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Evaluation of A Parabolic Basin Complex Using Porous Aluminum Filling In An Absorbent Receiver

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ABSTRACT

This study proposes a detailed PTC model. Our motive was to ensure accuracy while ensuring fast and inexpensive calculations. These tests were performed using aluminum porous media with two operation modes: an evacuated glass absorption tube. Air and metallic aluminum fibers are added inside the absorption tube. To improve the performance of the parabolic basin complex, the model was tested in Kirkuk, Iraq, under actual operating conditions. The results were as follows: Thermal efficiency reached a maximum of 27.51% without any substance at a flow rate of 0.8 LPM and a radiation intensity of 1202 W/m2. However, when including porous media, the maximum efficiency increased to 45.76% at the same flow rate of 0.8 LPM, with a radiation intensity of 1220 W/m2. That is, the results showed an improvement in performance by 18.25%. Therefore, porous materials' permeability and thermal conductivity are essential to determining the temperature gradient. The porous medium's porosity and increased thermal conductivity increased the exit temperature. The results indicated the possibility of using aluminum metallic fibers for the system to improve performance.

1. Introduction

Fossil fuels have met nearly all our energy demands in the last century due to their lower cost and greater convenience than renewable energy sources. The release of toxic gases into the atmosphere, a significant concern associated with natural energy sources such as the sun, ocean, sea, and wind, has resulted in air pollution. This has led to an increase in global warming. Many plants and animals have died because streams are polluted with heat from the power plant's large-scale waste heat discharge [1]. The energy reserves are naturally refilled; clean energy originates from natural sources like the sun, ocean, sea, and wind [2]. For a long time, solar power has been known to humanity as a viable energy source. Compared to other energy sources, SC has several apparent advantages, such as being safe for the environment, producing no harmful byproducts, and being readily available, inexpensive, and renewable [3]. Even more so. Renewable and unadulterated solar, thermal, and electrical energy is eco-friendly. SC's style and function differ from nation to nation [4]. Green energy is becoming increasingly popular worldwide. As a result, there has been a corresponding uptick in establishing and implementing energy policies that aim to do just that. As a result, the industry will continue to expand as renewable energy usage increases across all nations and price rivalry intensifies [5]. According to some estimates, by 2050, CSP might provide enough electricity to power 12% of the world's population [6]. Generating steam is the principal goal function of the power-generating system. Steam generators that reach temperatures of 300 °C commonly use PTC as a component. Many see PTC as a sustainable, low-cost thermal energy source for the future. [7]. Parabolic collectors focus the sun's rays onto a cylindrical receiver tube near the parabola's focal point. The concentration ratio of common PTCs reaches 50 [8]. Improving the thermal performance of the working fluid that flows through the absorber tube is necessary to ensure the PTC system is safe when running at high temperatures and to make the temperature distribution less uneven. [9]. PTC is mainly utilized in thermal systems, such as heating and steam turbine systems. Parabolic reflectors consist of a metallic sheet curved into a parabolic shape. The sheet should possess a high degree of reflectivity and be designed like a mirror that reflects sunlight. The PTC should be oriented toward the sun during daylight hours. The trough sections direct parallel sunlight onto the focal line. RT is located precisely along the focal line of the parabolic trough's reflective surface. The tube consists of two layers: an exterior layer of clear glass that is anti-reflective and transparent and an inner layer of copper or selective black nickel. RT collected thermal energy and transferred it to the HTF. A tracking system is supplied to the PTC to adjust its position to the sun's movement from sunrise to sunset. Figure 1 displays the specific information on a sample of the Positive Temperature Coefficient (PTC) system [10], [11], and [12].

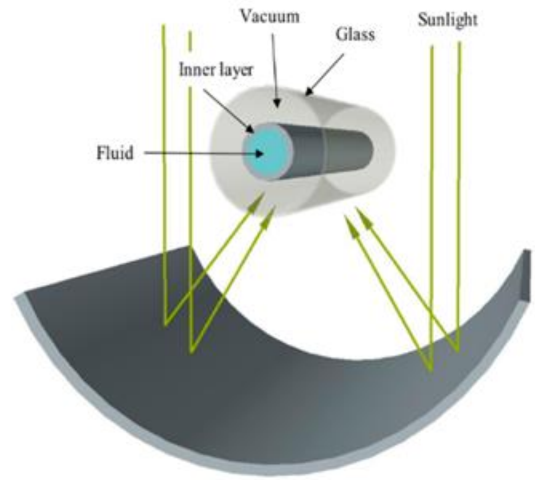

Figure 1. Solar collector with a parabolic trough in detail [1]

