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*Research article***Case study on spiral solar collector performance with lens****Marwa R. Mohammad<sup>1\*</sup>, Dhia A. Alazawi<sup>1</sup> and Abdulrahman Th. Mohammad<sup>2</sup>**<sup>1</sup> Mechanical Engineering Department, Engineering collage, Diyala University- Diyala –Iraq<sup>2</sup> Renewable Energy Department, Baqubah Technical Institute, Middle Technical University (MTU)-Baghdad-Iraq\* **Correspondence:** Email: mmohmerowa@gmail.com.

**Abstract:** The main objective of this study was to compare between two scenarios of spiral collector; the first one without lens and the other with lens. In the two scenarios, the spiral collector were fabricated from copper tube with 10 mm inner diameter, 15 m length and absorber area 0.5 m<sup>2</sup>. The lens was selected as acrylic flat lens with transmittance (80 to 90)% and focal distance is 1.3 m. Experiments were carried out at water mass flow rate 0.5 kg/min under the period between 1<sup>st</sup> to 31<sup>th</sup> of December over the ambient temperature range of 12 to 17 °C and hourly solar radiation range of 525 to 654 W/m<sup>2</sup>. The experimental results show that the maximum outlet-temperature, useful energy and efficiency was found to be about 19 °C, 109 W, 35% respectively in scenario of spiral collector without lens. While, in the scenario of spiral with lens was found to be about 21 °C, 178 W, 60% respectively. As compared between the two scenario, the lens was enhanced the efficiency of spiral collector by 25%.

**Keywords:** Flat plate collector (FPC); spiral collector; lens; efficiency

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**Nomenclatures:**  $A_c$ : Aperture area of the collector (m<sup>2</sup>);  $C_p$ : Specific heat of the water (J/Kg K);  $F_R$ : The collector heat removal factor;  $I$ : Solar radiation on the collector (W/m<sup>2</sup>);  $\dot{m}$ : Mass flow rate of the water (Kg/sec);  $Q_s$ : Solar heat rate (W);  $Q_u$ : Useful heat collector (W);  $T_{am}$ : Ambient temperature (°C);  $T_{in}$ : Inlet temperature (°C);  $T_{out}$ : Outlet temperature (°C);  $U_L$ : Overall heat transfer coefficient (W/m<sup>2</sup> °C)

Greek symbols: ( $\tau \alpha$ ): Cover-absorber property;  $\eta$ : Thermal efficiency (%)

