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RESEARCH ARTICLE

Investigation of the Thermophysical Properties of Nanofluids Based on Metal Oxides: Application in Concentrated Solar Power Plants

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Abstract

Solar energy is a renewable source of energy that does not emit greenhouse gases. The sun is free, inexhaustible and available all over the world. The sun's rays can be used to produce energy in two ways. The first technique converts the sun's rays into electricity using photovoltaic panels, while the second converts the sun's rays into heat using concentrated solar power plants (CSP). Several studies have been carried out with the aim of improving the performance of these solar power plants in order to achieve high efficiency, which is the case in our study. In this work a numerical study was carried out on the effect of nanoparticles on the thermophysical properties of nanofluids with the aim of determining the most optimal nanofluid for use as a heat transfer fluid in concentrated solar power plants. The nanoparticles examined were metal oxides (SIO_2, MgO and Fe_3O_4), which were dispersed in Therminol VP-1 and Syltherm 800. The thermophysical properties examined were density, thermal conductivity and heat capacity. To carry out this study, we set the temperature from 200 to 400°C at the same operating temperature as the concentrating solar power plant.After evaluating the effect of nanoparticles on the thermophysical properties, we studied the behaviour of the CSP plant based on nanofluids using SAM (System Advisor Model) software. The results obtained are very encouraging and show that the addition of nanoparticles to a base fluid improves its thermophysical properties compared with the pure base fluid, and the rate of improvement in thermal conductivity exceeds 9%. We also found that the nanofluid (Fe_3O_4 /Therminol Vp1) is the best selected for use as a heat transfer fluid in concentrated solar power plants with an efficiency and thermal energy produced equal to 40.87% and 588164 MWht, respectively.

Keywords: Energy ; Nanofluid ; Efficiency ; SAM ; Conductivity.

Introduction

Renewable energies are seen as an key component of any sustainable energy development strategy. The inclusion of renewable energies in the national energy mix constitutes a major challenge in terms of conserving fossil resources, diversifying electricity production and contributing to sustainable development.

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Considerable research has been carried out into solar energy (Huang et al. 2020), with the aim of improving its performance, because today solar energy is one of the solutions that can replace fossil fuels such as gas, oil, nuclear power, etc., which are responsible for pollution and greenhouse gas emissions. etc, which are responsible for pollution and the emission of greenhouse gases, causing climate change which is a real problem that puts the planet earth at risk(Huang et al. 2020)(Alnaqi et al. 2019). So, the use of energy of solar origin proves to play an important role in reducing these problems that are linked to the exploitation of fossil fuels, because, solar energy is an energy considered clean and renewable(Jan and Balaji 2022)(Desideri et al. 2013), and one of the solutions proposed to meet the energy needs of society such as electricity which is applied in several areas; industry, transport, health, etc.

Generally speaking, there are two ways of converting solar energy into electricity: directly using photovoltaic panels or indirectly using concentrated solar power (CSP) plants. In this case, the sun's rays are concentrated on a receiver into which a heat transfer fluid flows, in which the solar energy is transformed into thermal power. This energy is then conveyed by a fluid and transformed into electricity using turbines that drive the alternator (Boufoudi et al. 2023)(Mwesigye and Meyer 2016). The fig.1 shows the different types of CSP plants.Figure 1 shows the different types of concentrated solar power plants. Improving the performance of a concentrating solar power plant is one of the objectives of most of the researchers in the world. The heat transfer fluid is one of the techniques used to improve the performance of a solar thermal plant. Other methods used to improve the performance of a thermal system include magnetic fields and corrugated channels. However, researchers are currently working on a new technique that involves replacing conventional fluids with nanofluids(Boufoudi et al. 2023)(Bekhti and Rachid Saim 2022).