Increasing the thermal performance of PTCs is a key global priority because of their many potential applications. To further reduce heat loss, thermal enhancement technologies can increase the fluid's convective heat transfer coefficient. Experts in the field frequently categorize these technologies as active or, passive, or a mix of the two. Adding porous media, tabulators, wavy channels, fluid additives, phase change materials, and new geometries can improve the thermal performance of PTCs. However, several of these methods have the drawback of increasing the flow's pressure drop. Therefore, studying the hydrothermal properties of PTCs is crucial for determining the practical effectiveness of these methods. Here, we look at a few pieces of literature on the subject, classifying the existing performance methodologies according to what is stated in Ref [13]. Wang et al. [6] The parabolic basin collector's thermal and optical performance were calculated. The temperature is uneven because heat transfer is unequal along the absorption tube's circumferential direction. At 75 degrees, the pressure concentration zone appears near the tube's fixed end, and stress peaks at 100 MPa. An increased geometric concentration ratio shifts the limit. As the temperature distribution becomes unequal, the highest flow to the bottom of the tube heats the heat transfer fluid and increases tube pressure. The edge angle increases the temperature distribution, which lowers pressure and moves maximum heat flow to both ends of the tube. The geometric focus and edge angle can improve the parabolic basin collector's performance.

Mahmood et al. [14] This theoretical and practical study uses manual tracking devices and a galvanized receiver plate with 2-millimeter aluminum foil to evaluate three parallel PTC thermal performances. The internal and external diameters of the stainless-steel absorber tube are 30 and 33 millimeters. This PTC achieved 43% collection efficiency in experiments. B. Kurşun [15] examined the absorber tube's sinusoidal surface and internal longitudinal fins, utilizing the finite volume approach and realizable k under turbulent flow conditions. Longitudinal fins increased Nu by 25%, while sinusoidal fins boosted Nu by 78%.

Zaboli et al. [16] His numerical analysis focuses on PTCs with inner helical axial fins that generate swirls. Fin pitches ranging from 250 to 1000 mm were examined. The numerical results are calculated using FVM. The innovative PTCs could boost thermal performance by 23.1% compared to a traditional solar collector. Comparing cases with and without fins, thermal performance increases by 14.1–21.53% at P = 250 mm. Limboonruang et al. [17]. Use internal fins or more surface area to improve SPT receiver heat transmission. The experimental use of autonomous sun tracking system-controlled SPT equipment with a 300 mm focal length and 5.1 m collection length was limited. Receivers with and without fins were compared at five water flow rates. A solar receiver with a finned tube achieved 59.34 ◦C water temperature, surpassing a smooth tube at 0.5 L/min. At 834.61 W/m2, externally finned absorber tube efficiency was 18.20%, 48% higher than plain tubes. Outside-finned receiver tubes boost SPT collector thermal efficiency.

Jamal-Abad [18] The experiment demonstrated that using copper foam as a porous medium to fill the absorber tube increases the efficacy of PTC when the total loss coefficient u decreases by 45%. Valizade et al. [9] used copper foams with ten pore density and 0.95 porosity, which were examined using direct absorption. The outside test used a glass absorber tube and ASHRAE 93 criteria. Fully porous, partly porous, and nonporous absorption tubes were used with flow rates from 0.3 to 1.6 L/min and intake temperatures from 20 to 40 °C. The results seemed improved. Compared to smooth tubes, semi-inset and full-inset tubes offer the highest thermal efficiency (119.6% and 171.2%, respectively). Maximum temperature differences are 12.20, 8.80, and 3.30 °C for full foam, partly foam, and without foam. Loni et al. [19] The researcher studied its effects Using a rectangular absorption tube with an interior chamber. A cube contains tubes within its interior. The sensitivity analysis designs considered cavity placement bore opening, bore height, and bore tube diameter. The slot width was appropriate for the cavity depth. The bore must be in the focal line with a higher focusing aperture to maximize energy absorption because it was 77.26% thermally efficient. Shirole et al. [20] To make a new model, variations in PTP were tested with Nanofluids of CuO, SWCNH, magnetite, graphite, Al2O3, ZnO, Fe2O3, TiO, MWCNT, and SiO under high pressure using thermodynamic equations and properties. With the base fluid nanoparticles, heat conductivity increases. Graphite, SiO3, and O2Al all followed magnetite in thermal efficiency. Nanofluids are thermally efficient. At 0.4% concentration, the mass flow rate increased from 70 to 90 kg/s, increasing thermal efficiency from 10% to 20%.

Kumar et al. [21] reviewed recent numerical and experimental evacuated tube solar collector designs. They examined how optical design, mass flow rate, and working fluid types affected the output. Thappa et al. [22] performed thermodynamic and geometrical experiments on a double-evacuated receiving tube. Six receiver tubes with rim angles of 400o, 800o, and 1200o, flow rates of 16 to 216 L/h, and fluid input temperatures of 323, 423, 523, 623, and 723) K are examined. The 27-mm receiver tube with a double-evacuated glass tube has the highest energy and efficiency. It is 79% and 47% at 800 optimal rim angles and a 5.7-meter broad parabolic aperture, respectively.

The present study aims to improve the performance of a PTC system with available materials, low cost, and easy installation. In addition, to evaluate the thermo-hydraulic properties of a new PTC system, a receiver filled with porous aluminum medium, and compare its performance with the conventional PTC system. The receiver does not have metal tubes to transport the heat transfer fluid. Water is transferred to the evacuated tubes directly. The experiments will be conducted under the actual weather of Kirkuk City, Iraq, with the water flow rate range of (0.2, 0.4, 0.6, and 0.8) L/min.