## 1. Introduction

Solar thermal collectors have been recognized as promising devices for solar energy harvesting [1]. To improve the performance characteristics of solar thermal collectors, the researchers split into two groups; the first group deals with geometry of the collectors [2–4] while the second group deals with the effect absorbing properties of the working fluid using Nano fluids [5]. Yathin K. et al. [6] showed that the nano fluids and molten salt technology play an important role in increasing the solar thermal generation. As reported in Abd E. K. et al. [7] study, the performance of spiral and serpentine tube solar collector enhanced by using carbon Nanotube- nano fluids under natural flow method. The results of this study show that the outlet temperature of collector increased with maximum concentration of Nano fluids under a minimum flow rate during the peak intensity. Meibodi et al. [8] studied the impact of three concentrations of SiO<sub>2</sub>/EG-water nano fluid on the performance characteristics of flat plate collector. The results show that the collector efficiency increased dramatically due to the low thermal conductivity of SiO<sub>2</sub> nanoparticles. Mirzaei [9] experimentally showed that the collector efficiency increased by 55.1% under the effect of 4 L min<sup>-1</sup> flow rate from CUO Nano fluids compared to pure water. On the other side, many research have relied on the geometry and design to increase the efficiency of the thermal collector. Pavlović S. R. et al. [10] examined the optical and the thermal analysis of a parabolic dish concentrator with a spiral coil receiver. The optical analysis was proved that the ideal position of the absorber is at 2.1 m from the reflector in order to investigate the maximize of optical efficiency and to create a relatively uniform heat flux over the absorber. Verma S. K. [11] compared between single spiral shaped collector tube and conventional type flat plate solar collector in similar parameters design. The results showed that the thermal efficiency was enhancement by 21.94% compared to conventional flat plate collector design. On the other side, the exergy efficiency was enhanced by 6.73%. Sasa R. Pavlovic et al. [12] used a developed thermal model to compare between two cavity receivers for a solar dish concentrator (spiral and the conical cavities). The results show that the conical design leads to a 1.38% increase in the optical efficiency due to the increased intercept factor. The thermal efficiency enhancement with the use of conical design is found to be 5.63% at 100 °C and 40.45% at 200 °C. Ali Jabari Moghadam et al. [13] investigated the heat transfer performance of CuO/water nanofluids as a working fluid in a flat plate solar collector. The average diameter of CuO nanoparticles was about 40 nm. The mass flow rate of the fluids was varied within the range of 1–3 kg/min and the nanoparticles volume concentration was fixed at 0.4%. At a flow rate of 1 kg/min. The results found that the CuO-water nanofluid enhances the collector efficiency by about 21.8% in comparison with the base fluid. As reported in Wisam J. Khudhayer et al. [14] evaluate the heat transfer performance of a Flat Plate Solar collector with a spiral tube using CuO/water and TiO<sub>2</sub>/water Nano fluids constructive on the effect of the fluid type with a constant fluid flow rate 1.5 liters/min and constant nanoparticles 0.1% volume concentration of the nanofluids and the temperature difference between the inlet and outlet fluid streams and the FPSC thermal efficiency. The result shows that CuO/water nanofluid higher compared to TiO<sub>2</sub>/water nano fluid. The inlet-outlet temperature difference at 1.5 kg/min flow rate for water, CuO/water and TiO<sub>2</sub>/water nano fluids were 6.6 °C, 7.1 °C, and 7.9 °C, respectively. While the maximum efficiency was reported to be 55% for the CuO/water nanofluid compared to 54% and 50% for 0.1% by volume TiO<sub>2</sub>/water, respectively. M. Moravej et al. [15] study, experimental investigation of circular flat-panel collector performance with spiral pipes. The result showed that, the maximum efficiency of this collector is around 75.3%, with a maximum

temperature difference between the inlet and outlet of around 19 °C. On the other side, many studies were presented to enhance the thermal physical properties of nanofluids. Zetty Akhtar et al. [16] analyzed the thermal conductivity, viscosity and stability of titanium dioxide (TiO<sub>2</sub>)-multi-walled carbon nanotubes (MWCNTs) nanofluid in the presence of sodium dodecyl benzene sulfonate (SDBS) as a surfactant under different concentrations and ratios of the nanoparticle. According to the obtained results, zeta potential value for both nanofluid with different ratios range from -50 to -70 mV indicates excellent stability of the suspension. Thermal conductivity of nanofluid increase as nanofluid concentration and temperature increase and also shows enhancement compared to the base fluid. As reported in Ahmad Adlie Shamsuri and Rusli Daik [17] prepared the mechanical, crystallographical, morphological, and thermal properties of the nylon-6/liquid natural rubber/montmorillonite (nylon-6/LNR/MMT) nanocomposites through emulsion dispersion technique with contents of MMT from 2 to 10 wt.%. The results showed that the emulsion dispersion technique could prepare the nylon-6/LNR/MMT nanocomposites with improved mechanical and thermal properties. As reported in [18], the heat transfer performance of Aluminium Oxide (Al<sub>2</sub>O<sub>3</sub>) and Silicon Dioxide (SiO<sub>2</sub>) in water with low concentration value of 0.1%, 0.3% and 0.5% volume were adopted as cooling medium in PEMFC. The result shows that maximum improvement was at 2.14% improvement in Al<sub>2</sub>O<sub>3</sub> and 1.15% improvement in SiO<sub>2</sub> in term of heat transfer coefficient of 0.5% volume concentration as compared to water. In this study, flat plate collector with spiral geometry was designed and tested in two scenarios, the first scenario without lens and the second one with lens. A comparison between the two geometries was investigated to study the effect of lens on the improvement of collector performance.