To improve the efficiency and performance of a solar power plant or solar collector, researchers and specialists in this field generally consider modifying the heat transfer fluid. One of the most effective methods is to use nanofluids as the working fluid. The most commonly examined nanoparticles are (Al_2O_3, Al, Cu, TiO_2, SiO_2, Au, Ni, ZnO and Fe_3O_4) which can be dispersed in a fluid such as water, gas or thermal oil(Bekhti and Rachid Saim 2022). A great deal of research has been devoted to this type of technique, i.e. nanofluids, notably the work of (Potenza et al. 2017)who studied the effect of integrating nanofluids (CuO/Gas) into a solar receiver with a surface area of 4 m2 and consisting of two coaxial tubes. They proved that the use of nanofluids improves the efficiency and thermal performance of the prototype studied . (Kundan and Sharma 2013) observed that when nanoparticles of CuO nanoparticles are mixed with water, due to the increased optical properties, the heat absorption capacity of the nanofluids increases, resulting in a higher temperature difference. The density of CuO is higher than that of water, so after suspension, the heat capacity of the nanofluid increases, which improves the efficiency of the collector ,They may have found that the same as the efficiency of the collector of the temperature difference of the nanofluid increases, they concluded that nanofluids have potential for solar thermal applications and that nanofluids can be a good solution for limiting the heat transfer of conventional.(Allouhi et al. 2018) presented a one-dimensional mathematical model integrated in MATLAB to verify the effect of incorporating nanoparticles (TiO_2, Al_2O_3 and CuO) into a base fluid (synthetic oil) to be used as a working fluid in the PTC at medium temperature. They found that the use of nanofluids based on TiO_2, Al_2O_3 and CuO improved the performance of the collectors by around 1.14%, 1.17% and 1.06%, respectively, compared with the pure fluid, thereby improving energy efficiency.(Seyed Ebrahim Ghasemi and Ranjbar 2017) numerically examining the efficiency of the solar system and its performance based on the nanofluid (Al_2O_3/Therminol 66) with different concentrations and volume fractions, using CFD they found that the heat transfer and thermal performance of the nanofluid were improved compared with the pure base fluid, and that increasing the volume fraction leads to an improvement in thermal conductivity.(Liang et al. 2018)also numerically examined the efficiency and thermal performance of a directabsorption parabolic trough solar collector based on CuO/oil nanofluids. They demonstrated that the efficiency of the nanofluid-based collector improved by 10% compared with the pure fluid-based collector.(Abid, Ratlamwala, and Atikol 2017)carried out a comparative analysis of a parabolic trough solar collector and a parabolic trough solar collector placed separately with a Rankine cycle and an electrolyser, with the aim of examining and numerically evaluating their performance. A nanofluid based on Al_2O_3 and Fe_3O_4 and molten salt was examined. They concluded that the net power produced by the PTC-fed power plant is better than that of the parabolic trough power plant - their values are 8.17 and 6.23 KW respectively. They also found that ferric oxide (Fe_3O_4) and aluminium oxide (Al_2O_3) produce higher net power and better performance than molten salts.(Seiyed E Ghasemi and Ranjbar 2016) have numerically simulated the heat transfer inside the receiver tube of the PTC solar collector with Al_2O_3/Water and CuO/Water nanofluids as the working fluid, and have also examined the effect of the volume fraction on the thermal and hydrodynamic performance of the collector and on the heat flow. Their results show that the use of nanofluids as heat transfer fluids improves heat transfer by 28% for the (Al_2O_3/Water)-based nanofluid and by 35% for the (CuO/Water)-based nanofluid for a volume fraction equal to 3%.

The literature search showed that studies of the impact of nanofluids on their use in solar thermal power plants, have attracted enormous attention because of their excellent thermophysical properties, which could contribute to improving heat transfer.The main objective of this work is to provide two different studies, the first study consists of investigating the effect of nanoparticles on the thermophysical properties of nanofluids, the second part consists of evaluating the behaviour of the concentrated solar power plant based on nanofluids and comparing it with their pure base fluids.