2. PTC System

The PTC utilizes parabolic reflectors to focus solar radiation onto the absorber tube. In a PTC system, reflective materials form a parabolic shape, concentrating sunlight onto the absorber tube at the focal point. The absorber typically comprises two layers: an external layer of glass, which minimizes heat loss from the absorber, and an internal layer of copper, through which the HTF circulates.

A PTC absorbs solar radiation and converts it into thermal energy using an HTF, typically water. The HTF circulates in the absorber tube, reaching temperatures as high as 400 °C. After establishing the geometry and thermal properties, it is possible to compute the thermal efficiency and energy acquired by HTF across various arrangements and meteorological circumstances. Our simulation considers the PTC in conjunction with a tracking system, which naturally leads to a significant increase in the energy absorbed by the receiver. This, in turn, affects the temperature of the receiver's outlet and its various components [12] [23] [24].

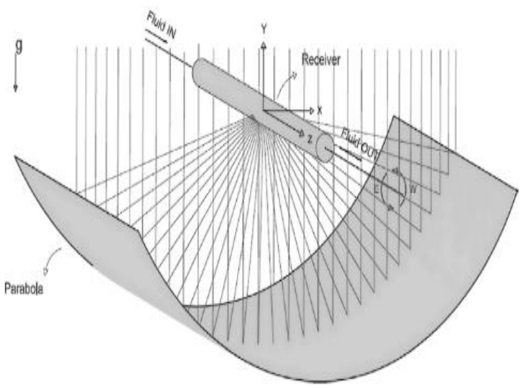

Figure 2 the collector and absorber tube [12].

3. Theory

The collector's thermal efficiency is the ratio of the heat transfer factor (HTF)'s instantaneous usable heat gain to the amount of direct sun radiation (Id) incident on the collector's aperture area (Aa) [25].

$$\eta_{Exp} = \frac{Q_u}{Q_a} \quad (1)$$

$$Q_u = \dot{m} Cp_w (T_{w,o} - T_{w,i}) \text{ [26].} \quad (2)$$

Where:
Qu: useful heat gain (W)
m·: mass flow rate of water (kg/s)
Cp: specific heat (J/kg. K)
ΔT: The temperature difference between the water outlet and inlet (C°)

$$Q_a = A_a * I_d \text{ [27].} \quad (3)$$

Where:
Aa: collector aperture area (m²)
I: solar radiation (W/m²)

4. Experimental Setup and Procedures

4.1 Experiment Setup

The test platform was built using locally available materials, consisting of a parabolic basin mounted on an iron base, measuring 1.5 x 1 m with an area of 1.5 square meters, the frame was made of 18 mm particle board for wind resistance, with a 0.07 mm thick aluminum plate securely fixed on top and a layer of solar film applied to the reflector surface. The solar concentrator system was mounted on an iron base with a guide for regular movement and rotation by a motor, the motor has one horizontal axis with an angle between -70 and +70, and mechanical elevators were installed to adjust the angle corresponding to the sun's altitude. The flat solar collectors use a 1.5 m layer of solar film, as shown in Figure 3.

Figure 3: Solar film layer fixed on the top aluminum plate of the reflector surface

In the absorber receiver, an evacuated glass tube consisting of two layers of borosilicate glass was separated by a sealed gap, as shown in Figure 4. Two Teflon grips, which are highly heat and corrosion-resistant, were made at both ends to fix the glass tube on the collector as shown in Figure 5. Table 3 provides the physical properties of the PTC. The process of circulating the heat transfer fluid in the system included transferring water to the pump, adjusting its flow rate, and then connecting it to the inlet of the absorber tube. The absorber tube returns the water to the same tank as shown in Figure 6, forming a closed loop. The instruments measured the flow, temperature, wind speed, and sunlight intensity. In addition, aluminum metal fibers were prepared to be used as a porous medium inside the absorber tube to study its effect on the performance of the PTC as shown in Figure 7.

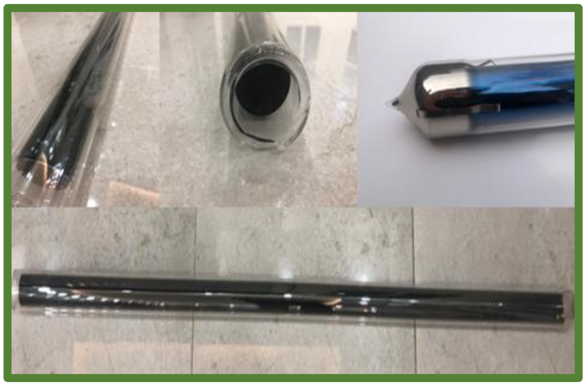

Figure 4: Evacuated glass absorber tube.

Figure 5: Stages of manufacturing a thermal Teflon grip for the ends of the absorbent tube.

