermionl VP-1 at a volume concentration of 0.05% by volume as HTF. Researchers discovered that the usage of nanofluids would increase their thermal efficiency by approximately 5–10 percent.

Numerically, three-dimensional convection heat transmission in trough collection tubes with a non-uniform turbulent flow of Al_2O_3-synthetic oil is tested by Skandera et al. [42]. The result indicated that at the working temperature of 400 K and Al_2O_3 nanoparticles added at a volumetric rate of 5%, the impact of the concentrations of the nanofluid on the average coefficient of the heat transfer increased by 8.6%.

Sayed et al. [43] conducted a numerical study of the convective heat transfer of turbulent flowing fluid within the receiver tube using nanofluids such as CuO-water and Al_2O_3-water as heat transfer fluid (HTF). The effect of the fraction of the nanoparticles volume on the PTC's thermal performance was studied. Nanofluids as a HTF could enhance a PTC's thermal efficiency in comparison to the use of pure water as an HTF. It was discovered that employing CuO-water and Al_2O_3-water nanofluids by 3 percent volume, increased the receiver tube's heat transfer coefficient by approximately 35 and 28 percent, respectively.

Kullar et al. [41] accomplished a thermal study theoretically and defined the parameters affecting a PTC while performing an analysis using exploratory parametric and theoretical thermal methods of a PTC using Aluminum-Therminol VP1 as nanofluid. It was discovered that the thermal efficiency improvement ranges between 5 - 10%.

Bellos et al. [33] established a comparison by using CFD analysis of the PTC's thermal performance while utilizing oil, water under high pressure, and an Al_2O_3-oil. The pressurized water achieved a thermal efficiency enhancement of about 6%. Meanwhile, using an Al_2O_3-oil as a nanofluid achieved an enhancement of about 4%. So, from a comprehensive point of view, the usage of nanofluid is more efficient, as there is no need for the external large amount of energy that is used to pressurize water. The following Table 2 and the plots in Fig. 7 define the thermal oil's characteristics and those of Al_2O_3 as nanoparticles and thermal oil as a based fluid.

Allouhi et al. [44] analyzed the influence of the Figure of Merit, outlet temperature, thermal heat gain, exergy and energy efficiencies by using water as the base fluid with Al, Cu, and Ti oxides nanoparticles. The result was as follows: for CuO, the Figure of Merit was greater than 1 for NP concentration of more than 1% (e.g., the Figure of Merit can exceed 1.8

with 5%). The use of CuO nanofluid produced the maximum outlet temperature. The maximum thermal heat gain was about 1.46 % when using 5% of Al_2O_3. 9.05% was the peak value of the exergy efficiency, achieved when using CuO nanofluid.

A PTC system whose concentration ratio is 11 has been analyzed by Rehan et al. [45] under the utilization of water as a base fluid with Al_2O_3 and Fe_2O_3 nanoparticles for weight fraction concentrations of 0.20%, 0.25%, and 0.30% at various flow rates of 1, 1.5 and 2.0 L/min for each. It has been found that, at 2 L/min, an enhancement in the maximum efficiency of about 13% is achieved when using Al_2O_3, and 11% when using Fe_2O_3 under the same operating conditions.

Kaloudis et al. [46] studied numerically 20 different test cases of using Al_2O_3-Syltherm 800 nanofluid as HTF, with NP concentrations ranging from (0.5-4%) in LS2-module PTC by using a two-phase approach. The conclusion was that an improvement in the thermal efficiency of about 10% was achieved when utilizing Al_2O_3 nanofluid with a concentration of 4% as demonstrated in Fig. 8.

Table 1. For the cases from 40°C to 70°C and at a flow rate of 0.5 Kg/s, peak exhaust fluid temperature and associated thermal efficiency [38-40].