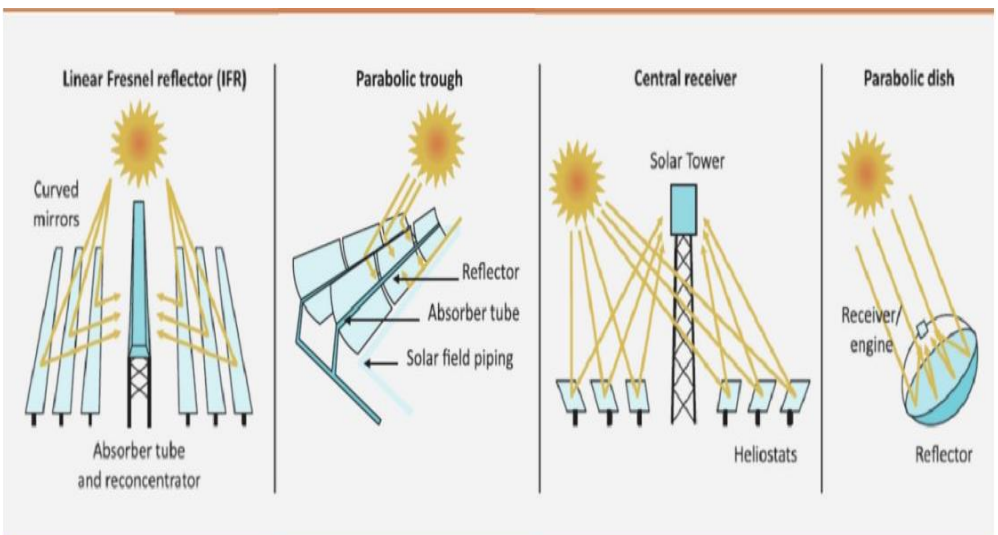


Figure. 1. The different types of CSP plants (Mihoub and Benahmed 2022)

Methodology

In this study, we will examine the effect of volume concentration and temperature on the thermal properties of nanofluids with different types of nanoparticles based on metal oxides (SIO_2 ,MgO and Fe_3O_4) compared with their pure base fluids, and select the best performing nanofluid for use in concentrating solar power plants as a heat transfer fluid. To answer these questions, a numerical study was carried out using MATALB software. We then integrated the nanofluids into the solar power plant as a working fluid and ran a numerical simulation to calculate its efficiency and quantify the energy produced over a year.

Liquids are normally used as a means of transporting energy for solar thermal collectors. Commonly used liquids are water, silicone oil, Therminol and a mixture of two liquids. The addition of small quantities of nanoparticles to these fluids (low-concentration nanofluids) improves their thermal and optical properties that play an essential role in theconversion. The nanofluid has attracted a great deal of attention because of its superior thermal properties. The thermophysical properties of the nanoparticles (SIO_2 ,MgO and Fe_3O_4) are presented in the table below (table-1).

Table 1: Thermophysical properties of the nanoparticles (SIO_2 ,MgO and Fe_3O_4)(Kadhim and Abdul Hassan 2016)(Ghalambaz et al. 2020)

	SIO_2	MgO	Fe_3O_4
Density (kg m^{-3})	2200	3570	5175
Thermal conductivity (W.m^{-1}.K^{-1})	1.3	5.11	7
Specific heat (kj/kg.K)	0.740	0.877	0.680

Governing equations

There are numerous models in the literature for determining nanofluid properties as a function of base fluid and volume fraction, but each correlation is applicable to a given situation.

- Density

Density can be determined using the classic formula of Pak et al (Cho, Pak et, OXIDE, and PARTICLES 2013):

$$\rho_{nf} = (1 - \varphi) * \rho_{fb} + \varphi * \rho_{np} \quad (1)$$

- Thermal conductivity

The evolution of nanofluid thermal conductivity as a function of volume fraction, base fluid thermal conductivity and nanoparticle thermal conductivity is presented in Maxwell's model(Xue 2003).

There are several theoretical models that can be used to estimate the thermal conductivity of suspensions under certain conditions. In this study, we use the most widely used model for nanofluids. In general, the most widely used model is the Maxwel model because it was the first to derive a model for estimating the thermal conductivity of a suspension containing particles.