## 2. Materials and measurements

### 2.1. Systems description

Solar heating system was fabricated in Mechanical Engineering Department-engineering collage of Diyala University-Iraq. The system fabrication includes two scenarios; the first one without lens and the second one with lens. For both scenarios, the system consists from spiral collector, storage tank, casing and fitting components. The spiral collector was select from copper tube with outer diameter 12.8 mm and inner diameter 10 mm. The total length of copper tube was 15 m and divided into 11 coils with inner and outer diameter about 0.2 m and 0.6 m respectively. Storage tank was used from plastic material with a capacity of 100 liters. The casing with dimensions (77 \*66) cm was manufactured from wood frame to contain the spiral solar collector and was installed above iron structure inclined in 30° with a horizontal surface. The frame is covered by 6 mm thickness glass. Totally, the aperture area of the collector is about 0.5 m<sup>2</sup>. In case of a system with a lens, the specification of the lens was selected as an acrylic flat lens with transmittance (80 to 90)%, lens color clear shape single-lens and the focal distance is 1.3 m as shown in Figure 1.

### 2.2. Measurements and instrumentations

Six DS18B20 waterproof sensors operates in a range of temperature -55 °C to 125 °C with an accuracy ±0.5 °C installed in six points to measure the temperature of ambient air temperature, inlet and outlet temperatures of water in the scenarios of without and with lens. Solar Power Meter, Type

CEM-Dt-1307 with an accuracy 5% used to measure the solar radiation. Arduino card type Mega based on the AT-mega 2560 was used to collect the sensors data. The specifications of Arduino can be summarized as: It has 54 digital input/output pins (of which 14 can be used as outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.



**Figure 1.** Solar system a) spiral without lens b) spiral with lens.

### 3. Mathematic model

The thermal efficiency of the solar collector is defined as the ratio of the useful heat energy output of the collector to the solar energy flux incident on the collector [19–21].

$$\eta = \frac{Q_u}{Q_S} \quad (1)$$

where:  $Q_u$  is the useful heat energy and  $Q_S$  is the solar heat rate.

The useful heat collector ( $Q_u$ ) can be calculated by the energy balance in the fluid volume [22,23].

$$Q_u = \dot{m} C_p (T_{out} - T_{in}) \quad (2)$$

where:  $\dot{m}$  is the mass flow rate,  $C_p$  is the specific heat and  $T_{out}$  &  $T_{in}$  are the outlet and inlet fluid temperatures respectively.

Solar heat rate represents as the product of the effective area of the collector and the beam radiation [11,24].

$$Q_S = A_c I \quad (3)$$

where:  $A_c$  is the area of collector and  $I$  is the beam radiation.

