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RESEARCH ARTICLE - PHYSICS

Parabolic trough solar concentrator performance using oil Heat transfer fluid

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Abstract

This study involves an experimental analysis of parabolic trough solar collectors (PTSC) that were designed, constructed, and assessed to evaluate their performance using evacuated tube receivers for the production of heated transformer oil. The PTSCs employ aluminum sheets configured as parabolic cylinders to concentrate and reflect solar radiation The glass tube measured 1.50m in length A nickel foil-based reflective material was affixed to increase the reflection process. The produced PTSC demonstrates considerable efficacy. The uncoated PTSC1, at 11:45 am, with solar radiation intensity of 811 W/m² and ambient temperature of 43°C, attained the maximum transformer oil temperature of 123°C and a thermal efficiency of 38%. Conversely, the coated PTSC attained a temperature of 200°C and a thermal efficiency of 52% under solar radiation intensity of 700 W/m² and an ambient temperature of 43°C. The results indicate that, at a rim angle of 45.41°, PTSC-2 featuring a black-coated receiver tube outperforms PTCS-1 with a non-coated receiver tube.

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Keywords: **Parabolic Trough Solar Collectors (PTSC) ,solar concentrators, solar energy, solar receiver, heat transfer analysis**

1. Introduction

Following the energy crisis of 2003 and the ensuing twenty-fold surge in oil prices, knowledge of alternative energy sources, particularly solar energy, has intensified in Iraq. Iraq is theoretically classified as having a second degree of solar radiation exposure, with the yearly average daily solar energy received ranging from 4.5 to 5.4 kWh/m², making it highly appropriate for solar applications [1].

Concentrating Solar Power (CSP) technologies are typically classified into three distinct categories: troughs, Towers, and Dishes. The Parabolic Trough Solar Collector (PTSC) is presently the most established solar thermal electric device[2]. PTSC is extensively utilized for power generation in irrigation, water heating, air cooling, and in conjunction with the Rankine cycle for electricity production [3,4]. The PTSC has undergone both analytical and experimental investigation by numerous researchers [5-8]. Clark examined the fundamental design parameters that affect the performance of a PTSC[9]. The analysis included factors including the spectral directional reflectivity of the mirror system, the mirror-receiver tube intercept factor, the incidence angle modifier, end loss, tracking errors, and receiver tube misalignment.

Jeter et al. investigated the geometrical influences on the performance of PTSC, focusing specifically on end effects. The results show that analyzing brief troughs significantly increases the relevance of end effects and mitigates this effect[10].

crucial for achieving accurate test results. Thomas created a sample structure of PTSC to examine its deflection and optical properties under several loading scenarios. In the absence of wind tunnel equipment, the test provides adequate information regarding the impact of wind load on the optical performance of a PTSC[11] .the Research Ghufran Hassoon A and others, along with others, studied the impact of air temperature and rainfall on climate change in the city of Baghdad based on the components of renewable energy[12]. The researcher R.H. Rhaif and others studied and analyzed the performance of a 15-kilowatt photovoltaic solar energy system to compensate for the shortage of electrical energy that Iraq has experienced in recent years[13]. Umamaheswaran provided a comprehensive study on the design, evaluation, and analysis of PTSC for small-scale home water distillation applications. Groundwater is heated by solar radiation as it circulates through the solar collector within an absorber pipe, generating steam directly in the absorber pipe[14]. Arasu and Sornalcumar devised a novel PTSC for the creation of hot water. The fluctuation of collector water outflow temperature and the storage tank water temperature has risen from 36°C to 73°C[15]. Kassem forecasted natural convection heat transfer within an annular region between a circular receiver tube and a glass envelope of a PTSC. In recent decades, energy consumption has markedly risen due to technological advancements and the broader application of energy across several sectors[16]. Furthermore, there are an increasing number of environmental concerns [17]. Research on energy-related issues and their impact on human existence is ongoing [18]. The influence of air, ambient temperature, and rainfall is significant in determining the Heat Transfer Fluid (HTF) [19]. Radiant heat transfer in PTSC in a porous media was studied computationally by Sharma et al. in 2023 utilizing a nanofluid as the heat transfer fluid. The implications of viscosity dissipation were carefully examined. As Reynolds number values grew, the results showed that the external appearance increased as well, affecting temperature and fluid velocity [20]. To improve performance and efficiency when the tracking system is present, Mustafa Al-Gharzi et al. developed a hybrid solar system in 2023 that combines a PTSC and an electric generator (PTC-TEG). As the pressure increased, the thermal efficiency increased by 6.88 and 14.64, and the overall efficiency of the proposed hybrid solar system increased by 15.75% [21]. PTSC can be utilized to generate power, heat water, or desalinate water (Asim et al., 2024). It's been studied as a means of storing excess thermal energy during bright periods and releasing it to generate electricity at night or during depressing periods. Because hybrid systems diversify energy inputs, they help ensure a steady power supply even in situations where solo solar solutions suffer from intermittency [22]. The researcher Falah Abdul Hassan Mutlaq designed a solar center with a parabolic trough and used transformer oil as the heat transfer fluid. The results showed good efficiency, reaching up to 61%[23]. The researcher Khalid Abdullah designed a solar collector of the parabolic trough type, using nanomaterial's as well as transformer oil as heat transfer fluids. Upon comparison, the results showed that transformer oil had better efficiency than the nanomaterial's[24].

