EFFECT OF THE DESIGN AND ENVIRONMENT PARAMETERS ON THE THERMAL EFFICIENCY AND HEAT LOSSES OF A PARABOLIC TROUGH SOLAR COLLECTOR USING NANOFLUID TECHNOLOGY

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ABSTRACT

In this paper, a mathematical model is developed to study the performance of a parabolic trough collector (PTC). The proposed model consists of three parts. The first part is a solar radiation model that used to estimate the amount of solar radiation incident upon Earth by using equations and relationships between the sun and the Earth. The second part is the optical model; This part has the ability to determine the optical efficiency of PTC throughout the daytime. The last part is the thermal model. The aim of this part is to estimate the amount of energy collected by different types of fluids and capable to calculate the heat losses, thermal efficiency and the outlet temperature of fluid. All heat balance equations and heat transfer mechanisms: conduction, convection, and radiation, have been incorporated. The proposed model is implemented in MATLAB. A new nanofluids like Water+PEO+1%CNT, PEO+1%CNT and PEO+0.2%CUO were tested and were compared with conventional water and molten salt during the winter and the summer to the city of Basra and good results were obtained in improving the performance of the solar collector. The results explained both the design and environmental parameters that effect on the performance of PTC. Percentage of improvement in the thermal efficiency at the summer when using nanofluids (Water+PEO+1%CNT, PEO+1%CNT and PEO+0.2%CUO) Nano fluids are (19.68%, 17.47% and 15.1%) respectively compared to the water and (10.98%, 8.93% and 6.7%) respectively compared to the molten salt, as well as the percentage decreases in the heat losses by using the Nano fluids through the vacuum space between the receiver tube and the glass envelope compared with water (86 %, 76 % and 66 %) and molten salt (79.15 %, 64.34 % and 48.47 %). As final a Water+PEO+1%CNT nanofluid gives the best performance

Keywords: parabolic trough collector, heat losses, nanofluids, length of heat collector element, polyethylene oxide
### Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Area</td>
<td>m²</td>
</tr>
<tr>
<td>Cp</td>
<td>Specific heat at constant pressure</td>
<td>J/(kg. K)</td>
</tr>
<tr>
<td>d</td>
<td>Diameter</td>
<td>m</td>
</tr>
<tr>
<td>Ds</td>
<td>Daylight savings time</td>
<td>hr</td>
</tr>
<tr>
<td>EOT</td>
<td>Equation of time</td>
<td>hr</td>
</tr>
<tr>
<td>fr</td>
<td>View factor</td>
<td>****</td>
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<tr>
<td>H</td>
<td>Heat transfer coefficient</td>
<td>W/m²K</td>
</tr>
<tr>
<td>h</td>
<td>Target height</td>
<td>m</td>
</tr>
<tr>
<td>k</td>
<td>Conductivity</td>
<td>W/m.K</td>
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<tr>
<td>L</td>
<td>Aperture height</td>
<td>m</td>
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<tr>
<td>LC</td>
<td>Longitude correction</td>
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<tr>
<td>LCT</td>
<td>Local clock time</td>
<td>hr</td>
</tr>
<tr>
<td>m</td>
<td>Mass flow rate</td>
<td>kg/s</td>
</tr>
<tr>
<td>N</td>
<td>Day number</td>
<td></td>
</tr>
<tr>
<td>pr</td>
<td>Prandtl number</td>
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<td>Q</td>
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<td>R</td>
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<td>Re</td>
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<tr>
<td>T</td>
<td>Temperature</td>
<td>°C</td>
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<tr>
<td>ts</td>
<td>Solar time</td>
<td>hr</td>
</tr>
<tr>
<td>FL</td>
<td>Volumetric flow rate</td>
<td>GPM</td>
</tr>
<tr>
<td>Fr</td>
<td>Heat removal factor</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>Interaction coefficient</td>
<td>m/s</td>
</tr>
<tr>
<td>V</td>
<td>Velocity</td>
<td>m/s</td>
</tr>
<tr>
<td>Nu</td>
<td>Nusselt number</td>
<td></td>
</tr>
<tr>
<td>Ts</td>
<td>Sky temperature</td>
<td>°C</td>
</tr>
<tr>
<td>Ta</td>
<td>Ambient temperature</td>
<td>°C</td>
</tr>
<tr>
<td>THTF</td>
<td>Temperature of heat transfer fluid</td>
<td>°C</td>
</tr>
<tr>
<td>Tm</td>
<td>Temperature at the inlet of PTSC</td>
<td>°C</td>
</tr>
<tr>
<td>Tpi</td>
<td>Temperature of inner absorber tube</td>
<td>°C</td>
</tr>
</tbody>
</table>

### Greek symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>η</td>
<td>Efficiency</td>
<td></td>
</tr>
<tr>
<td>ε</td>
<td>Emissivity</td>
<td></td>
</tr>
<tr>
<td>σ</td>
<td>Stefan–Boltzmann constant</td>
<td>W/m²K</td>
</tr>
<tr>
<td>μ</td>
<td>Dynamic viscosity</td>
<td>N.S/m²</td>
</tr>
<tr>
<td>ρ</td>
<td>Density</td>
<td>kg/m³</td>
</tr>
<tr>
<td>δ</td>
<td>Declination angle</td>
<td>deg</td>
</tr>
<tr>
<td>ω</td>
<td>Hour angle</td>
<td>deg</td>
</tr>
<tr>
<td>φ</td>
<td>Latitude angle</td>
<td>deg</td>
</tr>
<tr>
<td>α</td>
<td>Sun altitude angle</td>
<td>deg</td>
</tr>
<tr>
<td>A'</td>
<td>Sun azimuth angle</td>
<td>deg</td>
</tr>
<tr>
<td>θ</td>
<td>Incidence angle</td>
<td>deg</td>
</tr>
</tbody>
</table>

