The efficiency of steam production by the Parabolic Trough Collector PTC with the use of nanofluids in the region of Ouargla

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Abstract. Concentrated solar power plants (CSP) contribute to global production (at present) with a capacity of 400 MW, and by 2020 they will reach approximately 20 GW, then nearly 800 GW by 2050. This will prevent the emission of 32 million tons of CO2 annually in 2020, and rise to 1.2 billion tons in 2050, according to the International Greenpeace “Solar Thermal Electricity” 2016 report.

Among all the concentrated solar power (CSP) technology available to date, Parabolic Trough Collector (PTC) is the most promising, cost-effective, and efficient solution to generating electrical power, as PTC plants contribute in terms of global production capacity by 73.58% of the overall capacity of concentrated solar power plants (CSP).

PTC stations in the production of electricity depend on the generation of hot and pressurized steam that rotates the turbines and to increase the effectiveness of PTC in the production of steam, we use in this study nanofluids by adding copper nanomaterials in different proportions to improve the Thermal efficiency of PTC. We also studied the effect of the width of the PTC slot on the fluid temperature. And from it on the amount of steam produced.

The results of the study showed that the Thermal efficiency increases with the increase in the ratio of copper nanomaterials in the water, as the temperature of outlet water reaches 98°C, for the ratio of nanomaterials, 20%, in order to water flow 0.01 Kg/s and display the aperture 3.5 m.

Keywords: Parabolic Trough Collector, nanofluid, Thermal efficiency, steam.

1. Introduction

With the excessive doubling of global energy demand since after the industrial revolution and the consequent pollution of fossil fuel combustion and climate change, which leads to threatening the ecological balance of the environment on one hand and the depletion of the world's reserves of fossil fuels on the other hand, the world is in a race towards Exploitation and development of renewable energy sources (solar radiation, wind and biomass, Earth's gravity, tides and the heat of the Earth's interior) which are available and environmentally friendly.

The sun is one of the most important energy sources, as the energy flux density emitted from it is 63 MW/m² in all directions, while the Earth receives from it 1.7 1014 KW, and the energy flux density on the surface of the earth is within the limits of 1KW/m² [2,1].

The concentrated solar plant (CSP) technology is reasonably cost-effective and efficient. Of all the solar concentrated power (CSP) technologies available to date, the Parabolic Drum accumulators (PTC) are the most promising and cost-effective solution for generating electricity [3]. PTC plants contribute in
terms of global production capacity with 73.58% of the capacity of concentrated solar power plants (CSP) in general [4].

Choi was the first to use the term nanofluids since 1995 when he suggested the possibility of multiplying the heat transfer coefficients by convection using these fluids. In addition to researchers in Japan and Germany publishing articles related to similar fluids [5], Heris et al have experimented with Al2O3 and CuO nanoparticles suspended in water. They found that heat transfer could increase by about 40% while improving thermal conductivity did not exceed 15% [6].

Otani car et al. In 2010 studied the experimentally and numerically effect of various nanofluids on the performance of small-scale direct absorption solar collectors. Their results showed that suspending a slight amount (<0.5%) of the nanoparticles significantly improves the efficiency. However, for a volume fraction above 0.5%, the efficiency remains constant and even begins to decrease as the fraction size increases. They also found that the efficiency increases with decreasing the size of the nanoparticles [7].

In this study, nanofluids are used by adding copper nanomaterials in different proportions to improve the thermal yield of PTC. We also studied the effect of the width of the PTC opening on the fluid temperature and from it on the amount of steam produced that can be exploited in various industrial and home applications.

2. Theoretical study

In order to know the effectiveness of vapor production by the PTC parabolic center using nanofluids in different proportions and after calculating and determining the direct solar radiation. As well as the properties of the nanofluid, where the physical properties of the nanofluids can be expressed in terms of the physical properties of the base solution and the nanomaterials added to it according to the following relationships: [8].