2. Solar Collector Parabolic Trough

The movable reflecting surface and stationary tube of a parabolic trough solar collector (PTSC) travel along the focal line. The reflecting surface is situated in what appears to be a part of a cylinder. It aligns the surface of the tube carrying the liquid with the sun's daily path by focusing falling light on it. Its exceptional efficiency and high-temperature operation make the PTSC the best type of collector [25]. the creation of steam for industrial purposes [26], the generation of electricity [27,28], and the heating of residential buildings. A large number of researchers study PTSC.PTSC are therefore used in many different processes, such as the desalination of saltwater [29,30].

3. Observation on Design

The current project involved the development and construction of the PTSC. The huge weight, low cost, robust and solid structure, and ease of construction are experimental features of the modern PTSC. An aluminum sheet that was 1.80 meters long, 1.60 meters wide, and 1 millimeter thick served as the reflecting surface. Nickel paper was positioned on the aluminum panel. in order to capture more than 90% of the reflection. The booster framework and the aluminum panels are the same size. The overall aperture area of the matching basin is 2.88 m².

Computing the dimensions of the PTSC:

The following factors are taken into account when determining the PTSC's dimension:
Width (S) = 1.60 m ; rim angle (θ_r) = 45.41º.
(Wa) is equal to{ 2S. tan(θ_r/2) /{sec(θ_r/2) * tan(θ_r/2)+ ln(sec(θ_r/2)+tan(θ_r/2))} ……..(1)
Wa = 1.41 m
The parabola's focal length is $F = (W)^2 / 16hc$…………………………………………..(2)
where hc = 0.15m.
F = 1.066 m
Ration of geometrical concentration: C = Wa / Do …………………………………..(3)
C= 31.31
The dimensions and features of the PTSC systems are shown in Table 1.

Table 1. lists the PTSC specifications.

Name	Specifications
Receiver Type	Black Coated
Focal length (F)	1.066m
Rim angle (θ_r)	45.41°
Aperture width (Wa)	1.409m
receiver tube diameter (R)	0.045m
parabola length (L)	1.80m
Effective aperture area (Aa)	2.88m^2
Geometric Concentration Ratio(C_R)	31.31
collector reflectivity (ρ),	90%
receiver tube absorptivity (α)	0.93
receiver material length	1.50m
Receiver material	GI pipe
reflector material thickness	1mm
parabola width (w)	1.60m

4. Manufacturing of the PTSC System

The PTSC is characterized by its simple construction. A parabolic trough concentrator, a support structure, and a receiver are among the parts. The detailed description is as follows:.

4.1. Structure for Collector Support

For the precision and stability of the collectors, a strong and stiff supporting framework is designed using firm iron strips. The structure's mild steel iron frame is assembled by arc welding, drilling, and nut-bolt joints, which also serve to support the rotation axis of the parabolic reflecting surface. It is used to monitor the sun throughout the day by rotating the horizontal and vertical axes.

4.2. Concentrator with Parabolic Trough

To achieve the parabolic shape, the aluminum sheets used in the proposed trough concentrator, each with a thickness of 0.1 mm, had to go through a rigorous deformation procedure. The material can be shaped to the desired shape and is readily available. The focal length is 1.066 meters, the aperture width of the trough is 1.409 m ,and the trough width is 1.60m for the collector system ease of maneuverability.2.88$m^2$is the reflecting surface's aperture area.

4.3. Tube of Absorbent Material

Along the collector's focus line, the receiver is positioned concentrically. The round piece was chosen out of all the shapes that were considered because it was easier to obtain and covered less ground, which prevented the reflector from getting shaded. For the receiver purposes of both PTSCs, circular pipes composed of galvanized iron (GI) are utilized. Two criteria, especially the targeted concentration ratio and local accessibility, were used to define the receiver's size. The following are the final receiver dimensions:

1.50 m in length and 0.045 m in outer diameter. During the experimental phase, sun-tracking was done. The system was oriented north-south to optimize the quantity of solar light that could be captured. Tracking was done to rotate the collector along the east-west axis. By monitoring the sun's reflection on the reflective surface for the entire fifteen minutes, horizontal axis tracking was accomplished.