### List of Abbreviations

- CNT: Carbon nanotube
- CUO: Copper Oxide
- HTF: Heat Transfer Fluid
- PEO: Poly ethylene oxide
- PTC: Parabolic Trough Collector
1. INTRODUCTION

In terms of the impact of fossil fuels on the environment, the burning of fossil fuels and green gases such as carbon dioxide (CO₂) will cause global warming and the outer environment. Environmental and economic impacts have made the world a renewable energy source to provide environmentally friendly energy and thus reduce reliance on fossil fuels as well as reduce economic and environmental issues [1]. The solar collector is one of those thermal technologies that rely on solar energy sources. An overview of the relevant available literature. Heris et al (2006) [2] Experimental Investigation to improve the performance of PTC by nanofluid technology through add nanoparticles (Al₂O₃ and CuO) in water as base fluid in different concentrations. The results of experimental show that for both nanofluid, coefficient of heat transfer enhances through increasing concentrations of nanoparticles as well as. But Al₂O₃ / water nanofluid show more enhancement compared with CuO/water nanofluid. Concluded that transfer of heat improvement by nanofluid depends on several factors involving increase of thermal conductivity, nanoparticles chaotic movements, fluctuations and interactions. Experimental data and model predictions indicated that there is a good arrangement with an average error of 5 % and maximum error of 14% using water as working fluid in the range of (25-75 C). Yousefi et al (2012) [5] studied the effect of Al₂O₃ nanoparticles addition to the water for a PTCS with different concentration rates to enhance performance of PTC. Observed a 28.3% improvement in the collector’s efficiency by addition of (0.2 wt%) nanoparticles in comparison to pure water. De Risi et al (2013) [6] studied the improvement of solar system performance by mixing nanoparticles (0.25%CUO and 0.05 Ni) with water also studied the effect of volumetric flow, solar radiation and nanoparticle volume concentration on the thermal efficiency at used mixing fluid. Concluded that efficiency reaches its maximum value of 62.5% Nanofluid has improved performance compared with conventional fluids such as oil and molten salt.

Islam et al 2015[7] Studied simulation and design of the (PTC) to enhance the thermal efficiency of the (PTC) through the effect of the parameters such as, collector aperture area, heat removal factor and mass flow rate on the thermal efficiency of PTC by using three fluids (nitrogen, ammonia and carbon dioxide) were used as a working fluid and with a different mass flow rate (0.0362 kg/s, 0.0192 kg/s, 0.0491 kg/s) respectively. Concluded that the mass flow rate significantly affected the efficiency of the PTC. The final result was found to be high efficiency when using carbon dioxide (67.22%) comparable with ammonia (66.81%) and nitrogen (67.05%). Ghasemi et al (2016) [8] Studied the enhancement of the performance of the parabolic trough solar collector by utilization of CuO and Al₂O₃ nanoparticles dispersed in water for parabolic trough solar collector. Proved enhancement in the coefficient of heat transfer close to 28% for Cuo and to 35% for Al₂O₃. Conclude when using Al₂O₃, the coefficient of heat transfer enhancement better from used CuO. Mirza Abdullah (2017) [9] used two types nanofluids include (Al₂O₃/H₂O and Fe₂O₃/H₂O) as a working fluid with different concentration rates (0.20%, 0.25% and 0.30% by weight at 1.0, 1.5 and 2.0 L/min flow rates) to improve the performance of the solar collector. Conclude the maximum efficiencies achieved with Al₂O₃ and Fe₂O₃ nanofluids at 2 L/min are 13% and 11 % higher respectively compared to water under same operating conditions. Tagle Salazar et al (2018) [10] studied the theoretical and experimental of the heat transfer model for thermal performance analysis of a parabolic trough solar collectors using nanofluids (Al₂O₃/water nanofluid with 1% of volume concentration). The effect of the intensity of solar radiation on this efficiency was studied by increasing the intensity of solar radiation. The thermal efficiency increases until it reaches its maximum value (61.1%) when the value of solar radiation (905.3 W/m²). Mwesigye et al (2018) [11] investigated of the thermal performance of the parabolic trough solar collector in
addition single-walled carbon nanotubes (SWCNTs) to the working fluid (Therminol®VP-1) to increase the thermal conductivity of the fluid. It was concluded from this study that the addition of (SWCNTs) to (Therminol®VP-1) this improved the heat transfer, which in turn led to improved thermal efficiency by 4.4%. The table 1.1 shows the heat transfer fluids used by former researchers in the PTC field.