HTF	wt%	40		50		60		70	
		T_f,Peak(°C)	η (%)	T_f,Peak(°C)	η (%)	T_f,Peak(°C)	η (%)	T_f,Peak(°C)	η (%)
H_20	-	47.79	63.14	57.73	62.73	67.74	62.30	77.61	61.85
TiO_2	1	47.85	63.14	57.80	62.74	68.36	62.30	77.67	61.85
TiO_2	10	48.49	63.12	58.43	62.71	69.19	62.28	78.29	61.83
TiO_2	20	49.33	63.07	59.26	62.67	70.78	62.24	79.11	61.79
TiO2	35	50.94	62.96	60.87	62.55	67.73	62.13	80.69	61.68
SiO2	1	47.85	63.14	57.79	62.73	67.97	62.29	77.66	61.84
SiO2	5	48.09	63.13	58.04	62.72	69.45	62.29	77.90	61.83
SiO2	25	49.60	63.03	59.53	62.61	68.01	62.18	79.37	61.73
Fe2O3	5	48.13	63.12	58.07	62.71	68.38	62.28	77.94	61.83
Fe2O3	10	48.50	63.09	58.44	62.68	69.22	62.25	78.30	61.80
Fe2O3	20	49.36	63.02	59.30	62.62	67.74	62.19	79.14	61.74
ZnO	1	47.86	63.14	57.80	62.73	68.02	62.30	77.67	61.85
ZnO	5	48.14	63.13	58.8	62.73	68.40	62.29	77.95	61.84
ZnO	10	48.53	63.12	58.47	62.71	67.68	62.28	78.33	61.83
Al2O3	0.1	47.79	63.14	57.74	62.73	67.73	62.30	77.61	61.85
Al2O3	1	47.85	63.14	57.79	62.73	67.79	62.30	77.67	61.85
Al2O3	2	47.91	63.13	57.85	62.73	67.67	62.30	77.73	61.85
Au	0.1	47.79	63.15	57.73	62.74	67.67	62.31	77.61	61.86

Table 2. The thermal oil's characteristics and those of the Al_2O_3 as nanoparticles and thermal oil as a based fluid [33].

Temp (K)	Type of Material	ρ (Kg/m3)	Cp (J/Kg.K)	K (W/m.K)	μ (Pa.s)
–	Al_2O_3	4000	773	40	–
300	Thermal oil	1058	1570	0.13570	0.003570
	Nanofluid	1117	1513	0.14392	0.003758
400	Thermal oil	977	1850	0.12425	0.000739
	Nanofluid	1037	1767	0.13179	0.000778
500	Thermal oil	889	2120	0.10900	0.000331
	Nanofluid	951	2007	0.11615	0.000348