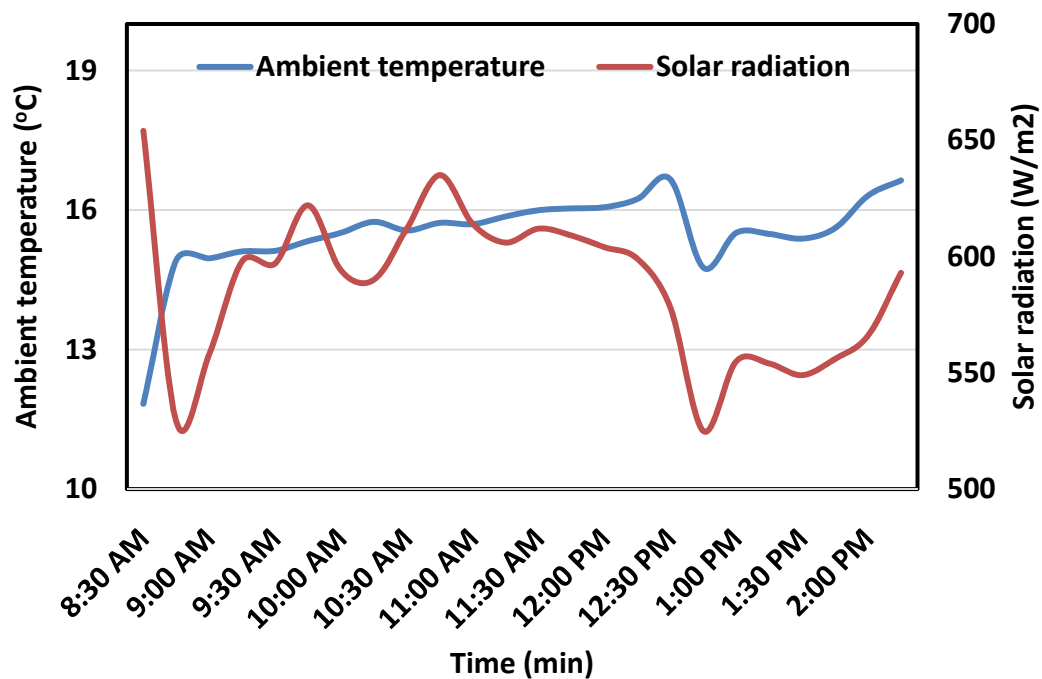
Therefore, the instantaneous efficiency of a flat plate collector can be defined as follows:

$$\eta = F_R \left[ (\tau\alpha) - U_L \frac{T_{in} - T_{amb}}{I} \right] \quad (4)$$

where:  $F_R$  is the collector heat removal factor,  $(\tau\alpha)$  is the cover-absorber property,  $U_L$  is the overall heat transfer coefficient and  $T_{amb}$  is the ambient temperature.