Table 1 Heat transfer fluids used by former researchers in the PTC field.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Heat transfer fluids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jaramillo et al [12]</td>
<td>Water</td>
</tr>
<tr>
<td>Bellos et al [13]</td>
<td>Thermal oil /pressurized water</td>
</tr>
<tr>
<td>Kaloudis et al [15]</td>
<td>Syltherm 800/Al2O3 nanofluid</td>
</tr>
<tr>
<td>Mosleh et al [16]</td>
<td>Ethanol</td>
</tr>
<tr>
<td>Wang et al [17]</td>
<td>Molten salt</td>
</tr>
<tr>
<td>TagleeSalazar et al [10]</td>
<td>Al2O3/water nanofluid</td>
</tr>
<tr>
<td>Moshsen et al [18]</td>
<td>Pure water, Al2O3/water nanofluid and CuO/water nanofluid</td>
</tr>
</tbody>
</table>

Based on literature survey was focused on parabolic trough collectors, the review of the relevant published works found in the open literature had led us to conclude the following the researcher focused on performance analysis that include three fields of studies that are: performance evaluation, technique and using of different types of working fluid. First field study the analysis of the energy, exergy, environment (ambient temperature, solar irradiance, wind speed and sky temperature) and economic (4E) and the effect parameters (such as mass flow rate and biomass fuel) to improve the performance of the parabolic trough collector. And other field studies the techniques to enhance the performance of PTC. Such as, Change the size of the receiver tubes, different materials such As Aluminum, half insulated annulus, single or double glass, twisted tape in the receiver tube, tracking system, metal tube with coating and Placed inside the absorption tubes hinged blades. In addition most of researchers focused in their study to utilize different working fluid as shown in table 1.

As results from review, using a recent types of Nano fluids never been used previously in the field of PTC and the performance evaluation of parabolic trough solar collectors includes of thermal efficiency, outlet temperature, heat gain, all heat transfer (conduction, convection and radiation) and all heat losses (convection and radiation) by using new types of Nano fluids. Not shown in pervious. In addition, comparison of the numerical results of nanofluids used in this research with conventional fluids is most commonly used in solar collectors, which include water and molten salt.

2. METHODOLOGY

This section presents details the theoretical model of the solar collector in detail. The model consists of three basic parts. The first part of the model includes calculating the amount of solar radiation reaching the parabolic solar collector as well as calculating all required data. The
Effect of the design and environment parameters on the thermal efficiency and heat losses of a parabolic trough solar collector using nanofluid technology

second part includes optical analysis to calculate the optical efficiency of the solar collector. The third part of the model represents thermal analysis. The purpose of this part is to predict the value of external fluid temperature, thermal efficiency, heat gain and all heat losses of the solar collector.

2.1. Solar radiation Model

This model focus of calculation of solar angles like the sun altitude angle, sun azimuth angle, declination angle, hour angle and incident angle. Using the input data, the selected location. In this model the calculate of extraterrestrial radiation, it can be defined as the amount of energy that is received for each time unit on the unit area of the vertical surface on the sun outside the Earth's atmosphere.

Figure 1; which can be estimated applying the following equation [19]:

\[ I = I_o (1 + 0.033 \cos \frac{360}{365} n) \]  

(1)

Figure 1 Extraterrestrial radiation during the year the relationship between the solar constant and extraterrestrial radiation

Can also be evaluated using inverse square law [20]:

\[ I = I_o \left(\frac{D_o}{D}\right)^2 \]  

(2)

Where is the distance between the sun and the earth, D is the earth-sun average distance. The term \( \left(\frac{D_o}{D}\right)^2 \) can be determined as follows:

\[ \left(\frac{D_o}{D}\right)^2 = 1.00011 + 0.034221 \cos B + 0.001280 \sin B + 0.000719 \cos 2B + 0.000077 \sin 2B \]

And calculate the terrestrial radiation. In Figure 2. Radiation beam ,\( I_b \), represents the energy to be received directly without dispersion on the surface of the earth.

Figure 2 Attenuation of solar radiation as it passes through the atmosphere [21]
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\[ I_{\text{irradianc}} = I_{bn} \cos \theta + I_d \]  \hspace{1cm} (3)

Beam radiation \( I_b \) can be expressed for moving surfaces as it follows [33] [22]:

\[ I_b = I_{bn} \cos \theta \]  \hspace{1cm} (4)

Where \( I_b \) is beam radiation in the direction of the rays, \( \theta \) is angle of incidence. Therefore, the insolation becomes with

\[ I_{\text{irradianc}} = I_{bn} \cos \theta + I_d \]  \hspace{1cm} (5)

\[ I_{bn} = A \exp \left[ -\frac{B}{\cos \theta} \right] \]  \hspace{1cm} (6)

\[ I_{\text{irradianc}} = I_{bn} \cos \theta + I_d \]  \hspace{1cm} (7)

A, B and C are constants which change throughout the year due to seasonal changing of water vapors and dust content on the earth’s atmosphere. These constants have given by Threlkeld and Jordan and revised by Iqbal [22].