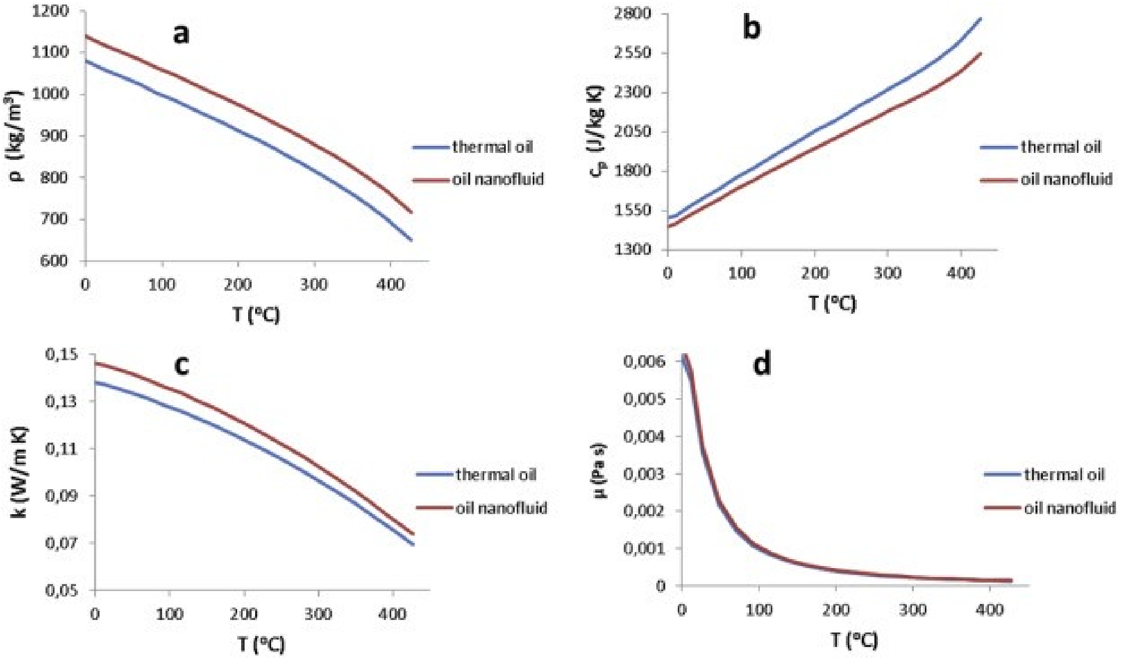

Fig. 7. The thermal oil's characteristics and those of the Al_2O_3 as nanoparticles and thermal oil as a based fluid [33].

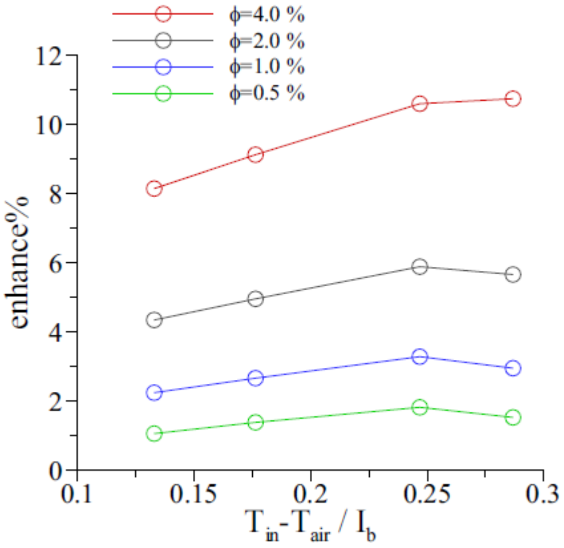

Fig. 8. Percentage of the enhancement of the PTC thermal efficiency with various NP concentrations against inlet temperature.

In order to examine the PTC's structural and thermal performance with a receiving tube employing Al_2O_3-synthetic thermal oil nanofluid as a HTF with non-uniform heat flux distributions, Wang et al. [47] designed a model for multi-field coupling based on finite element approach. The numerical findings showed that as the concentration of nanoparticles rose, the temperature gradient and the receiver tube deformation reduced. It was also found that whenever the volume fraction of the nanoparticles rose from 0 to 0.05 percent, the receiver tube's deformation fell from 2.11 mm to 0.54 mm [47].

Ghasemi and Ranjbar [43] investigated the thermal efficiency by using the CFD analysis, water had been used as the base fluid, and nanoparticles different in type and volume fraction were added while the flow is turbulent. They concluded that using CuO as a nanoparticle with water as the base fluid, the thermal efficiency goes to reach 35%, but using Al_2O_3 with water, the thermal efficiency does not reach this high efficiency, such as in the CuO-based nanofluids. Pure water and Al_2O_3 and CuO nanoparticles' thermo-physical properties are illustrated as in Table 3.

Table 3. Nanoparticles' thermo-physical properties and those of pure water [43],[48].

Properties	(Water) Base fluid	(Al_2O_3) Nanoparticles	(CuO) Nanoparticles
ρ (Kg/m^3)	998.2	3970	6500
C_P (J/Kg.K)	4182	765	535.6
K (W/m.K)	0.613	40	20
μ (N.S/m^2)	0.001003		

Duangthongsuk et al. [49] experimentally analyzed a PTC system's thermal efficiency utilizing TiO_2 as nanoparticles with a volume fraction of 0.2% and water as the base fluid. It was noticed that the heat transfer coefficient increased by 6 - 9%. Table 4 shows an estimation of the improvements in TiO_2 nanofluid's thermal conductivity [50].