4.4. Measurement of flow meter

The transformer oil fluid used in this study was pushed using a pump that could move 10 liters per minute. The flow rate, which was 0.5 liters per minute in the employed research, was then ascertained by connecting a liquid flow rate device to the pump. With gradations ranging from 1 to 18 liters per minute, it is a flow measuring device. Their accuracy was confirmed by experimental readings that required figuring out how much fluid left the system in a specific amount of time at different flow rates. If the measurement was less than one liter, a graduated ruler was employed.

5. Setup for Experiments

In the experimental arrangement, the collectors are parabolic troughs. A 50-liter storage tank and a 1.50-meter receiver pipe, one end of which is closed and the other open, are features of each PTSC. In both PTSCs, aluminum sheets served as the reflector material. Nickel foil was affixed to the metal sheets to enhance their reflectivity. A dot The heating fluid was moved by a pump that could move 10 liters per minute. It was also used The range of the mass flow rate flow speed scale is 1 L/min to 18 L/min. The storage tank is filled by the main water supply. Temperatures at the water input and outlet of the absorber tube, the ambient temperature, the reflector temperature, the temperatures at the inlet, middle, and outlet surfaces of the receiver, the wind speed, and the sun's ray intensity are all continually recorded during the experiment. In July 2024, the experiment is carried out. The work was completed at the Al-Mustansiriya University Solar Energy Laboratory on the roof of the College of Education. The testing system is oriented North-South to maximize solar energy absorption, as illustrated in figure (1).

Fig.1. PTSC Experimental Configuration

5.1. Measurements procedures

Use a flow meter to determine the flow rate.

2. The concentrator is continuously shifted so that it faces the sun.

3. Every fifteen minutes, a thermometer is used to measure the temperatures entering and leaving the absorption portion, the storage tank, and the surrounding air.

4. Every quarter-hour, the incident normal sun radiation intensity is monitored.

5. The measurement procedure is conducted between the hours of 8:00 AM and 1:30 PM.

6. Two case studies are available:

For PTSC-1 with an uncoated receiver tube, Case 1

Date: 28/07/2024

Minimum ambient temperature: 30^{o}C at 8 AM.

Maximum ambient temperature: 46 ^{o}C at 1:30 PM

Maximum wind sped :7.1m/s at 1:30

Maximum beam radiation: 823 w/m^2 at:1:00PM

Thermal Efficiency Calculation: $\eta = Q_{usf,Ex} / (Aa \times Hb)$……………………………….(4)

The net usable heat gained by the transformers oil (Watt) is represented by $Q_{usf,Ex}$ and may be found using the formula $Q_{usf,Ex} = \dot{m} C_p (T_2 - T_1)$…………………………………………………(5)

$\dot{m}$= mass flow rate of fluid (kg/sec) = 0.008333kg / sec

C_p= specific heat of transformers oil = 2500 J/kg K

T_2 = Maximum temperature attained by transformers oil (^{o}C)

T_1 = Initial temperature of transformers oil (^{o}C)

Aa = Aperture area (m^2)

H_b = Solar radiation intensity (W/m^2)

at 11: 45AM, Maximum outlet Temperature (T_2) = 123 ^{o}C

at 11: 45AM inlet Temperature (T_1) = 80 ^{o}C

$Q_{usf,Ex} = 896W$

Efficiency (η) = 0.38

Case2-For PTSC-2 having coated receiver tube.

Date: 25/07/2024

Minimum ambient temperature: 33 ^{o}C at 8 A.M.

Maximum ambient temperature: 48 ^{o}C at 12: 30 P.M&1:00PM

Maximum outlet Temperature (T2) =200^{0}C at 12:00 P.M

For, Inletl Temperature (T1) = 150^{0}C at 12:00 P.M

$Q_{usf,Ex} = 1042W$

Efficiency (η) = 0.52

5.2. Results and Discussion

Numerous observations of the system were conducted in July 2024 at Mustansiriyah University's Solar Lab, which is part of the Department of Physics in the Faculty of Education. The collected data has been used to make graphs for a particular day.