2.2. Calculations of collector field efficiency

The optical losses, geometrical losses and thermal losses that occur in the collector. These losses define the field efficiency [23].

\[ \eta_{\text{field,c}} = \eta_{\text{geo}} \eta_{\text{opt}} \eta_{\text{thermal}} \]  \hspace{1cm} (8)

\[ \eta_{\text{geo}} = \frac{\text{IDR}}{\text{DNI}} = \eta_{\text{cos}} \eta_{\text{Shading}} \eta_{\text{Endloss}} \eta_{\text{IAM}} \]  \hspace{1cm} (9)

\[ \eta_{\text{opt}} = \tau_m \tau_g \alpha_{\text{pipe}} \]  \hspace{1cm} (10)

Incident Direct Radiation (IDR) on the solar collector (watts per square meter). The effective useful irradiation (IDR). angle of incidence is given by [24]:

\[ \cos \theta = (1 - \cos \theta^2 \delta \sin^2 \omega)^{1/2} \]  \hspace{1cm} (11)

2.2.1. Optical End-losses

End-losses are determined as follows [25]:

\[ \eta_{\text{Endloss}} = 1 - \frac{\tan \theta}{L_{\text{col}}} \]  \hspace{1cm} (12)

Where: \( f \) is the focal length of the collectors, and \( L_{\text{col}} \) is length of a single solar collector.

![Figure 3](http://www.iaeme.com/IJM/index.asp)  

**Figure 3** End losses for PTC [21].

Table (1) lists coating emittance equations for all coating types [26].
Effect of the design and environment parameters on the thermal efficiency and heat losses of a parabolic trough solar collector using nanofluid technology

Table 2: Emittance for different coating types

<table>
<thead>
<tr>
<th>Coating type</th>
<th>Coating emittance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luzzblack chrome</td>
<td>0.0005333(T+273.15)-0.0856</td>
</tr>
<tr>
<td>Luzzcermet</td>
<td>0.000327(T+273.15) – 0.065971</td>
</tr>
</tbody>
</table>

2.2.2. Incident Angle Modifier Losses
The losses related with the IAM are approximately calculated as follows:

\[
IAM = \cos \theta \left(1 + \sin^3 \theta \right)
\] (13)

2.3. Thermal modeling of a parabolic trough collector
The objective of the thermal model is to predict thermal efficiency, outlet temperature, heat gain and all heat losses of the solar collector. The performance of the thermal solvent depends on the balance of energy between the fluid transfer of heat and atmosphere. Figure 4 shows the typical absorber used for PTC. Figure 5a [27] shows the proposed one-dimensional steady-state energy balance for a cross-section of selected absorber with the glass envelope intact, while Figure 6b [27] shows the thermal resistance model used and subscript definitions. The model assumes that all temperatures, heat fluxes, and thermodynamic properties are uniform around the circumference of the receiver. This is not very true as the radiation profile is not uniform, and the bottom part receives much higher solar flux than the top part.

![Typical receiver used for PTC](image)

**Figure 4** Typical receiver used for PTC, [28].

![Collector receiver model](image)

**Figure 5** Collector receiver model a- nomenclature , b- Thermal resistance network for the cross-section of the receiver
The incoming solar energy, which effectively is equal too the solar energy input minus optical losses, is absorbed by the glass envelope \((Q_{\text{glass.go}})\) and receiver pipe \((Q_{\text{rec.po}})\). Most of the energy that is absorbed by the receiver is conducted through the receiver pipe materials \((q_{\text{po-conv}})\) and eventually transferred to the fluid by convections \((q_{f-\text{pi.conv}})\). The remaining energy is transmitted back to the glass envelope by convection \((q_{po-gi.conv})\) and radiations \((q_{po-gi.rad})\). The energy reaching the glass cover from radiation and convection then passes through the glass envelope wall by conduction \((q_{gi-go.conv})\) and along with the energy absorbed by the glass envelope wall \((Q_{\text{glass.go}})\) is lost to the environment by convection to ambient air \((q_{go-a.conv})\) and radiation towards the sky \((q_{go-s.rad})\) [26].

The energy balance equations are determined by considering that the energy is conserved at each surface of the receiver cross section, shown in Figure 3.20. Therefore, the energy balance equations:

\[
q_{f-\text{pi.conv}} = q_{\text{po-conv}}
\]

\[
Q_{\text{rec.po}} = q_{\text{po-conv}} + q_{\text{po-gi.total}}
\]

\[
q_{\text{po-gi.total}} = q_{\text{gi-go.conv}}
\]

\[
q_{\text{go-a.total}} = Q_{\text{glass.go}} + q_{\text{gi-go.conv}}
\]

\[
q_{\text{go-gi.total}} = q_{\text{po-gi.conv}} + q_{\text{po-gi.rad}}
\]

\[
q_{\text{rec.tot.loss}} = q_{\text{go-a.total}}
\]

\[
q_{\text{go-a.total}} = q_{\text{go-a.conv}} + q_{\text{go-s.rad}}
\]

### 2.3.1. Convection heat transfer between the inner absorber wall and the HTF

From Newton’s law of cooling, the convection heat transfer from the inside surface of the absorber pipe to the HTF [29] can be given by:

\[
q_{f-\text{pi.conv}} = h_f A_{\text{pi}} (T_{\text{pi}} - T_f)
\]

Where,

\[
h_f = N_u f \frac{k_f}{\rho_f}
\]

\[
N_u = \frac{f_{\text{pi}}}{1 + 12.7 \sqrt{\frac{f_{\text{pi}}}{f_{\text{pi}} + 0.3}}} \left(\frac{Pr_f}{Pr_{\text{pi}}}\right)^{0.11}
\]

Where,

\[
Re_{\text{pi}} = \frac{\rho_f v_{\text{tr}} D_{\text{pi}}}{\mu_f}
\]

\[
f_{\text{pi}} = \left[1.82 \log Re_{\text{pi}} - 1.64\right]^{-2}
\]

### 2.3.2. Conduction heat transfer through the receiver pipe wall

The conduction heat transfer correlation through a hollow cylinder is calculated by Fourier’s law of conduction [30]:
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\[ q_{pi-po,\text{cond}} = \frac{2\pi k_{\text{tube}}(T_{pi}-T_{po})}{\ln(D_{po}/D_{pi})} \]  

Thermal conductivity of the receiving tube depends on the type of material made of that tube. There are three common types of pipes obtained from stainless steel (304L, 316L, and 321H). Table 3 shows the thermal properties of the three types of stainless steel.