Maxwell's model is satisfactory for suspensions containing spherical particles with relatively low volume concentrations, but does not take into account the effect of particle size or shape. It should also be noted that the effect of inter-particle interactions is neglected in this model.

$$\frac{\lambda_{nf}}{\lambda_{fb}} = \frac{\lambda_p + 2\lambda_{fb} - 2\varphi(\lambda_{fb} - \lambda_p)}{\lambda_p + 2\lambda_{fb} + \varphi(\lambda_{fb} - \lambda_p)} \quad (2)$$

- Specific heat:

The model Leong et al (Leong et al. 2017) Is among the model used for the determination of The specific heat of nanofluid taking into consideration the percentage of nanoparticles and the type of base fluids and density of nanofluids .

$$C_{pnf} = \frac{\varphi \rho_p C_{pp} + (1-\varphi)\rho_{bf} C_{pfb}}{\rho_{nf}} \qquad (3)$$

SAM indicates the total amount of energy produced by the system in the first year, generally for all performance models except solar water heating systems, annual energy equals the sum of hourly energy.

- Annual Energy Saved (Q) kWh/year(System Advisor Model (SAM) 2020).

  The annual energy saved is the electrical energy that the project avoids using thanks to the solar heating system. It is given by the following formula:

$$Q = \left(wt_s - w_s - p_p\right) \qquad (4)$$

Where, $\mathrm{wt_s}$is a value related to the energy obtained without solar energy

$\mathrm{w_s}$ with solar energy,

$\mathrm{p_p}$ is the power of the pump.

The thermal power of the field at design is given by the following formula:

$$Field\ Thermal\ Power\ (MWt)\ =\ SM\ \times\ Cycle\ Thermal\ Power\ (MWt) \quad (5)$$

The solar multiple (SM) is defined as the ratio between the real power collected in the solar field and the power needed to operate the turbine, the SM is given by the formula (4) (Mihoub and Beltagy 2017)(Izquierdo, and Montan 2010) :

$$SM = \frac{P_t}{P_s} \qquad (6)$$

Where Pt : Receiver Thermal Power (MWt), P_s : Heat Sink Power (MWt).
The capacity factor is given as the ratio of the electrical output produced by the system in its first year to the nominal output that should be produced when operating at full capacity..The capacity factor can be calculated by the following formula (Mihoub, Chermiti, and Beltagy 2017)(Serradj and Fadlallah 2022):

$$CF = \frac{P_e}{P_n} \qquad (7)$$

Where; Pe: Electrical power produced by the system in its first year.

Pn; Nominal production that must be produced when it operates at its capacity

Results and discussion

Improving the thermal properties of heat transfer fluids is currently the most promising way of increasing the performance of heat exchangers, and in general of systems where heat transfer is an important part of the energy flow. The effect of temperature and nanoparticle volume concentration on the density of nanofluids (MgO/Therminol VP1,SiO_2 /Therminol VP1 ,Fe_3O_4/ Therminol VP-1) and (MgO/Syltherm 800,SiO_2 / Syltherm 800,Fe_3O_4/ Syltherm 800) are shown in fig.2. Firstly, we set the volume concentration at 1% and varied the temperature from 200 to 400°C. We found that increasing the temperature caused the density to decrease. In the second step, we set the temperature at 400°C and varied the volume fraction from 0 to 1%, noting that each time we added concentration, the density increased in parallel, as shown in fig2.