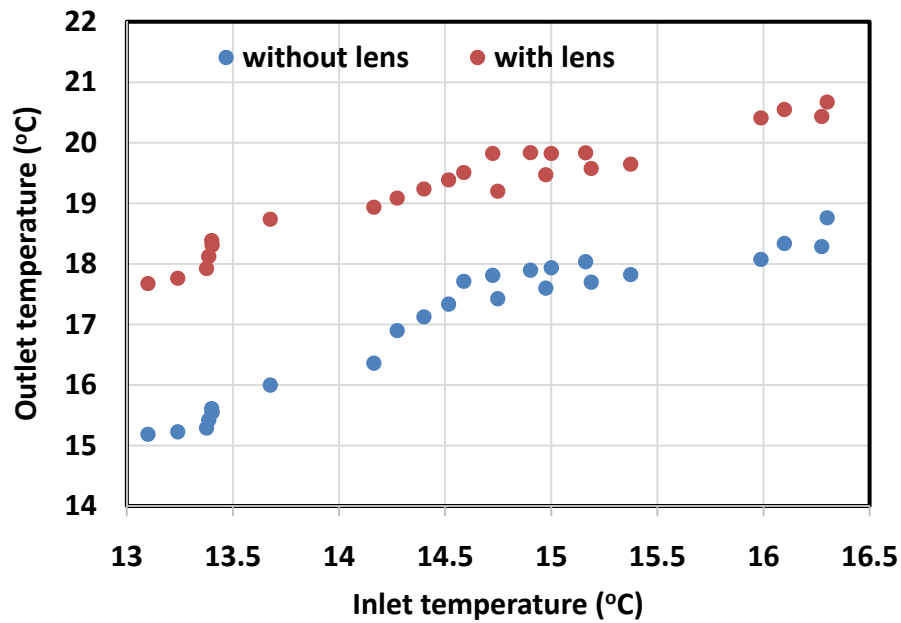
#### 4. Results and discussion

In this study, experimental results were investigated to analyze the performance of a spiral solar collector in two scenarios; the first one without lens and the second one with lens. Experiments were carried out at water mass flow rate 0.5 kg/min under the period between 1<sup>st</sup> to 31<sup>th</sup> of December and the data was plotted in average-hourly between 8:30 am and 2:30 pm. As shown in Figure 2, the ambient temperature varied between 12 and 17 °C and reached the maximum value about 17 °C at 12:30 PM. While, the maximum average value of solar radiation was recorded in the first hour of morning about 654 W/m<sup>2</sup>.



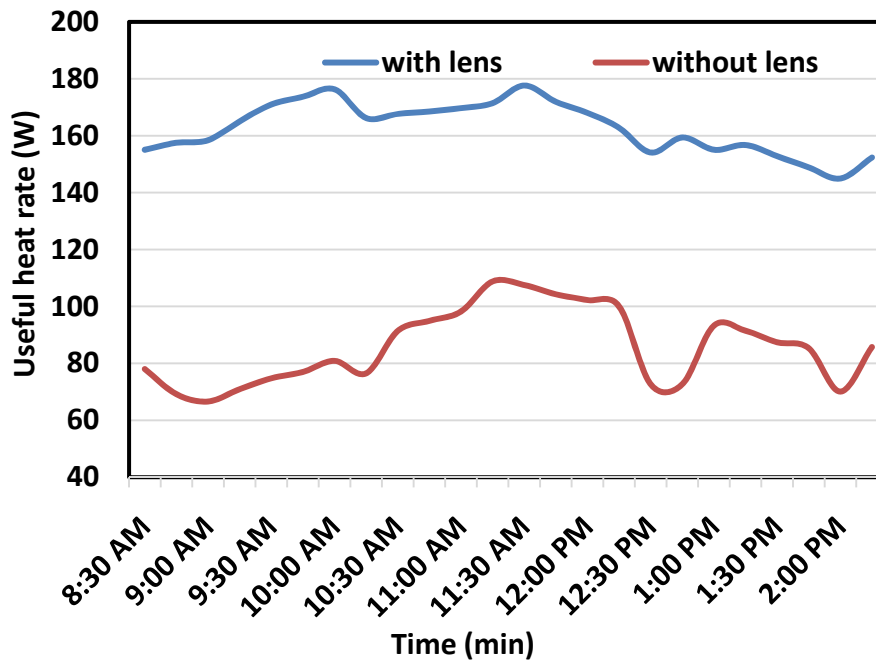
**Figure 2.** Variation of ambient temperature and solar radiation with time in December.

The outlet temperatures of water in two scenarios were represented in Figure 3. The figure shows that the maximum outlet collector temperature was 21 °C in scenario of with lens and 19 °C in scenario of without lens. In the other word, the lens can be investigate a maximum difference temperature between inlet and outlet of water about 5 °C as compared with 3 °C difference in the scenario of without lens.