Mwesigye et al. [51] have examined the PTC's thermal characteristics with three separate copper, silver, and aluminum therminol based nanofluids. It has been deduced that the silver-therminol nanofluid has better transportation characteristics and an improved thermal efficiency.

Sokhansefat et al. [52] employed Al_2O_3-synthetic oil nanofluid exposed to random heat flux. It had been discovered that the coefficient of heat transfer rose according to the temperature of the nanofluid at constant volume fraction equals to 5%. It was found that when the temperature was 300K, the coefficient of heat transfer rose by 14%, and at 400 K, it increased by 9.6%.

Mohamed Abubakr et al. [53] found that Syltherm® 800, Therminol® VP-1 and Dowtherm® Q are three synthetic oils that are widely used in industrial and CSP applications. CuO, Al_2O_3 and SiO_2 nanoparticles were the nanoparticles picked due to the comparatively low cost of these nanoparticles, and their properties have been demonstrated in Table 5 and Fig. 9.

3.4. FLOW RATE

The influence of the rate of mass flow is more important than that of the water inlet temperature [54]. Roy et al. presented a PTC with a 1.42 m^2 aperture area and a concentration ratio of 45.83, thus obtaining a maximum thermal efficiency of 65%. Fig. 10(a) demonstrates how the thermal efficiency varies in relation to water inlet temperature. Fig. 10(b) illustrates that with the rise of the rate of mass flow, PTC's efficiency rises first to a maximum value, then it reduces. A maximum efficiency of approximately 51% is attained at a mass flow rate of 4.8 Kg/s. However, the collector's thermal efficiency is reduced regardless of mass flow rate by the solar insolation that is greater than 552 W/m^2 [21]. The higher the fluid mass flow rate contributes to greater equal stress along the walls of the tube of the absorber [55].

The efficiency analyses of PTC for the following flow rates (30, 42, and 60 kg/h) were performed. Over time, the level of solar intensity is increased and the thermal efficiency of the collector increases. If solar intensity decreases, efficiency decreases. For the optimum case flow rate of 42 Kg/hr, the total heat was found to be 2349.5 KJ/hr.m^2, heat available of 3618.3 KJ/hr, heat gained by the water of 1758.1 KJ/hr, and thermal efficiency of 48.6% [56].

Table 4. an estimation of the improvements in thermal conductivity of TiO_2 nanofluid [50].

No.	Particle concentration (%)	Thermal conductivity (W/m.K)	improvement in thermal conductivity (%)	Dynamic viscosity (P.s)
1	0.05	0.61	1.66	0.92
2	0.1	0.66	9.24	1.02
3	0.2	0.68	13.21	1.26

Table 5. The properties of CuO, Al_2O_3, and SiO_2 nanoparticles [53].

Type of nanoparticles	Density (Kg/m^3)	Specific Heat Capacity (J/Kg.K)	Thermal Conductivity (W/m.K)
CuO	6000	551	33
Al_2O_3	3960	773	40
SiO_2	3970	765	1.4