Figure 6: Aluminum metallic medium

Figure 7. PTC system

Table 1 Dimensions of the PTC setup

Parameter	Symbol	Dimensions
reflector length	L	1.5 m
reflector width	W	1 m
reflector area	$Aref$	1.534 m^2
focal length	f	0.375
opening area	Aa	1.5 m2
The height of the arc of the parabola	hp	0.167 m
Edge angles	θR	67.40
the radius of the parabola arc edge	rr	0.54 m
is the arc length of the parabola	Sp	1.067 m
diameter of the evacuated absorption	dout	0.047 m
	din	0.034 m

5.2 Experimental Procedures

Location Procedure The experiment is on the roof of the building of the Department of Power Mechanical Technology Engineering at Kirkuk Engineering Technical College, located at longitude (44.34) and latitude (35.39). fixed the PTC direction towards the south. The movable base is raised to an angle of 31 in April and connected to four K-type thermocouples when (T_1) is the inlet to the receiver tube, (T_2) is the outlet of the receiver tube and (T_3-T_4) is on the absorber tube surface, connecting all of them to the thermometer.

Ensure that the water circulation system, consisting of connecting the pump to the water source and the accumulator through the flow control meter, is good. Without water leaking during the connections. First, the vacuum glass absorber tube was connected and the experiment began for four consecutive days to ensure the accuracy of the results according to the flow of water (0.2, 0.4, 0.6, and 0.8).

The duration of the experiment was from 9 a.m. to 2 p.m. Recorded the temperature, sun radiation intensity, and air velocity for every half hour when the flow rate of water was constant.

Data recording continues simultaneously with tracking the movement of the sun until two o'clock in the afternoon. After completing four experiments, we begin the second part, which is adding 352-gram aluminum porous inside the evacuated absorber tube, as shown in Figure 8. We repeat all the steps for four consecutive days. All data is recorded depending on the water flow (0.2, 0.4, 0.6, 0.8).

Figure 8. Evacuated tube filling Aluminum metallic medium

6. Uncertainty analysis

Uncertainty analysis in solar energy systems, especially parabolic trough solar collectors, is important because the errors caused by the researcher or the devices during experiments for various reasons affect the accuracy of the experimental study, which is why it is useful and necessary. In addition, it helps identify the factors that affect the system's efficiency, including environmental factors such as temperature, flow rate, solar radiation, and wind speed, which play a role in improving the performance of the system and its response to environmental conditions. This leads to enhancing the performance of the PTC [37].

The uncertainty of a calculated parameter gives the equation below [37].

$$\boldsymbol{WR}=[(\frac{\partial R}{\partial X_1}*\boldsymbol{W_1})^2+(\frac{\partial R}{\partial X_1}*\boldsymbol{W_2})^2+\ldots+(\frac{\partial R}{\partial X_1}*\boldsymbol{Wn})^2]^{½}hg \quad (4)$$

The (Uncertainty) ratio of the measuring devices was calculated using the (RSS) method (where the experimental error ratio is calculated according to the equation:

$$\boldsymbol{Ux} = \pm\, [\boldsymbol{Ust}^{\,2} + \boldsymbol{Px}^{\,2}]^{0.5} \quad (5)$$

The error rate in the measuring devices according to the device specifications is calculated from the following equation:

$$\mathbf{Ust}=\pm\, [(\mathbf{Resolution})^{2} + (\mathbf{Accurecy})^{2}] \quad (6)$$

To calculate the experimental error of the measured values at a 95% confidence limit and a degree of freedom (N-1)

$$\boldsymbol{px} = \boldsymbol{t}_{(N-1),95\%} \times \boldsymbol{\sigma}_{\bar{x}} \quad (7)$$

The law of propagation of uncertainty allows the estimate of how the uncertainties in individual measurements (input and output energies) affect the overall uncertainty in thermal efficiency by the equation provided:

$$\sigma_\eta = \eta\sqrt{\left(\frac{\sigma Q_{out}}{Q_{out}}\right)^2 + \left(\frac{\sigma Q_{in}}{Q_{in}}\right)^2} \quad (8)$$

Table 2. Relative error rate of measuring devices used in the tests.

Instruments	Accuracy	resolut	uncertainty
Temperature(Thermometer)	±0.2 %±0.1 C°	0.1 C°	0.109331 C°
Anemometer (wind velocity)	±3% ± 0.1	0.001MPS	0.252917 MPS
Anemometer (air temperature)	±1.0 C°	0.1 C°	0.152285 ℃
Flowmeter	0.50%	-	0.765142LPM
Solar intensity meter	10 W/m2	1 W/m2	1.267639 W/m2

7. Results and Discussion

In April, an Eight-day experimental test of the system was conducted through two cases of absorption tube operation, with and without a porous medium.) was conducted in Kirkuk, Iraq. The system's operating environment was examined, the effect of water flow rate on the temperature difference between the water entering and exiting the absorber tube was investigated, thermal energy was assessed, and the thermal efficiency of the solar collector with and without aluminum fiber was computed to gather the PTC test results. The final point is to compare solar radiation intensity and thermal efficiency with and without the porous aluminum fiber media.

In the second case of this study, to improve PTC performance and investigate the impact of a porous medium on the assembly, 352 grams of aluminum fiber were added to an evacuated glass tube and absorber. During the experiments, the temperatures entering and exiting the absorber tube, solar radiation intensity, wind speed, and air temperature were recorded every half hour throughout the experiment.