The density of the nanofluid is written as follows:

$$\rho_{nf} = \rho_{bf} \cdot (1 - \phi) + \rho_{np} \cdot \phi_f$$  \hspace{1cm} (01)

The heat capacity of nanofluids is written as follows:

$$C_{p,nf} = \frac{\rho_{bf} \cdot (1 - \phi)}{\rho_{nf}} \cdot C_{p,bf} + \frac{\rho_{np} \phi}{\rho_{nf}} \cdot C_{np}$$  \hspace{1cm} (02)

The conductivity of a nanofluid can be expressed as:

$$K_{nf} = K_{bf} \frac{K_{np} + 2K_{bf} + 2(K_{np} - K_{bf})\phi}{K_{np} + 2K_{bf} + (K_{np} - K_{bf})\phi}$$  \hspace{1cm} (03)

Nanofluid viscosity is written as follows:

$$\mu_{nf} = \mu_{bf} (1 + 2.5\phi + 6.2\phi^2)$$  \hspace{1cm} (04)

3. PTC model thermal equilibrium

Thermal equilibrium equations for all surfaces of the components of the PTC, across a cross-section of the system, based on the first law of thermodynamics.

For the fluid “f”:

$$m_f \cdot C_{p,f} \frac{dT_f}{dt} = h_{conv} (T_f - T_{r}) A_{int}$$  \hspace{1cm} (05)

For the absorbent tube “r”:
\[ \rho_r A_r C_p \frac{dT_r}{dt} = I C_g \alpha_r \rho \pi D e_{ext} + \left( h_{conv} (r-e) + h_{rad} (r-e) \right) (T_e - T_r) \pi D e_{ext} + h_{conv} (r-f) \left( T_f - T_r \right) \pi D e_{int} \]  

(06)

For the glass envelope "e":

\[ \rho_e A_e C_{pe} \frac{dT_e}{dt} = I C_g \alpha_e \rho \pi D e_{ext} + \left( h_{conv} (e-r) + h_{rad} (e-r) \right) (T_e - T_r) \pi D e_{ext} + \left[ h_{conv} (e-amb) (T_{amb} - T_e) + h_{rad} (e-sky) (T_{sky} - T_e) \right] \pi D e_{ext} \]  

(07)

4. Results and Discussion

4.1. Characteristics of the study area and its day

The region of Ouargla is located at longitude \( \lambda = 5.24^\circ \), latitude \( \varphi = 31.57^\circ \), and \( H = 141 \) m above sea level. This excellent location makes it a good place to exploit and value the enormous solar energy, in several fields: electrical using solar cells, and thermal directing and focusing on solar collectors such as Fresnel lens and parabolic collector used in our study. In this region, the solar radiation flux reaches 2650 Kwh / an / m\(^2\), with about 3500 hours of insolation per year [9].

In our study, we chose the coldest day of the year, which we find out by calculating the air temperature or The ambient during the day, and at every moment of solar time, using the following relationship [10]:

\[ T_{amb} = \left( \frac{T_{max} + T_{min}}{2} \right) \sin \left( \frac{t - 8}{12} \right) + 1 \]  

(08)

By measuring the daily temperatures at the meteorological stations located in the region of Ouargla over a period of ten years (1996-2006), and after calculating the monthly average of the highest and lowest temperatures, it was found that January is the coldest (5.1-18.6 °C) [11].

It was also found by calculation and through the previous relationship that the lowest temperature in this region is on the twentieth day of this month, as \( T_{amb} \) is estimated = 19.89 °C, which appears after one o'clock in the afternoon by about 52 minutes and 12 seconds, which is evident in figure (1) below. Which shows the evolution of this temperature with solar time.

![Figure 1](image-url)

Figure 1. presents the change in the ambient temperature on the 20th of January in the Ouargla region with the change of solar time.

It can also be calculated by obtaining the change in the intensity of direct solar radiation with the solar time on this day, represented in the following figure (2):
Fig. 2. represents the change in the intensity of direct solar radiation theoretically calculated on the 20th of January in Ouargla region with the change of solar time.

From the figure, it is noticed that there is an increase in the intensity of the solar radiation until midday and 37 minutes and 8 seconds, where it reaches its maximum value estimated at about 740\,w/m², and then retracts until it ceases to exist at sunset, as the duration of insolation lasted nine hours and a quarter.