For two scenarios in which the receiving tube is coated and uncoated for two distinct days, Figure 2 shows the value of direct solar radiation from 8:00 a.m. to 1:30 p.m. According to the figure, the amount of solar radiation intensity is at its lowest at 8:00 am, when 700 W/m^2 of radiation falls on the coated tube and 823 W/m^2 falls on the uncoated tube. The uncoated tube's maximum direct radiation value was 823 W/m^2 at 11:30 a.m., whereas the coated tube's was 700 W/m^2 at 12:00 p.m .the Table 2 shows the absorption tupe calculations in the absence of an absorbent material, while the Table3 shows the absorption tube in the presence of an absorbent material. While the maximum outlet temperature of the uncoated receiver tube reached 123°C, with an inlet temperature of 80°C at 11:45 AM when the wind speed was 1.2 m/s and the ambient temperature was 43°C (as shown in Table 2), the maximum outlet temperature of the coated receiver tube reached 200°C, with an inlet temperature of 150°C at 12:00 PM when the wind speed was 4.3 m/s and the ambient temperature was 46°C (as shown in Table 3). When comparing the results, the coated receiver tube shows significantly better efficiency compared to the uncoated one. The difference in the liquid outlet temperature is approximately 77°C. This is attributed to the absorptive material's ability to capture the maximum possible solar radiation, which aligns with research findings [24].

Table 2: Observation Table for PTSC-1

S.No	Time(h)	Inlet Temp (T1)	OutletnTemp (T2)	I_b W/m^2	Wind m/sec	Ambient Temp (Ta)
1	8:00	32	38	347	2.1	30
2	8:15	34	45	408	2.5	32
3	8:30	35	52	500	.3	33
4	8:45	39	60	544	1.8	35
5	9:00	45	67	553	2	38
6	9:15	48	73	570	1.7	38
7	9:30	50	80	582	1.7	38
8	9:45	54	87	626	1.9	39
9	10:00	57	93	671	1.9	39
10	10:15	64	103	709	2.5	40
11	10:30	68	110	738	3	40
12	10:45	70	112	764	5.4	40
13	11:00	74	118	783	6	41
14	11:15	75	120	814	4.5	42
15	11:30	81	122	823	1.8	43
16	11:45	80	123	811	1.2	43
17	12:00	82	119	801	1.6	43
18	12:15	76	115	792	3.5	44
19	12:30	75	114	780	4	45
20	12:45	74	110	800	2	45
21	1:00	74	110	800	1.6	46
22	1:15	73	108	770	6.4	46
23	1:30	73	108	757	7.1	46

Table3.Observation Table for PTSC-2

S.No	Time(h)	Inlet Temp (T1)	outletTemp(T2)	I_b W/m^2	Wind m/sec	Ambient Temp (Ta)
1	8:00	35	50	276	4.3	33
2	8:15	43	60	320	4	36
3	8:30	52	69	366	4.3	38
4	8:45	60	85	418	2.5	38
5	9:00	70	105	472	2.2	39
6	9:15	82	117	496	1	40
7	9:30	102	135	535	1.3	40
8	9:45	112	150	602	1.3	42
9	10:00	124	165	642	1.3	42
10	10:15	132	177	600	3.5	43
11	10:30	140	186	637	4	43
12	10:45	140	188	638	4	44
13	11:00	142	190	633	4	44
14	11:15	143	192	653	1.5	46
15	11:30	147	195	677	1.1	46
16	11:45	150	197	689	4	46
17	12:00	150	200	700	4.3	46
18	12:15	148	195	686	5	47
19	12:30	148	195	666	6.7	48
20	12:45	146	190	585	5	48
21	1:00	145	190	544	5	48
22	1:15	144	188	514	4.5	46
23	1:30	144	188	489	4.5	46