The tests conducted on the variable flow rate showed that a decrease in temperature difference occurs when the water flow rate is increased; in the first case, the temperature difference rate was (12.28, 9.7, 7.8, 6.6) C° for the flow rate of (0.2, 0.4, 0.6, 0.8) L/m, respectively. Because the heat transfer fluid travels faster and spends less time in the tube absorbing heat, there is less of a temperature differential. However, in the second instance, the results (24.08, 19.18, 14.9, 12.3) C° for flowrate (0.2, 0.4, 0.6, and 0.8) L/m were obtained, respectively, when aluminum metallic fibers were used.

Figures 5 through 8 illustrate the temperature differences over a day for the same flow rate with and without a porous medium.
Figure 9 shows the average temperature difference in variable flow rate (with and without porous medium).

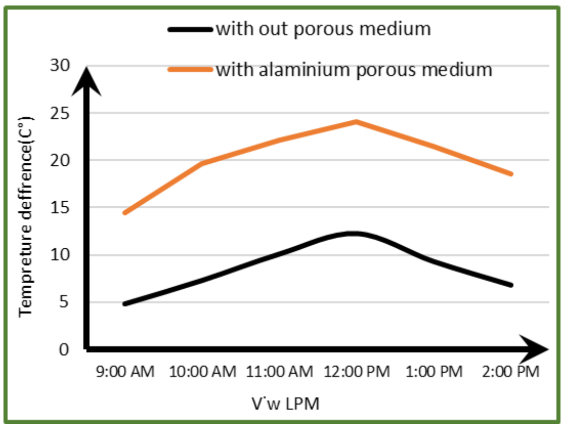

Figure 5. Temperature differences with and without porous medium (0.2L/m April 2024)

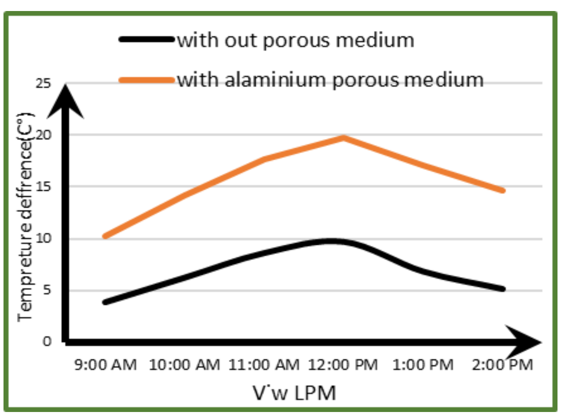

Figure 6. Temperature differences with and without porous medium (0.4 l/m April 2024)

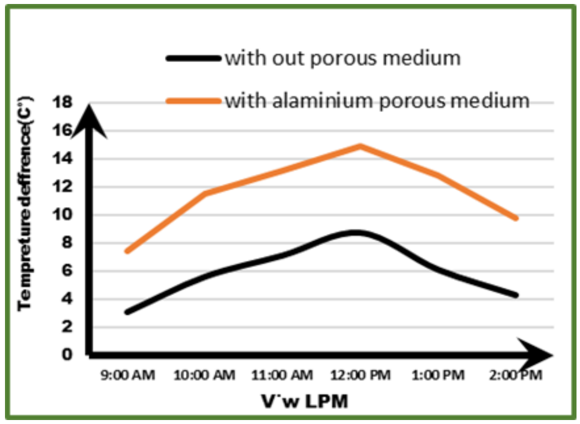

Figure 7. Temperature differences with and without porous medium (0.6 L/m April 2024).

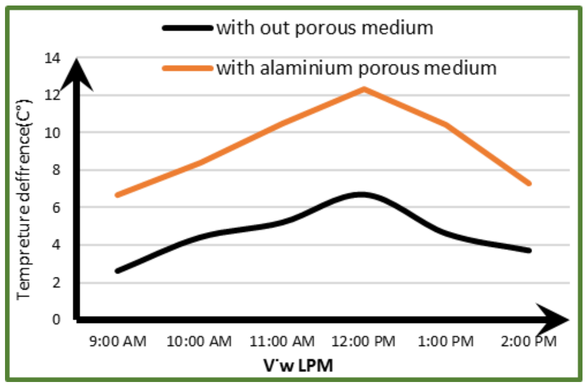

Figure 8. Temperature differences with and without porous medium (0.8 L/m April2024).