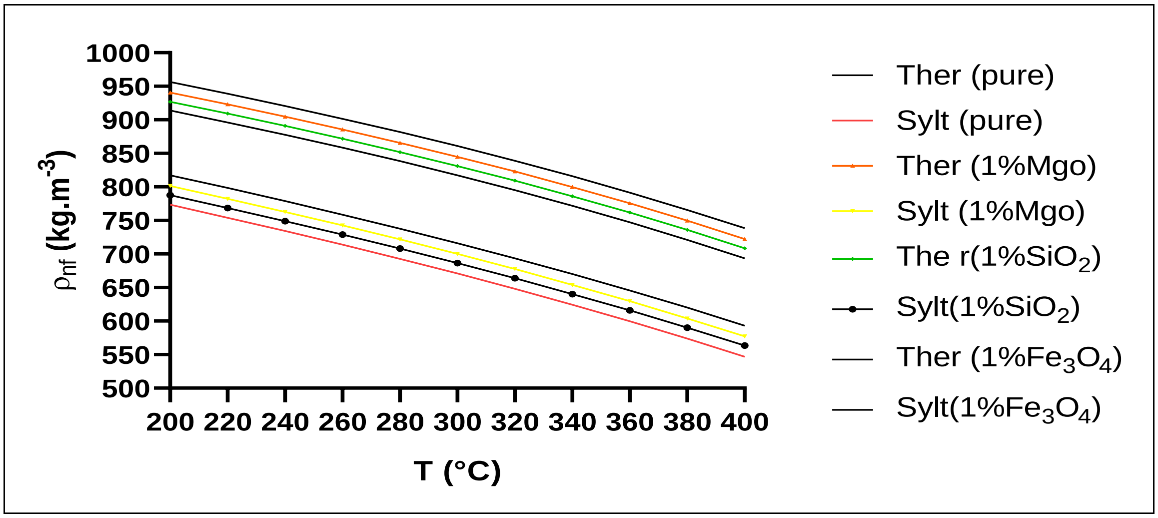


Figure.2. Effect of temperature and nanoparticle concentration on nanofluid density.

The thermal conductivities of eight nanofluids are shown in fig-3, for a constant value of nanoparticle concentration $\Phi = 1\%$, decreasing with increasing temperature. We then compared each nanofluid with its pure fluid, and noted that the nanofluids have a higher conductivity than the pure fluids, and the presence of MgO, $SiO_2$and Fe_3O_4nanoparticles improves the conductivity of the synthetic oils. We also see that the nanofluid (Fe_3O_4-Therminol VP -1) has a higher conductivity value than the rest of the nanofluids.
The improvement in thermal conductivity is very responsive when adding the volume fraction as shown in fig.3, and the best conductivity shown has the volume concentration equal to 4%, and the conductivity of nanofluid MgO/Therminol VP-1 and Fe_3O_4 /Therminol VP-1 is higher compared to other nanofluids.