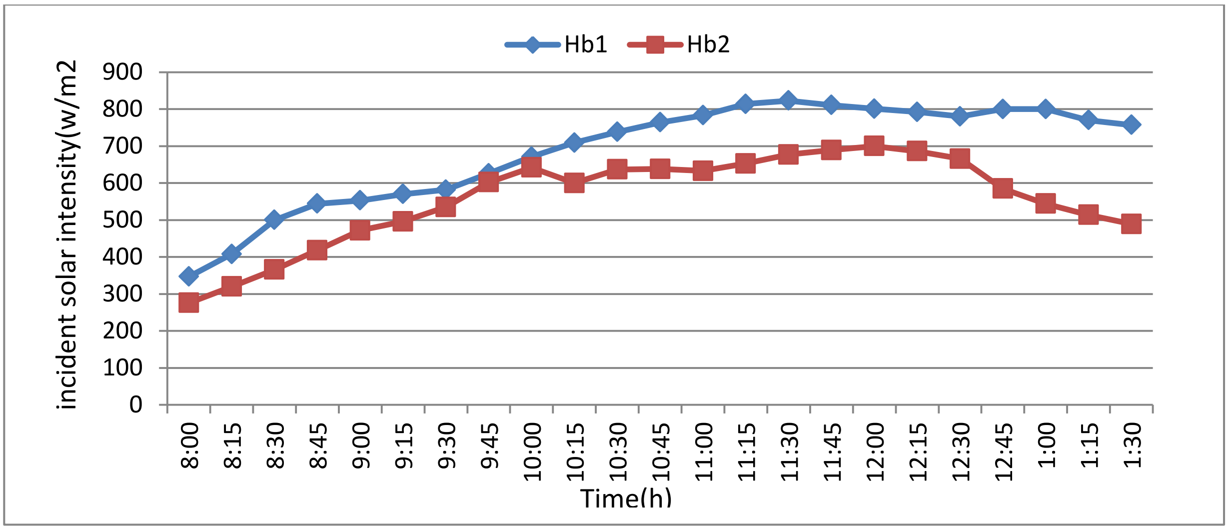

Fig.2. Changes over time in the incident solar intensity on the coated and uncoated receiver tubes.

Figure 3 shows the moderate variation in wind speed for the two cases, PTSC-1 which have uncoated receiver tube and PTSC-2 which have coated receiver tube. This figure indicate that the maximum value is about 7.1 m/s at the hour1:30pm. and the minimum value is about1.2 m/s at 11:45a.m for PTSC-1, while the maximum wind speed 6.7 m/s at 12:30 a.m. and the minimum value is about1.1 m/s at11:30a.m for PTSC-2.

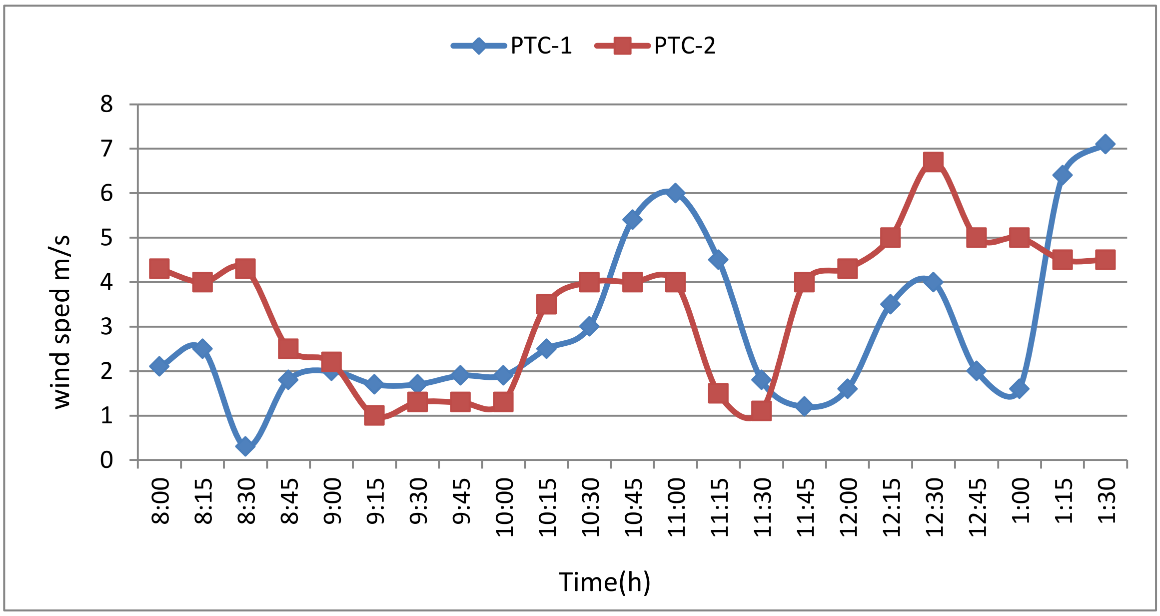

Fig.3. Variation of wind velocity with time

Figure 4 shows the ambient temperature for the two cases, PTSC-1 which have uncoated receiver tube and PTSC-2 which have coated receiver tube. This figure indicate that the maximum value is about 46^{o}C at the hour 1:00 p.m&1:15pm&1:30pm when the wind speed was 7.1 m/s. and the minimum value is about 30 ^{o}C at 8:00 a.m when the wind speed was 2.1 m/s for PTSC-1, while the maximum value is about 48^{o}C at 12:30p.m&1:00pm when the wind speed was 6.7 m/s. and the minimum value is about 33 ^{o}C at 8:00 a.m. when the wind speed was4.3 m/s for PTSC-2.