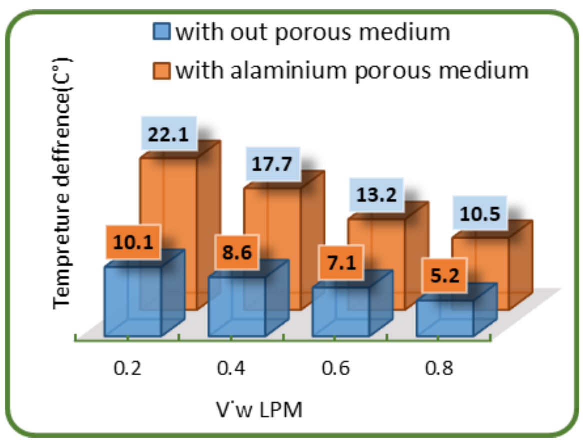

Figure 9. Average temperature differences in variable flowrate, (with and without porous medium)

1. The maximum temperature difference was concluded, which was (12.28 C°) when the flow rate was equal to (0.2 L/m) and the radiation intensity (1298.4 W/m²) in April 2024, but the lowest temperature difference (2.6 C°) in the flow rate (0.8 L/m) and radiation intensity (1210.7 W/m²) on the date of April 2024. In the second stage, when the porous medium inside the absorber tube the maximum temperature difference was (24.08C°) at the flow rate (0.2 L/m) with a radiation intensity of (1283.5 W/m²). Still, the minimum temperature difference was (6.7 C°) at the flow rate (0.8 L/m) and radiation intensity (1198.8 W/m). Figure 10 shows maximum and minimum temperature differences (with and without porous medium).

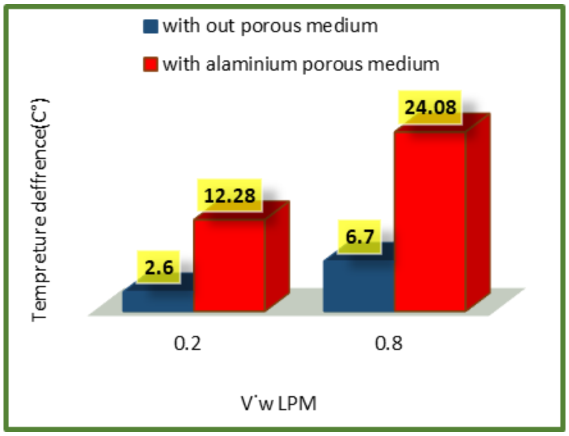

Figure 10. Maximum and minimum temperature differences (with and without porous medium).

2. The flow rate of the heat transfer fluid greatly affects the rate of thermal energy acquired practically, as the thermal energy acquired increases with the increase in the flow rate under the influence of the intensity of solar radiation, because breaking the sealing layers formed on the inner wall of the absorption tube leads to improving the heat transfer between the liquid and the inner wall of the absorption tube and increases the heat gain, and the difference is clear between increasing the water flow rate and increasing the acquired energy.

In the first case, i.e. without using porous media, and as a result of the data recorded through the experiments, the maximum rate of thermal energy acquired was (136.6, 269.4, 325.7, 366.7) KW.hr, within the flow rate (0.2, 0.4, 0.6, 0.8) liters/minute respectively, while in the second case, the maximum rate of thermal energy acquired was (318.3, 447.1, 617.7, 681.8) KW.hr, within the flow rate (0.2, 0.4, 0.6, 0.8) liters/minute respectively.

Figures 11 to 14 show the actual heat energy gained over the course of a day for varying flow rates (with and without porous media).

Figure 15 shows the average heat energy gained (with and without porous media), with the effect of increasing flow rate on the actual heat energy gained.

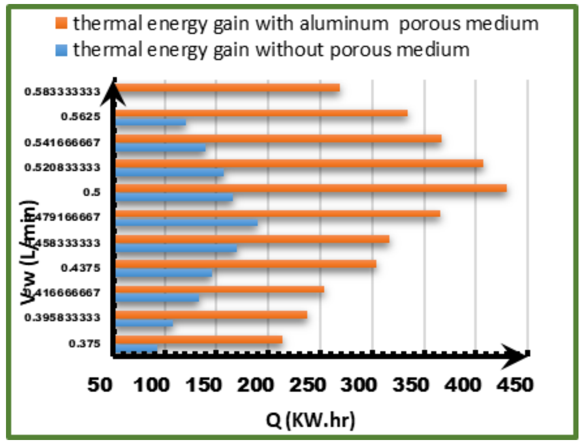

Figure 11. thermal energy gained with and without porous medium) at 0.2 LPM.

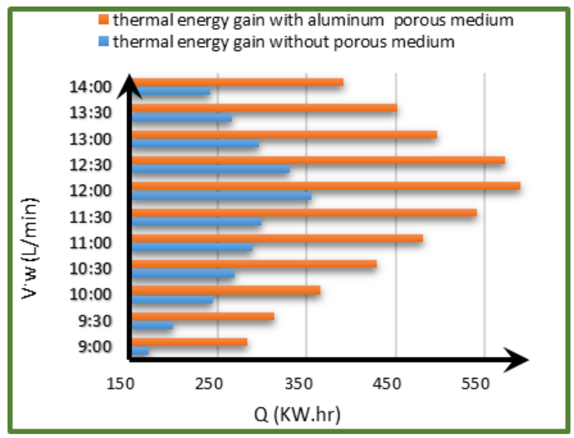

Figure 12. thermal energy gained with and without porous medium) at 0.4LPM

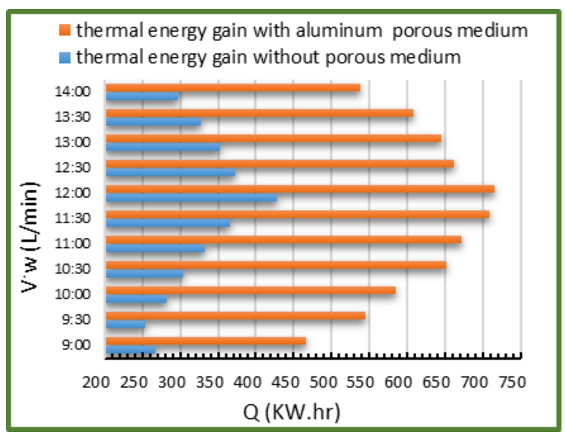

Figure 13. thermal energy gained with and without porous medium) at 0.6 LPM.