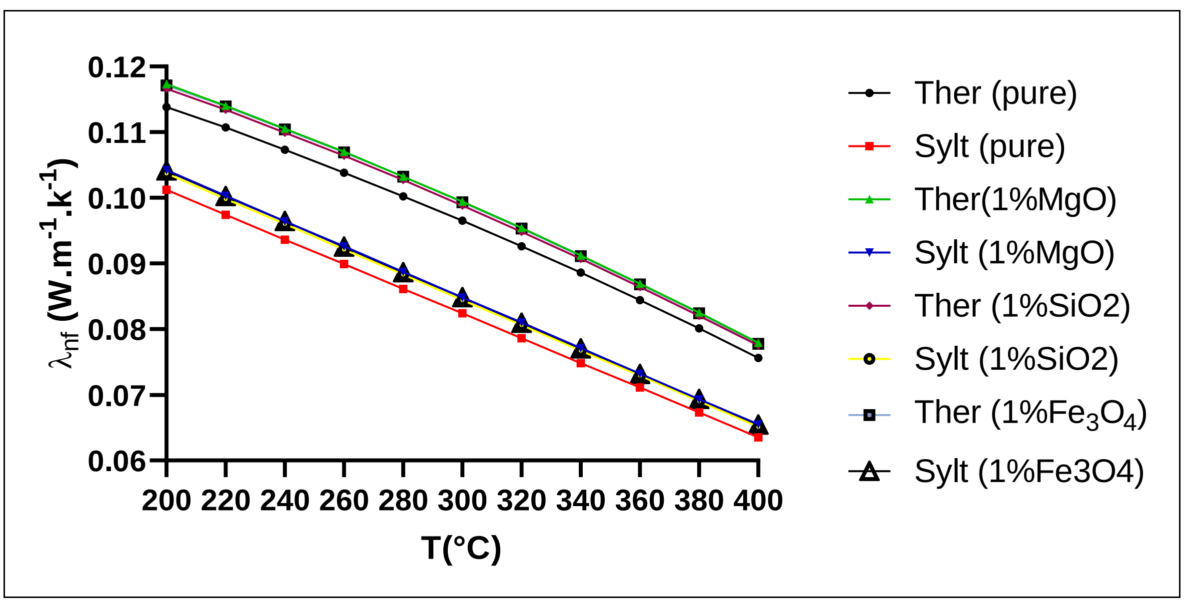


Figure.3. Effect of temperature and volume fraction on the thermal conductivity of nanofluids

The effect of temperature and nanoparticle volume concentration on the specific heat of the nanofluids (MgO/Therminol VP1,SiO2 /Therminol VP1 , Fe_3O_4/ Therminol VP1) and (MgO/Syltherm 800,SiO_2 / Syltherm 800,Fe_3O_4/ Syltherm 800) are shown in fig.4. It can also be seen that the specific heat of MgO/Therminol VP-1 is superior to that of other nanofluids when nanoparticles are added, which explains the important role of nanoparticles, since improved specific heat improves storage capacity in concentrated solar power plants.

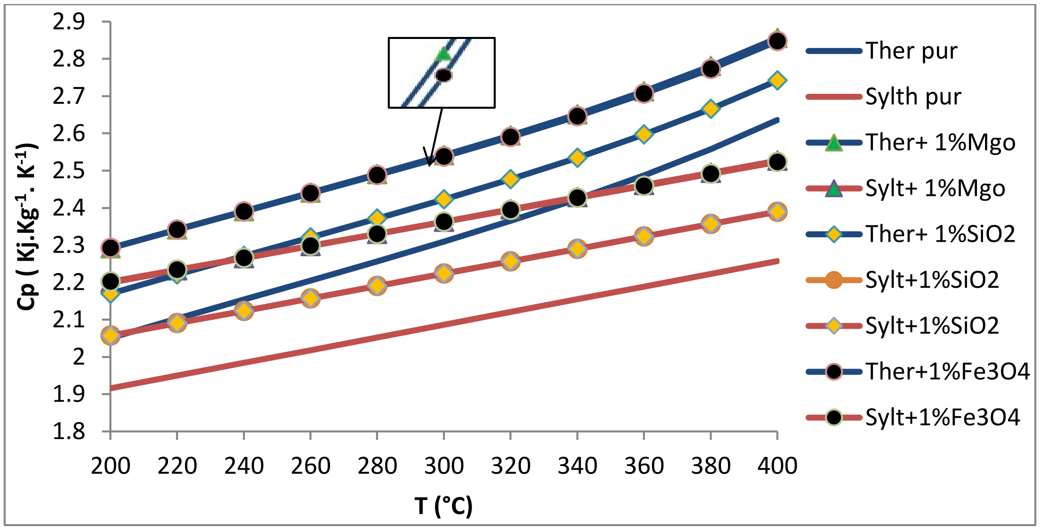
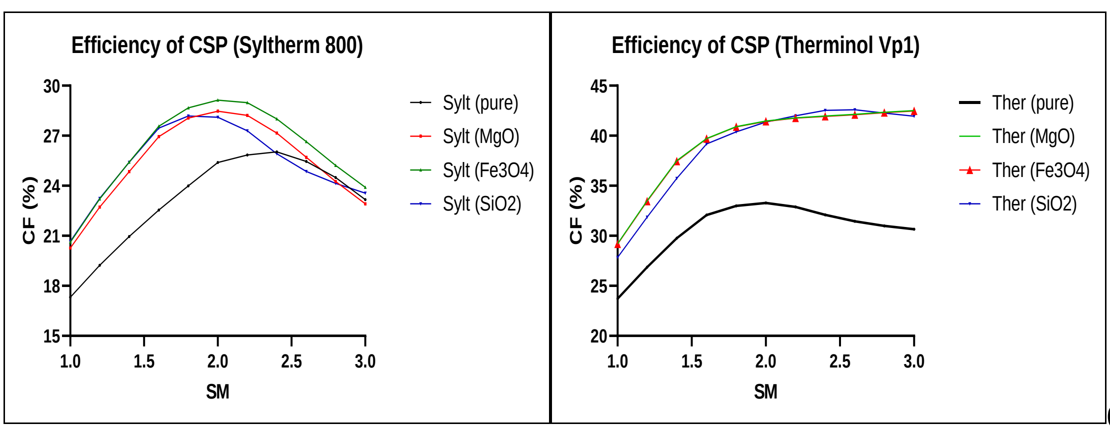