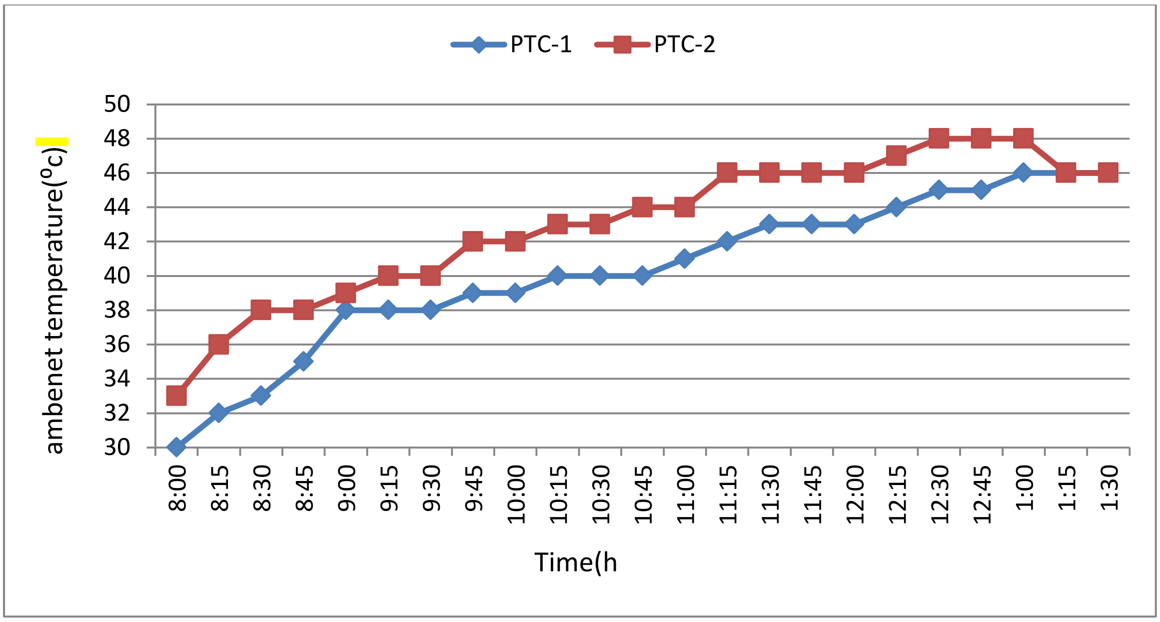

Fig.4. Variation of temperature ambientPTC-1&PTC-2 with time

Figure 5 shows the relationship between the absorber inlet temperature, absorber outlet temperature and ambient temperature for the first solar collector PTSC-1 with an uncoated receiver with time from 8:00 a.m. to 1:30 p.m. It is clear from this figure that the temperature increases from the lowest value at 8:00 a.m. to the maximum value at 1:00 p.m., the outlet temperature is about 38 ^{o}C and the inlet temperature 32 ^{o}C when the ambient temperature 30 ^{o}C at 8:00 a.m At this point, the solar radiation intensity is 347 W/m², accompanied by a wind speed of 2.1 m/s.. these values increase with time, thus they reach to 123 ^{o}C, 80 ^{o}C and 43^{o}C for outlet, inlet and ambient temperatures, respectively at 11:45a.m At this point, the solar radiation intensity is 811 W/m², accompanied by a wind speed of1.2 m/s.. after that they decrease to 108 ^{o}C, 73 ^{o}C and 46 ^{o}C at 1:30 p.m At this point, the solar radiation intensity is 757 W/m², accompanied by a wind speed of 7.1 m/s..