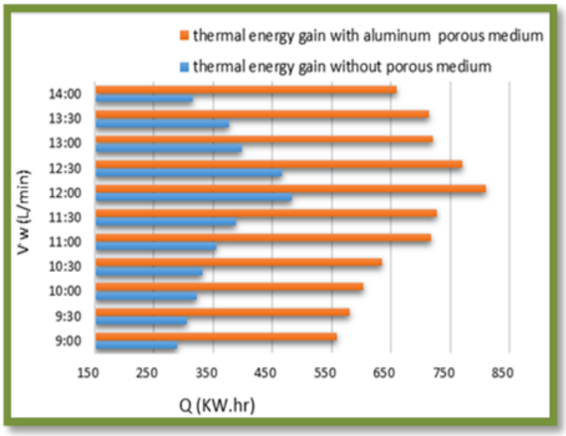

Figure 14. thermal energy gained with and without porous medium) at 0.8 LPM

In the first case without porous media, the maximum heat energy gained was 366.7(kw. hr) at the flow rate of (0.8) LPM, but the maximum heat energy gained in the second case was 681.8 kw. hr for the same flow rate, Due to the effect of (the aluminum porous medium). the minimum heat energy gained was 136.6 kW.hr at the flow rate of (0.2) LPM. Still, the minimum heat energy gained in the second case was 330.4 kW.hr for the same flow rate, as shown in Figure 15, shows the maximum and minimum heat energy gained at the variable flow rate (with and without porous media).

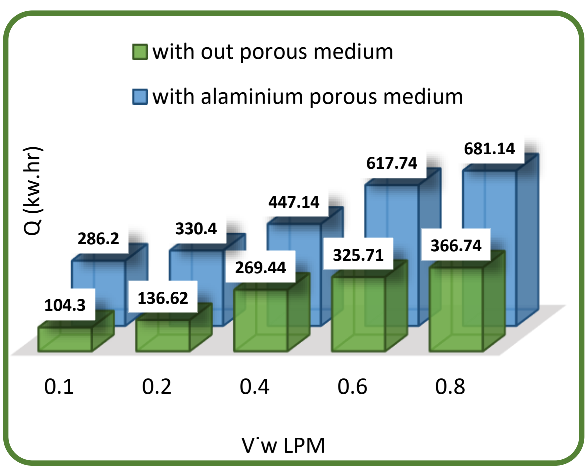

Figure 15. thermal energy and various flow rates with and without porous material.

3- We can see that the higher thermal energy gained corresponds to the higher efficiency of the collector. More specifically, the increase of HTF flow causes the efficiency of the PTC collector to increase because the better absorber promotes faster heat transfer within the system, reduces the formation of hot spots, better absorbs solar radiation, and reduces heat loss from heat transfer between the absorber tube and the surrounding environment. The highest efficiency was obtained in the case without using porous medium (13.0, 20.2, 24.6, 27.5) % in the flow rate (0.2, 0.4, 0.6, 0.8) LPM. in the case of using porous medium, the highest efficiency was obtained (23.2, 32.1, 39.9, 45.8) % in the flow rate (0.2, 0.4, 0.6, 0.8) LPM. These results show a clear improvement in the efficiency of the PTC because the porous medium causes better heat transfer. As a result, the efficiency of the PTC increases. In addition, Figures 16 and 17 show the effect of increasing the flow rate on the collector's efficiency (with and without porous medium).

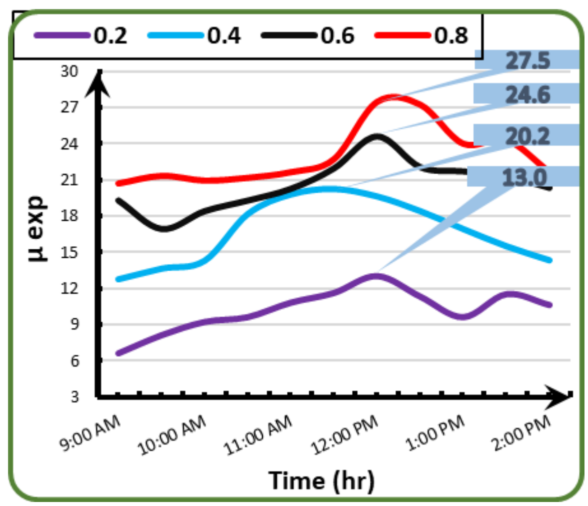

Figure 16: PTC efficiency in variable flow rate LPM without porous medium.