Table 3 Thermal properties of different types of stainless steel [30]

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity W/m K</th>
<th>Density Kg/m3</th>
<th>Specific heat KJ/kg K</th>
</tr>
</thead>
<tbody>
<tr>
<td>304L</td>
<td>0.0130 T+14.9732</td>
<td>8027.1</td>
<td>0.5024</td>
</tr>
<tr>
<td>316L</td>
<td>0.0130 T+14.9732</td>
<td>8027.1</td>
<td>0.5024</td>
</tr>
<tr>
<td>321H</td>
<td>0.0151 T+14.5837</td>
<td>8027.1</td>
<td>0.5024</td>
</tr>
</tbody>
</table>

2.3.3. Heat transfer from the absorber to the glass envelope

The heat transfer from the receiver pipe to the glass envelope is calculated by:

\[ q_{po-gi,\text{total}} = q_{po-gi,\text{conv}} + q_{po-gi,\text{rad}} \]  

2.3.3.2. Convection Heat Transfer

The convection heat transfer between the receiver pipe and glass envelope occurs by free-molecular convection [31] and is given by

\[ q_{po-gi,\text{conv}} = h_{po-gi} A_{po} (T_{po} - T_{gi}) \]  

While the heat transfer coefficient calculated by[25]:

\[ h_{po-gi} = \frac{k_{\text{std}}}{D_{po} + bMD(\frac{D_{po}}{D_{gi}} + 1)} \]  

\[ K_{\text{std}}=0.02551 \text{W/m.}, \text{ The molecular diameters of air ; MD}=3.55 \times 10^{-5} \text{ cm, the interaction coefficient } b=1.57 \text{ [26].} \]

2.3.3.2. Radiation heat transfer

The relationship used for radiation heat transfer between the absorber pipe and the glass envelope is developed by Cengel [32]:

\[ q_{po-gi,\text{rad}} = \frac{\sigma A_{po} (T_{po}^4 - T_{gi}^4)}{(1 + (1 - \varepsilon_{po})b_{po} \varepsilon_{gi} b_{gi})} \]  

In deriving this equation, many assumptions were developed:

- Long concentric isothermal cylinders
- Diffuse reflection and irradiations
- The glass envelope is opaque to infrared radiation
- Nonparticipating gas in the annulus
- Gray surfaces
2.3.4. Conduction heat transfer through the glass envelope

The relationship used for conduction heat transfer through the glass envelope is the similar relationship described in section 2.3.2. Additionally, the thermal conductivity of the glass envelope which is Pyrex glass is constant (1.04 W/m K) [26].

\[
q_{\text{gi-go.cond}} = \frac{2\pi k_{\text{glass}}(T_{\text{gi}} - T_{\text{go}})}{\ln(D_{\text{go}}/D_{\text{gi}})}
\]  

(29)

2.3.5. Heat transfer from the glass envelope to the atmosphere

Convection and radiation heat transfer occurs through the outer surface of the glass envelope depending on whether there is wind. The below equation used to calculate such losses:

\[
\begin{align*}
q_{\text{go-a.total}} &= Q_{\text{glass.go}} + q_{\text{gi-go.cond}} \\
q_{\text{go-a.conv}} &= h_{\text{go-a}}A_{\text{go}}(T_{\text{go}} - T_{\text{a}}) \\
A_{\text{go}} &= \pi D_{\text{go}}L, \text{The outside area of glass, the convection heat transfer coefficient for air, is given by:} \\
h_{\text{go-a}} &= \frac{k_{\text{air}}}{D_{\text{go}}} \quad \text{(32)}
\end{align*}
\]

The Nusselt number in this case is estimated with Zhukauskas correlation for external forced convection flow normal to an isothermal cylinder [27]:

\[
\text{Nu}_{D_{\text{go}}} = C \text{Re}_{D_{\text{go}}}^{m} \text{Pr}_{\text{air}}^{n} \left(\frac{\text{Pr}_{\text{air}}}{\text{Pr}_{\text{go}}}\right)^{\frac{1}{3}}
\]  

(33)

For the conditions: \(0.7 < \text{Pr}_{\text{a}} < 500\) and \(1 < \text{Re}_{D_{\text{go}}} < 10^6\)

The constants \(C\) and \(m\) are given in below, while the constant \(n\) is equal to 0.37 for \(\text{Pr} \leq 10\) and is equal to 0.36 for \(\text{Pr} > 10\) [30]

The values of \(C\) and \(m\) are given in Table 4.