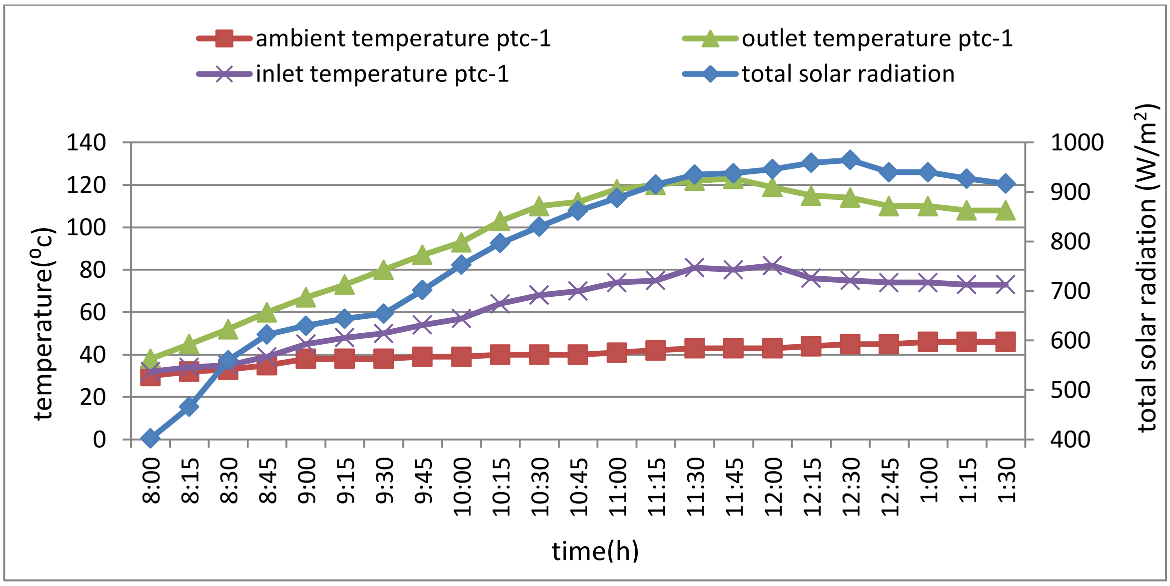

Fig.5. outlet, inlet and ambient temperatures and total solar radiation ηwith time (PTSC-1)

Figure 6 shows the relationship between the absorber inlet temperature, absorber outlet temperature and ambient temperature for the second solar collector PTSC-2 with a coated receiver with time from 8:00 a.m. to 1:30 p.m. It is clear from this figure that the temperature increases from the lowest value at 8:00 a.m. to the maximum value at 12:45 p.m., then decreases until it reaches its value at 1:30 p.m. the outlet temperature is about 50 ^{o}C and the inlet temperature 35 ^{o}C when the ambient temperature 33 ^{o}C at 8:00 a.m At this point, the solar radiation intensity is 276 W/m², accompanied by a wind speed of4.3 m/s. these values increase with time, thus they reach to 200 ^{o}C, 150^{o}C and 46 ^{o}C for outlet, inlet and ambient temperatures, respectively at 12:00 p.m At this point, the solar radiation intensity is 700 W/m², accompanied by a wind speed of 4.3 m/s. after that they decrease to188 ^{o}C, 144 ^{o}C and 46 ^{o}C at 1:30 p.m At this point, the solar radiation intensity is 489 W/m², accompanied by a wind speed of4.5 m/s. When comparing the results between this graph and Figure 5, it is evident that the coated receiver tube demonstrates superior performance in terms of temperature results. This advantage can be attributed to the presence of the absorptive material, which effectively captures a higher amount of the incident solar radiation. Additionally, the influence of wind speed plays a role in enhancing the performance of the coated receiver this is consistent with research[23].

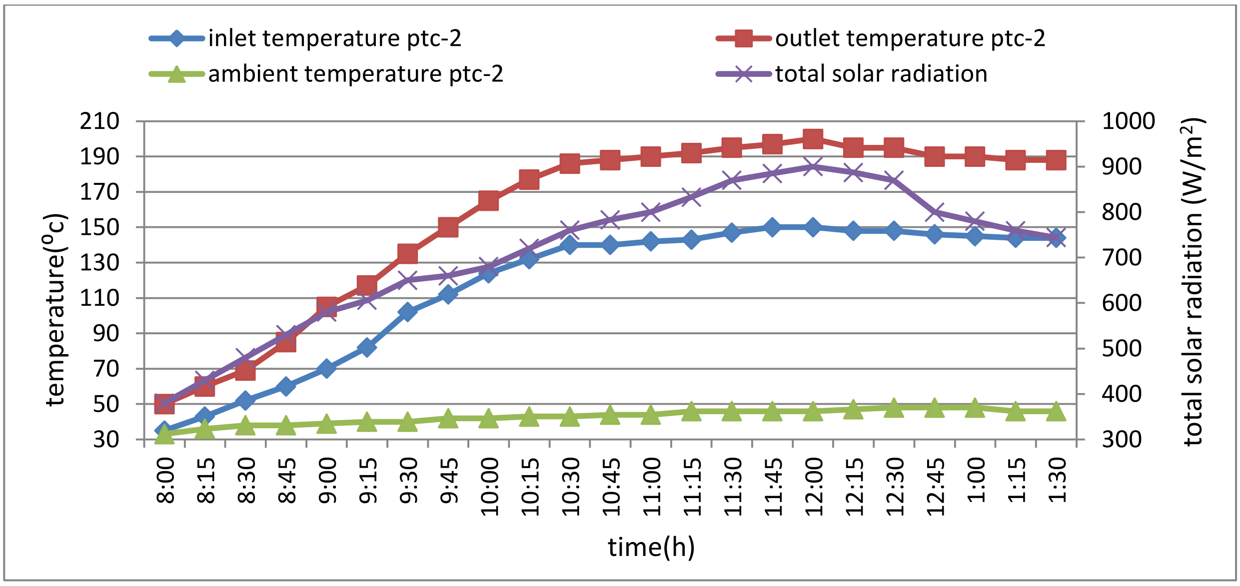

Fig.6. outlet, inlet and ambient temperatures and total solar radiation with time (PTSC-2)