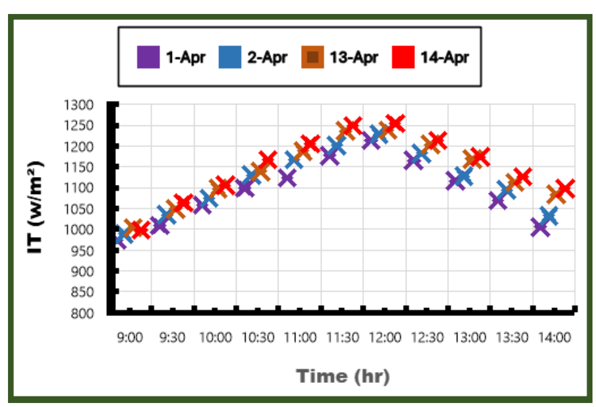

Figure 17 PTC efficiency in variable flow rate LPM without porous medium.

The average maximum efficiency was (42.29) %, at the flow rate (0.8) L/min, while the average maximum efficiency in the first case was (23.1) % at the same flow rate. Figure 18 shows the average maximum efficiency rate and the effect of the porous medium on PTC efficiency compared with the first case.

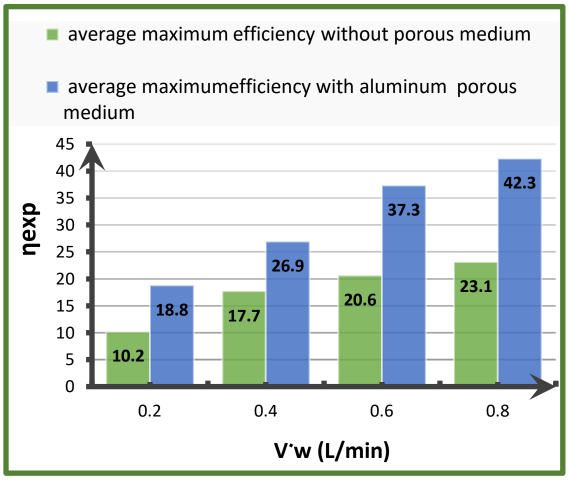

Figure 18. compare PTC efficiency with and without porous medium

4- The intensity of solar radiation is a major aspect that greatly affects the thermal efficiency of a solar collector. Figure 19 shows solar radiation during four days of April in Kirkuk/Iraq. It directly affects the temperature of the heat transfer fluid as it flows through the receiving pipe, as the exit temperature increases with the increase in solar radiation intensity.

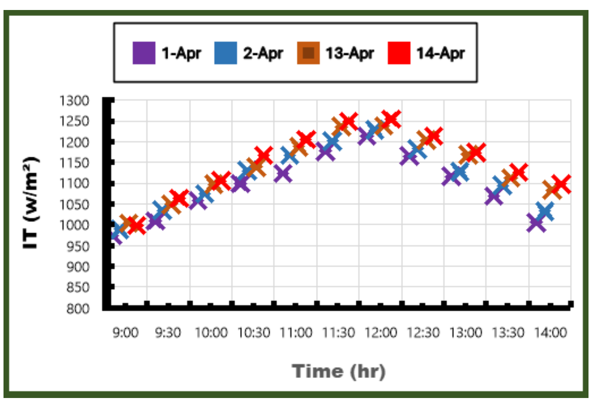

Figure 19 shows solar radiation during the day

8. Conclusions

The thermal efficiency reached a maximum of 27.51% without any material at a flow rate of 0.8 L/min, with a heat flux of 1202 W/m2. However, when porous media was included, the maximum efficiency increased to 45.76% at the same flow rate of 0.8 L/min, with a slightly higher heat flux of 1220 W/m2. The permeability and thermal conductivity of porous materials are important factors in determining the temperature gradient. The decreased porosity and increased thermal conductivity of porous media increased the output temperature. This is consistent with research on the use of aluminum as a porous medium to improve the performance of the system, where compared to solid materials, aluminum fibers are lightweight, making PTCs easy to handle [28]. Porous aluminum fibers provide a durable and long-lasting material solution that can withstand exposure to sunlight and moisture because they are naturally corrosion-resistant [29]. The addition of porous aluminum fibers increases the surface area. The surface of the receiving tube absorbs heat from concentrated sunlight [30]. The interconnected pores create paths for the flow of the working fluid. This allows better flow of fluid to the receiving tube and improves heat exchange between the fluid and the tube surface [31]. The high temperatures and porous aluminum fibers help to relieve thermal stress, which increases the heating efficiency of the working fluid flowing through the tube and thus increases the thermal efficiency of the collector in the PTC [32]. The results indicated that the system can be used to heat water in winter without the need for additional devices.

NOMENCLATURE

PTC	parabolic-trough-collector
ETC	evacuated-tube-collector
SP	solar power
SHS	solar heat system
EES	engineering equation system
SDD	solar during day
HTF	heat transfer fluid
CPS	collector solar power

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