4.2. Study of the fluid outlet temperature

In this study, the parabolic collector supposed to be used as a length of L=5 m and a width that varies between 3 to 3.5 m, passing the value of 3.25 m, and with a nanofluid formed from nanoparticles of copper metal placed in water, the ratio of which changes from zero to up to 20 \%, Also by 10\%, with a constant flow through the collector tube of 0.01kg/s.

Through Figures (3 and 4), we notice:

The temperature of the fluid outlet increased with time in a linearly, starting from ten in the morning until one midday until it stabilized at a maximum value before sunset, until it stabilized at a maximum value before sunset, as this temperature exceeds the ambient temperature twice as low as possible (see table). This table contains the values of the maximum fluid outlet temperature and the time of its emergence for each collector, along with the change of the ratio of nanoparticles in the water.

Fig. 3. shows the change in the outlet temperature of the water (the nanofluid ratio is null) with the change of the center width and the change of the solar time.
Through both Figures (3) and Table (1), it is clear that the outlet temperature of the fluid increases with the increase in the width of the collector, starting from ten in the morning. As for Fig (4) and Table (1) also, the increase in the outlet temperature of the fluid can be clearly seen with the increase in the presence of nanoparticles in the water, starting from nine in the morning. The highest temperature is reached in the case of the collector with a width of 3.5 m and for the fluid of the particle percentage present in one hundred to 20%.

![Figure 4](image)

**Figure 4.** shows the change in the outlet temperature of a nanofluid with a change in the presence of the copper nanoparticles and the solar time.

| PTC dimension | Proportion (%) | Temperature (Time) | T stored fluid |
|---------------|----------------|--------------------|----------------|
| 5 m . 3 m     | 0              | 55.19 °C (16.63 h) | 36.08 °C       |
|               | 10             | 58.21 °C (16.63 h) | 37.83 °C       |
|               | 20             | 61.11 °C (16.63 h) | 39.53 °C       |
| 5 m . 3.25 m  | 0              | 70.35 °C (16.88 h) | 43.68 °C       |
|               | 10             | 74.30 °C (16.88 h) | 46.06 °C       |
|               | 20             | 78.01 °C (16.88 h) | 48.34 °C       |
| 5 m . 3.5 m   | 0              | 80.11 °C (16.88 h) | 48.44 °C       |
|               | 10             | 84.60 °C (16.88 h) | 51.22 °C       |
|               | 20             | 88.73 °C (16.88 h) | 53.87 °C       |

**Table 1.** presents the maximum outlet temperatures of the fluid, the time of its emergence, and the temperature stored in the fluid from each collector, with the change in the proportion of nanoparticles in the water.

#### 4.3. Study the temperature of the stored fluid
Through Figure (5), it can be observed that the temperature of the copper nanofluid is changed by 20% after leaving the collector with a width of 3.5 m, on the basis that this storage is in a thermally insulated tank. As it appears that the temperature change here is similar to the change in the fluid outlet.
temperature in general, as it reaches 53.87 °C at sunset, which is twice the highest temperature of the ambient, with a stored value in the mass of fluid estimated at 342 kg. This is a mass suitable for domestic use with a limit of water Despite its weakness.

![Temperature change of stored nanofluid](image)

**Figure 5.** shows the temperature change of the stored nanofluid with the change in solar time.

In Table 1, the values of the temperature of the stored fluid are recorded for the various cases in which the study was conducted, and the increase in the temperature of the stored fluid is confirmed by an increase in both the width of the collector and the percentage of nanoparticles in the water.

5. **Conclusion**

This work focused on changing the width of the 5 m long PTC collector and the ratio of copper nanoparticles placed in 0.01 kg/s water flow, leading to the following conclusion:

1- The two degrees of fluid outlet temperature and the temperature stored in it increase with the increase in the width and the ratio together, as the two increases are the same (figure).

2- The fluid outlet temperature can be doubled from the ambient temperature to more than four times, while the temperature stored in it can be doubled twice.

3- The amount of heat storing material is small, but it can be considered sufficient for personal use within the small dimensions of the collector.

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