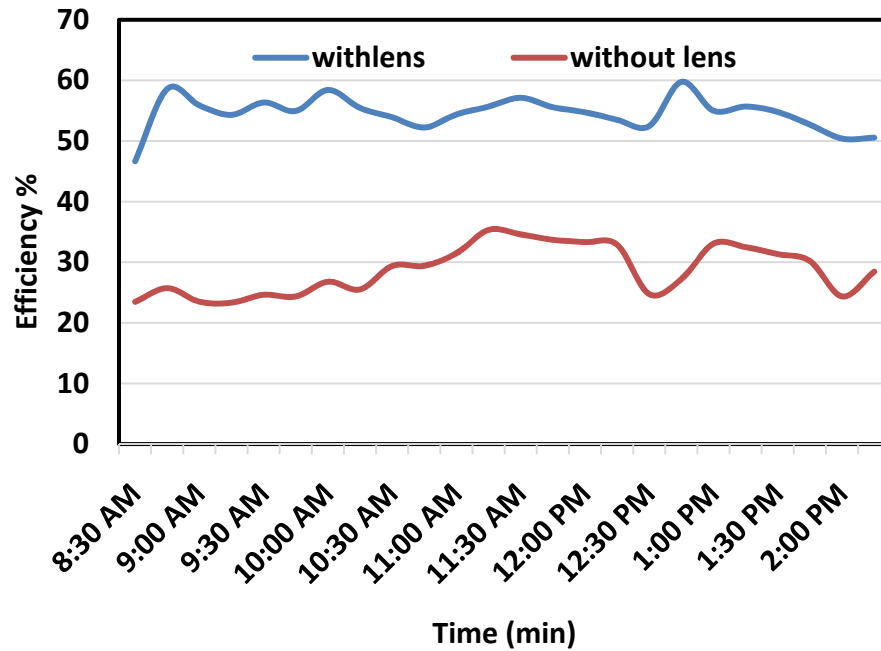


**Figure 3.** Outlet temperature according to the inlet temperature for two cases.

As compared between the useful energy of two scenarios in Figure 4, the maximum value of useful energy was recorded 178 W in scenario of spiral collector with lens by increased of 39% more than the scenario of spiral collector without lens. This increase of useful energy in using of lens is accompanied by an increase of thermal efficiency by 25% from the scenario of without lens as shown in Figure 5. It is clear that the maximum efficiency of spiral collector with lens was recorded 60% while, in case of spiral without lens was recorded 35%.