<table>
<thead>
<tr>
<th>Re(<em>{D</em>{\text{go}}})</th>
<th>C</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-40</td>
<td>0.75</td>
<td>0.4</td>
</tr>
<tr>
<td>40-1000</td>
<td>0.51</td>
<td>0.5</td>
</tr>
<tr>
<td>1000-200000</td>
<td>0.26</td>
<td>0.6</td>
</tr>
<tr>
<td>200000-1000000</td>
<td>0.076</td>
<td>0.7</td>
</tr>
</tbody>
</table>

2.3.5.2. Radiation heat transfer

In this case, net radiation transfer between the glass envelope and sky [28][39] is given by:

\[
q_{\text{go-s.rad}} = \sigma\varepsilon_{\text{go}}A_{\text{go}}(T_{\text{go}}^4 - T_{\text{s}}^4)
\]  

(34)

Where, \(T_{\text{s}}\) is the sky temperature and equal to \(T_{\text{a}}-8^\circ\text{C}\) [26] [33].
2.3.6 Heat removal factor
Is expressed as:

\[ F_R = \frac{\text{Actual output}}{\text{Output for the collector temperature}=\text{Fluid inlet temperature}} \]  

or,

\[ F_R = \frac{mC_p(T_{\text{out}}-T_{\text{in}})}{\dot{U}_L[S-\dot{U}_L(T_{\text{in}}-T_a)]} \]  

2.3.7 Performance of PTSC.
The thermal efficiency of a PTSC can be defined as the ratio of heat gained by the collector, \( q_u \), to the total incident radiation, \( I_{\text{irradiance}} \), that is incident on the aperture of the collector [34]:

\[ \eta_{\text{th}} = \frac{q_u}{A_{\text{a}}I_{\text{irradiance}}} \]  

Where the useful heat gained, is a function of the inlet and outlet temperature of the receiver as shown in the following expression [34]:

\[ q_u = mC_p(T_{\text{out}}-T_{\text{in}}) \]  

The useful heat collected by the receiver can also be expressed in terms of optical efficiency, heat loss coefficient, heat removal factor, and receiver inlet temperature [35]:

\[ q_u = F_R[I_b\xi_oA_a - A_r\dot{U}_L(T_{\text{inlet}}-T_a)] \]  

Table 5 PTC input design parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector length</td>
<td>50 m</td>
</tr>
<tr>
<td>Collector width</td>
<td>1 m</td>
</tr>
<tr>
<td>Inner absorber diameter</td>
<td>0.025 m</td>
</tr>
<tr>
<td>Outer absorber diameter</td>
<td>0.028 m</td>
</tr>
<tr>
<td>Inner glass envelope diameter</td>
<td>0.045 m</td>
</tr>
<tr>
<td>Outer glass envelope diameter</td>
<td>0.05 m</td>
</tr>
<tr>
<td>Focal distance</td>
<td>0.34 m</td>
</tr>
<tr>
<td>Absorber absorptance [26]</td>
<td>0.9</td>
</tr>
<tr>
<td>Glass envelope conductance [26]</td>
<td>1.04 W/m K</td>
</tr>
<tr>
<td>Glass envelope emittance [26]</td>
<td>0.86</td>
</tr>
<tr>
<td>Glass envelope transmittance [27]</td>
<td>0.9</td>
</tr>
<tr>
<td>Glass envelope absorptance [26]</td>
<td>0.02</td>
</tr>
<tr>
<td>Mirror reflectivity</td>
<td>0.94</td>
</tr>
<tr>
<td>HCE shadowing [27]</td>
<td>0.95</td>
</tr>
<tr>
<td>Tracking error</td>
<td>0.85</td>
</tr>
</tbody>
</table>
2.3.2. Thermal properties of the working fluid
Nanofluids are the most attractive mean to enhance the performance of a parabolic trough solar collector. In this paper, new nanofluids were used that where previous researchers, water and molten salt were selected as a reference for comparing the improvement in the performance of the PTC.

3. MODEL VALIDATION
For the purpose of verifying the accuracy and accuracy of the numerical results and the behavior of the curves obtained by the Matlab program. Validity has been done with data from some former researchers. The validity of the numerical data was confirmed with the researchers Sreekumar et al [38] as in figure (6) explains effect of the local time on the outlet temperature, note that the curves have the same behavior. The behavior of curves was confirmed by the effect of local time on the heat gain as shown in figure (7) with Tadahmun Ahmed Yassen [39], Where the numerical curves obtained by simulations have the same behavior.

![Figure 6 Effect of the local time on the outlet temperature](image-url)
Effect of the design and environment parameters on the thermal efficiency and heat losses of a parabolic trough solar collector using nanofluid technology

4. RESULTS AND DISCUSSION

In this section, the effect of local time on the performance of the PTC In summer on 15 July 2018 to the city of Basra is located on the latitude and longitude (30°30’56.0”N, 47°39’44.9”E). by using Nano fluids such as a work fluids. Nano fluids were compared with conventional fluids that are more commonly used in solar collectors.

Figure (8) shows the effect of the length of the HCE on the thermal efficiency during the summer. When the length is (5m) the thermal efficiency of five fluids (Water, Molten salt, PEO +0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid) is (66.98%, 67.26%, 67.26%, 67.26% and 67.26%) sequentially. When increase the length of HCE the thermal efficiency will decrease (56%, 62.27%, 64.54%, 65.87% and 67.11%) at length (50 m). The table 6, shows the percentage enhance in the thermal efficiency compared with water and molten salt.