Figure 7 shows the system efficiency for two cases (PTSC-1 and PTSC-2) from 8:00 a.m. to 1:30 p.m. it is clear from this figure that the maximum efficiency for PTSC-1 is about 41% at 10:30a.m &11:00 a.m At this point, the solar radiation intensity is 738 W/m², with a temperature difference of approximately 42°C between the liquid's outlet and inlet. The wind speed during this time is 3 m/s. and the minimum value is about 13% at 8:00 a.m. At this point, the solar radiation intensity is 347 W/m², with a temperature difference of approximately 6°C between the liquid's outlet and inlet. The wind speed during this time is 2.1 m/s., while the maximum efficiency for PTSC-2 is about 65% at the solar radiation intensity is 700 W/m², with a temperature difference of approximately 50°C between the liquid's outlet and inlet. The wind speed during this time is 4.3 m/s.. and the minimum value is about 34% at 8:30 a.m At this point, the solar radiation intensity is 276W/m², with a temperature difference of approximately 15°C between the liquid's outlet and inlet. The wind speed during this time is 4.3 m/s.. When comparing the results, it is evident that the parabolic trough solar collector with a coated receiver tube exhibits higher efficiency and better performance compared to the uncoated receiver tube. This can be attributed to the presence of the absorptive material, which enables the coated tube to capture a greater amount of the incident solar radiation. Additionally, the impact of wind during operation also plays a role in enhancing its performance. These findings align well with the research conclusions [31].

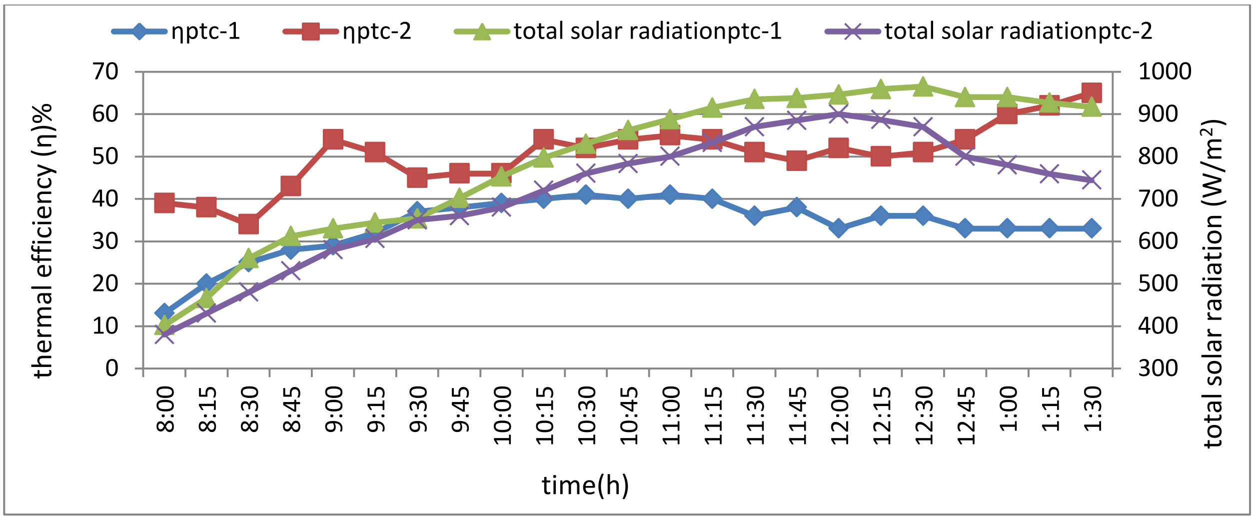

Fig.7. Variation of thermal efficiency of PTC-1&PTC-2 and total solar radiation with time

6. CONCLUSION

This study yielded a number of conclusions, including the following.

When the temperature of the transformer oil inside the absorbent tube increases, heat losses take place. Therefore, it is preferable to increase the transformer oil flow through the absorbent tube. When the fluid's mass flow rate is raised, the solar collector's efficiency rises. The mass flow rate of the fluid increases when the temperature differential between its intake and output is reduced. In accordance with the increase in solar radiation, the useful energy recovered from the collectors increased from 8:00 to its maximum value between 11:00 AM and 11:15 PM hours for PTS-1. In contrast, PTC-2 usable energy recovered from the collectors increased from 8:00 to its highest value between 11:00 am and 12:00 pm.

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