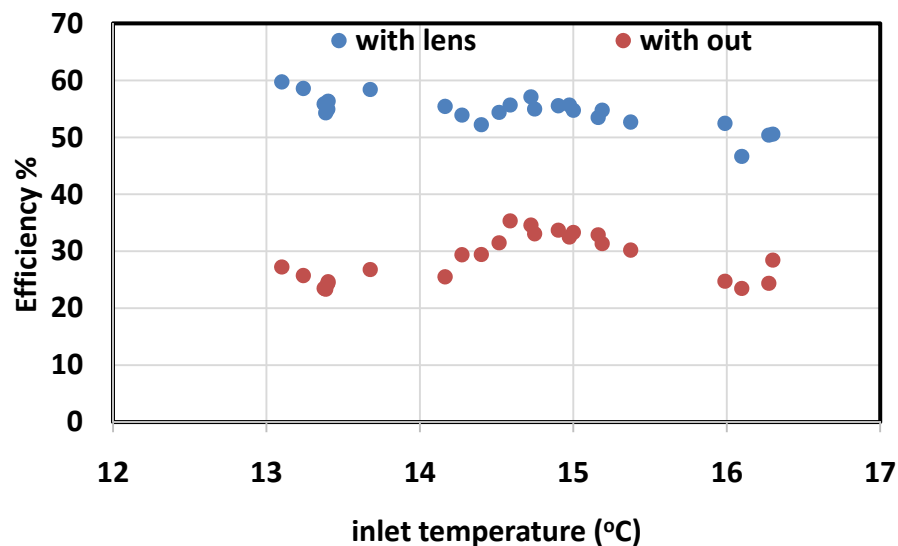


**Figure 4.** Useful heat rate in two cases.



**Figure 5.** Thermal efficiency of the spiral collector in two cases.

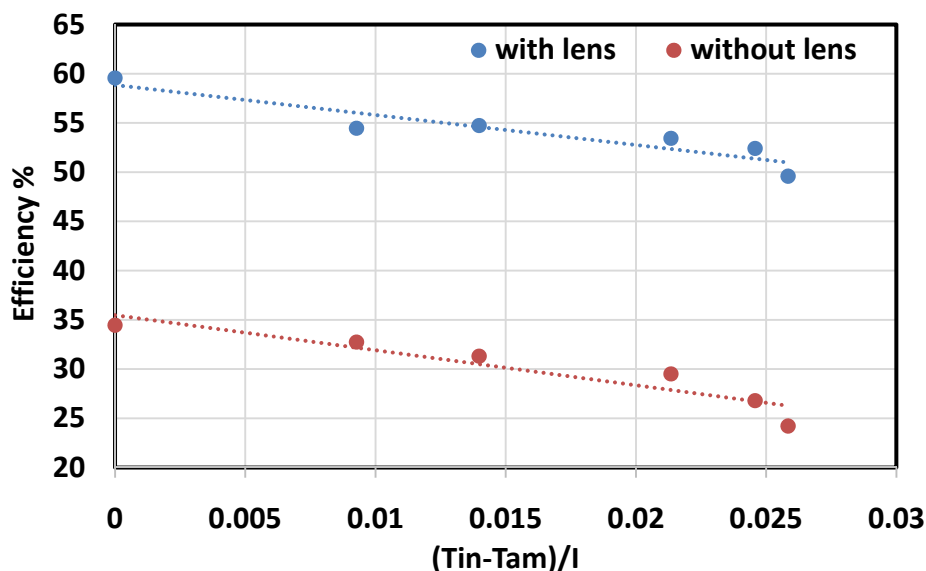
Figure 6, shows the thermal efficiency of the two scenarios of spiral collectors with fluid inlet temperature. The result clearly indicates that the spiral collector with lens leads to higher thermal efficiency from the spiral collector without lens for all the examined temperature levels. It is essential to state that thermal efficiency enhancement is more intense at a higher temperature which is more important for spiral flat plate collector.



**Figure 6.** variation of efficiency of a spiral collector with fluid inlet temperature.

As shown in Figure 7, the thermal efficiency is affected by the inlet temperature within the

range between (50 to 60)% in case of spiral collector with lens. In more description, the maximum value of thermal efficiency was recorded 60% when the examined inlet temperature equal to the ambient temperature at 12 °C. While, the thermal efficiency decreases by 16% when the inlet temperature increased to 17 °C. On the other hand, the thermal efficiency in case of spiral collector without lens changes between (24 to 35)% when the inlet temperature decrease from 17 °C to 12 °C.



**Figure 7.** Average plot efficiency with  $(T_{in}-T_{am})/I$  for the designed solar collector.

## 5. Comparative the performance of the collector

Few researchers have conducted experiments on the performance of spiral thermal collector in the literature with vary in design and geometry. The study of Verma S. K. et al. [11] was selected to compare the experimental results of our study with previous studies. The comparison was based on the three most important factors: area of collector, mass flow rate and solar radiation as shown in Table 1. According to the thermal efficiency of the collector, we noticed that the efficiency of our spiral collector was less than the efficiency of spiral collector in [11] but the effect of adding the lens leads to increase the efficiency gradually.

**Table 1.** Comparative of collector performance.

References	Area of collector (m <sup>2</sup> )	Mass flow rate (Kg/sec)	solar radiation (W/m <sup>2</sup> )	Thermal efficiency (%)
Verma S. K. et al. [11]	0.23	0.005–0.01	650	50
Present study without lens	0.5	0.0083	525–654	35
Present study with lens	0.5	0.0083	525–654	60

## 6. Conclusions

In this study, two scenarios of spiral collector (with and without lens) were experimentally investigated and tested with water mass flow rate 0.5 kg/min under the period between 1<sup>st</sup> to 31<sup>th</sup> of



December. The results show that the maximum outlet temperature increased up to 21 °C in scenario of spiral collector with lens while 19 °C in scenario of without lens. On the other side, the useful energy and thermal efficiency of the spiral collector with lens enhanced by 69 W and 25% respectively as compared with spiral collector without lens.

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## Conflict of interest

All authors appear no conflicts of interest.

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