Table 6 Percentage enhance in the thermal efficiency compared with water and molten salt.

<table>
<thead>
<tr>
<th>HTF</th>
<th>% Thermal efficiency</th>
<th>% Enhance compared with water</th>
<th>% Enhance compared with molten salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water+(PEO+1%CNT)</td>
<td>67.11</td>
<td>19.68</td>
<td>10.98</td>
</tr>
<tr>
<td>PEO+1%CNT</td>
<td>65.87</td>
<td>17.47</td>
<td>8.93</td>
</tr>
<tr>
<td>PEO+0.2%CUO</td>
<td>64.54</td>
<td>15.1</td>
<td>6.73</td>
</tr>
</tbody>
</table>

Showed in the figure (9) of the length of HCE on the heat losses (q_{po−gtotal}) (convection and radiation) between the vacuum space and receiver tube. When the length is (5 m) the heat losses of five fluids (Water, Molten salt, PEO+0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid) is (2 KW, 1.7 KW, 1.7 KW, 1.7 KW and 1.7 KW) sequentially. When increases the length of HCE (50 m) the heat losses will be gradually increase.
(1366.7 KW, 703.7 KW, 461.8 KW, 319.9 KW and 186 KW). Because the increase in length leads to increase the area exposed to solar radiation and this lead to increase the energy absorbed by the receiving tube and this causes the increase in temperature of the tube received because of the difference between the temperature of the tube receiving and glass envelope, leading to increase in the heat losses during the space between the receiving tube and the glass envelope.

The effect of the width collector on the thermal efficiency was calculated by the use of these fluids (Water, Molten salt, PEO+0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid), The values of thermal efficiency are (56.07%, 60.47%, 64.54%, 65.87% and 67.11%) sequentially. When the width collector (1 m). When increase the width to (5 m) the thermal efficiency values become (11.54%, 12.46%, 13.38%, 13.69% and 13.98%) sequentially. When increasing in width the thermal efficiency will begin to decrease gradually due to the increase in the area exposed to solar radiation, leading to an increase in the amount of heat losses.

Figure (11) shows the effect of the width of collector on heat losses (q_{po−gl,total}) by the use of these fluids (Water, Molten salt, PEO+0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid), The values of (q_{po−gl,total}) are (1366.7 KW, 896.3 KW, 461.8 KW, 319.6 KW and 186.8 KW) sequentially. When the width collector (1m). When increasing the width to (5 m) the heat losses (q_{po−gl,total}) they begin to increase gradually until reached to (1500KW, 1008.3 KW, 521.1 KW, 356.1 KW and 197.5 KW) sequentially. The increase in the width of collector leads to an increase in these losses because of the energy absorbed by the receiving tube that is larger than the energy absorbed by the glass envelope.

Figure (12) illustrate the influences of the thickness of the glass envelope on the thermal efficiency, when the thickness of the receiver tube is (5mm) the thermal efficiency of the fluids (Water, Molten salt, PEO+0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid) is (56.07%, 62.27%, 64.54%, 65.87% and 67.11%) sequentially. When the thickness of the glass envelope increases to (11 mm), the thermal efficiency of the fluids begins to decrease to the values (51.4%, 56.48%, 58.02%, 58.86% and 59.59%) respectively. In the case of increasing the thickness of the glass lead to decrease in the intensity of solar radiation received by the receiving tube and thus will reduce the thermal efficiency of the solar collector.

Figure (13) expression influences of the thickness of the glass envelope on the heat losses (q_{po−gi,total}), using the fluids (Water, Molten salt, PEO+0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid) the heat losses (q_{po−gi,total}) when the glass thickness is (5 mm) are (1366.7 KW,703.7 KW,461.8 KW,319.6 KW and 186.8 KW) respectively. When the thickness of the glass increases to (11 mm), the losses of using the fluids decreases to the (1036.1 KW, 492.7 KW, 328.6 KW, 238.5 KW and 160.7 KW) respectively. Increasing the thickness of the glass as mentioned previously reduces the value of solar radiation absorbed by the glass and thus reduces those losses.

Figure (14) expression effect of the volumetric flow rate (FL) on the thermal efficiency, when the FL is (0.000063 m³/s) the thermal efficiency of the fluids (Water, Molten salt, PEO+0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid) is (56.07%, 60.47%, 64.54%, 65.87% and 67.11%) respectively. If the volumetric flow rate is increased to (0.0001386m³/s), the thermal efficiency is (65.02%, 69.42%, 73.49%, 74.82% and 76.06%) respectively. Increased volumetric flow leads to increased thermal gain due to increased flow mass and this in turn leads to increased thermal efficiency. The thermal
Effect of the design and environment parameters on the thermal efficiency and heat losses of a parabolic trough solar collector using nanofluid technology

Efficiency of water is relatively small compared to the other fluids because the heat gain of the water is low.