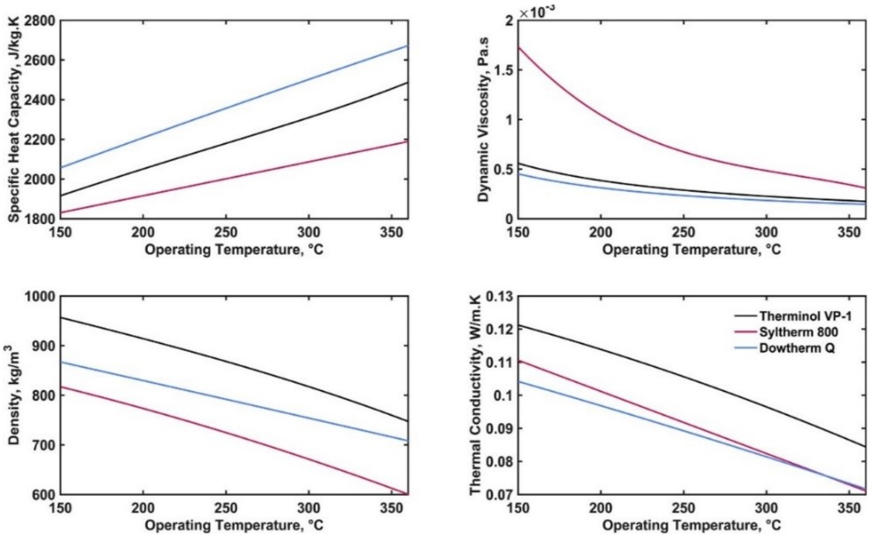

Fig. 9. The properties of CuO, Al_2O_3, and SiO_2 nanoparticles [53]