Figure (15) and (4.66) expression effect of the volumetric flow rate on the heat losses ($q_{po-gi\text{.}total}$), when the FL is (0.000063 m$^3$/s) the heat losses of the fluids (Water, Molten salt, PEO+0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid) is (1366.7 KW, 896.3 KW, 461.8 KW, 319.6 KW and 186.8 KW) respectively. If the volumetric flow rate is increased to (0.0001386 m$^3$/s), the heat losses ($q_{po-gi\text{.}total}$) is (410.4 KW, -60KW, -494.5 KW, -636.7 KW and -796.5 KW) respectively. The heat losses decrease when the volumetric flow rate increases, leading to an increase in the flow mass. Thus, thermal gain increases and decreases loss.

The local time of the factors is very significant in solar energy because it clearly affects the performance of solar collector including efficiency, external temperature, heat loss as well as heat gain. And most researchers studied this factor and its impact on the performance of the PTC.

Figure (16) effect of the local time on the thermal efficiency, thermal efficiency of the fluids (Water, Molten salt, PEO+0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid) begins to increase gradually as time increases due to the gradual increase in the intensity of solar radiation until it reaches the peak at (13.45 p.m.) (56.07%, 62.27%, 64.54%, 65.87% and 67.11%) respectively. After (13.45 p.m.) the thermal efficiency begins to decline gradually due to the gradual decrease in the intensity of solar radiation. When increasing the intensity of solar radiation, the heat absorbed by the receiving tube increases, which in turn increases, the efficiency of the solar collector.

Figure (17) expression that effect of the local time on the heat losses ($q_{po-gi\text{.}total}$), during the summer the heat losses of the fluids (Water, Molten salt, PEO+0.2%CUO Nano fluid, PEO+1%CNT Nano fluid and Water+(PEO+1%CNT) Nano fluid) begins to increase gradually as time rises due to the gradual increase in the intensity of solar radiation until it reaches the peak at (13.45 p.m.) (1366.7 KW, 703.73 KW, 461.82 KW, 319.61 KW and 186.81 KW) respectively. In the case of increasing the intensity of solar radiation, the absorbed energy is increased by the glass envelope and the received tube, as a result of the difference between the energy absorbed by the glass envelope and the receiving tube, this results in a difference between the temperature of the receiving tube and the glass. This loss is caused by temperature difference. The table 7, shows the percentage decreases in the heat loss through the vacuum space between the receiver tube and the glass envelope compared with water and molten salt.

Table 7 percentage decreases in the heat loss through the vacuum space between the receiver tube and the glass envelope compared with water and molten salt.

<table>
<thead>
<tr>
<th>HTF</th>
<th>($q_{po-gi\text{.}total}$) (KW)</th>
<th>% Decreases (KW) with water</th>
<th>% Decreases (KW) with molten salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water+(PEO+1%CNT) nanofluid</td>
<td>186.8</td>
<td>86</td>
<td>79.15</td>
</tr>
<tr>
<td>PEO+1%CNT nanofluid</td>
<td>319.6</td>
<td>76</td>
<td>64.34</td>
</tr>
<tr>
<td>PEO+0.2%CUO nanofluid</td>
<td>461.8</td>
<td>66</td>
<td>48.47</td>
</tr>
</tbody>
</table>
Figure 8. Influences of the length of HCE on the thermal efficiency.

Figure 9. Influences of the length of HCE on the heat losses (convection and radiation) between the vacuum space and receiver tube.
Effect of the design and environment parameters on the thermal efficiency and heat losses of a parabolic trough solar collector using nanofluid technology

Figure 10 Variation width of collector with thermal efficiency.

Figure 11 Variation width of collector with heat losses (convection and radiation) between the vacuum space and receiver tube
Figure 12 Influences of the thickness of the glass envelope on the thermal efficiency.

Figure 13 Influences of the thickness of the glass envelope on the heat losses (convection and radiation) between the vacuum space and receiver tube.
Effect of the design and environment parameters on the thermal efficiency and heat losses of a parabolic trough solar collector using nanofluid technology

**Figure 14** Effect of the volumetric flow rate on the thermal efficiency.

**Figure 15** Effect of the volumetric flow rate on the heat losses (convection and radiation) between the vacuum space and receiver tube.
5. CONCLUSION
In this paper, a detail thermal model was presented. The model showed solar radiation section, and collector field efficiency, and thermal model to calculate the different types of heat loss. The new developed model showed a detail thermal study and have more accurate results compared with another model. The results showed: Percentage of enhancement in the thermal efficiency when using nanofluids (Water+EPO+1%CNT, PEO+1%CNT and PEO+0.2%CUO) Nano fluids are (19.68%, 17.47% and 15.1%) respectively compared to water and (10.98%, 8.93% and 6.7%) respectively compared to molten salt, as well as the heat losses by using the Nano fluids are much less than the use of water and molten salt. And the heat losses (convection and radiation) during the vacuum space between the receiving tube and the glass envelope by
Effect of the design and environment parameters on the thermal efficiency and heat losses of a parabolic trough solar collector using nanofluid technology

using the Nano fluids are much less than the use of water and molten salt. The heat transfer by the conductivity through the receiving tube and heat gain using the Nano fluids are greater than in the case of using water and molten salt. When the length of HCE increasing the heat losses (convection and radiation) during the vacuum space between the receiving tube and the glass envelope by using the Nano fluids are much less than the use of water and molten salt.

As final, the (Water+EPO+1%CNT) nanofluid the suggested nanofluids have a good impact to improve the performance of PTC and can use in large scale for industry using.

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Ahmed I. Hadi and Mahmood S. Jamel


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