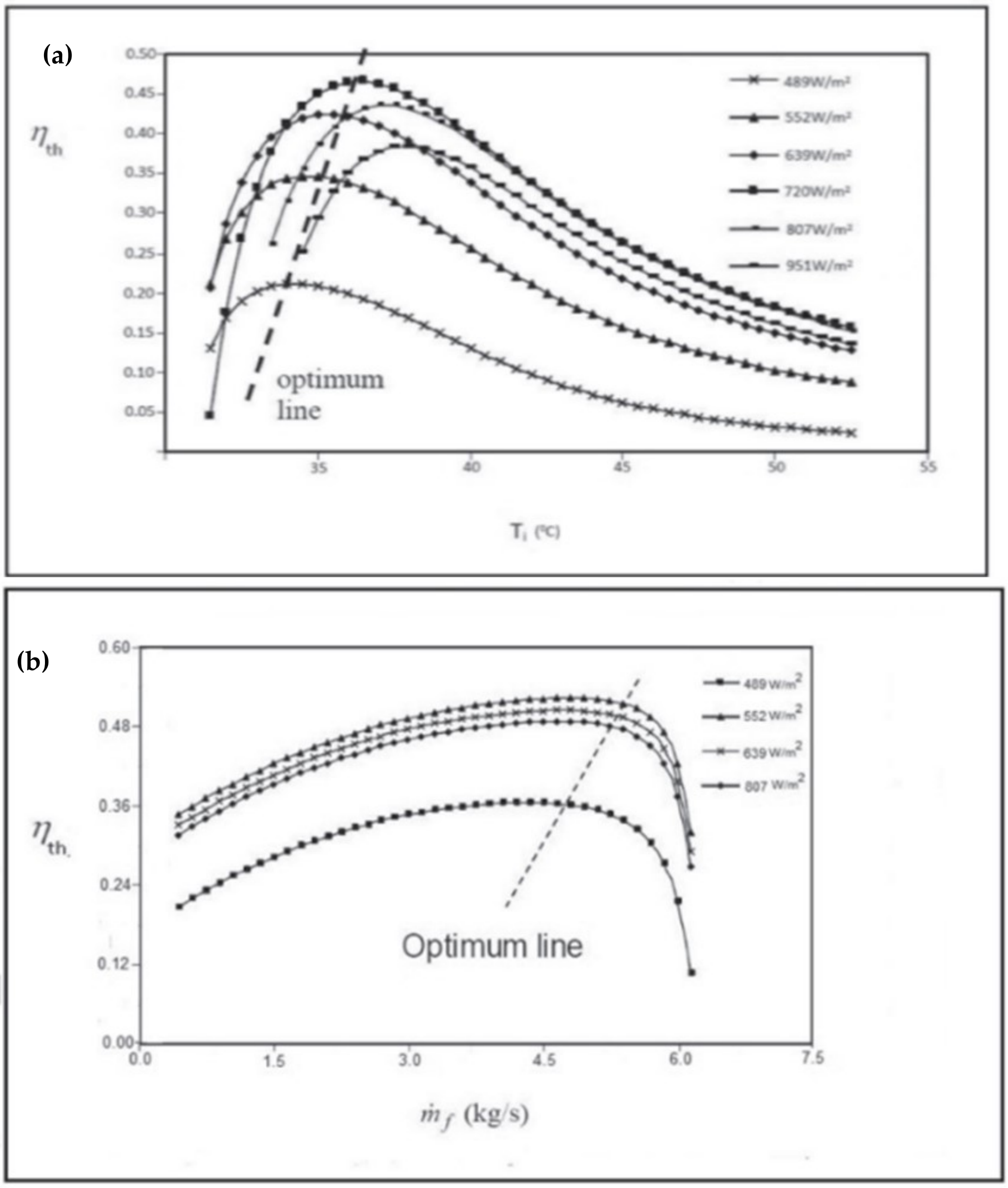

Fig. 10. Efficiency of PTC versus water inlet temperature, (b) Efficiency of PTC versus mass flow rate [55].

4. FUTURE WORK

The development of the optimum techniques for investigating the parabolic trough collectors' performance presents a significant area for future research.

- The experimental investigations are crucial for determining an accurate result for the performance of an alternative design [57]. This can be justified as the conclusions drawn from experimental investigations offer researchers and investors a significant and easily accessible way to invest money in alternative design ideas.
- The PTC's thermal performance will be enhanced by choosing the right coating, including effective porous media, internal fins, and various inserts in the receiving tube.
- The stability of nanofluid is very challenge in the practical application. Hence, researchers must study how the stability affects the efficiency of the PTC.
- Studying the effect of using cavity receivers, especially those lacking selective surface coatings for the absorbers will enhance the performance of PTC.
- Furthermore, using thermal storage materials will be an effective method to achieve a constant and permanent performance of PTC during the whole day, especially when the solar irradiation intensity is low. Hence, the thermal storage materials can be used to offset the shortage of solar energy.
- The cost of PTC should be discussed if the mono and hybrid nanofluid are used.
- Heat transfer efficiency can be analyzed with varied receiving surface area and profile modifications, such as internal finned tubes with various fin profiles, convergent divergent tubes with dimples, etc.
- In the modification of the absorber tubes, inserts that have been examined in heat exchangers can be studied [58].

5. CONCLUSION

The comprehensive literature study of the parabolic trough collectors has provided a deep understanding of the research efforts made to improve the optical efficiency and the thermal one. The impact of several effective parameters, as well as their potential for future research, has been highlighted in this review and can be summarized in the following points:

- The PTC that uses an aluminum composite reflector provides a maximum temperature of 87°C, while the one that uses a chrome plate with a glass cover produces a temperature of 98°C, and it is 82°C without a glass cover.
- The non-adjusted tube has an efficiency of about 26.7%, meanwhile, the adjusted tube efficiency goes up to 42.1%.
- When employing a metal foam with 0.1% of CuO-water volume, thermal efficiency of the PTC has improved from 55.65 to 79.29%.
- There is a rise in thermal efficiency of a PTC uses Al2O3-synthetic oil nanofluid with the gradual rise of the NP concentration, the maximum improvement in the thermal efficiency is 10% with the highest NP concentration of 5%.
- Employing CuO-water and Al2O3-water nanofluids by 3% volume, increased the receiver tube's heat transfer coefficient by approximately 35 and 28%, respectively.
- Rehan et al. found that, at 2 L/min, an enhancement in the maximum efficiency of about 13% is achieved when using Al2O3, and 11% when using Fe2O3 under the same operating conditions.
- Duangthongsuk et al. noticed that the heat transfer coefficient of a PTC utilizing TiO2 as nanoparticles with a volume fraction of 0.2% increased by 6 - 9%.

Hence, the important findings can be applied as a reference tool for future research and experimental work in construction of modified parabolic trough collectors.

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