Figure.4. Effect of temperature and volume fraction on the specific heat of nenofluids

The figure below (fig-5) shows the effect of integrating nanofluids on the efficiency of the concentrated solar power plant based on nanofluids (Mgo, SIO2 and Fe_3O_4). We compared the efficiency of the plant with that of pure nanofluids and found that the addition of nanofluids plays an important role in improving efficiency. The best performing nanofluid is Therminol Vp1/Fe_3O_4 with an efficiency of 41.78%.



(a)

(b)

Figure 5 : Efficiency of the concentrating solar power plant: (a) based on Syltherm 800 ,(b) based on Therminol Vp 1.

The figures 6 and 7 show thermal energy to the power block and thermal power produced by the field as a function of nanofluids and solar multiple. The results clearly show that the amount of energy produced for a nanofluid is greater than for a pure base fluid, which explains why the nanofluid plays an important role in increasing the energy produced.

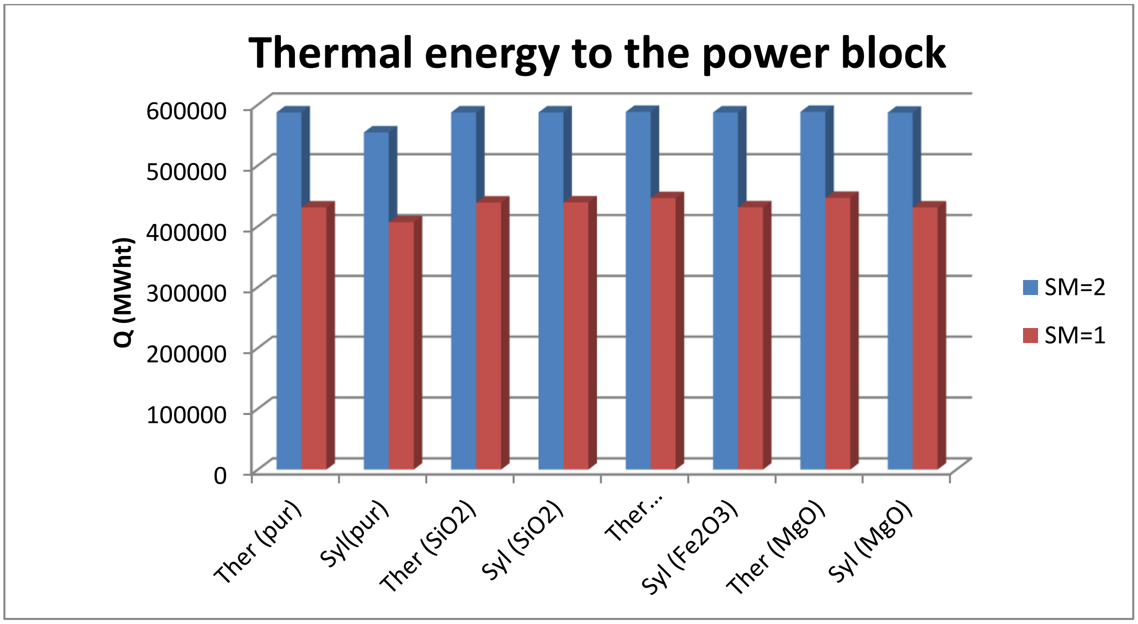


Figure.6 : Thermal energy to the power block as a function of nanofluids and SM

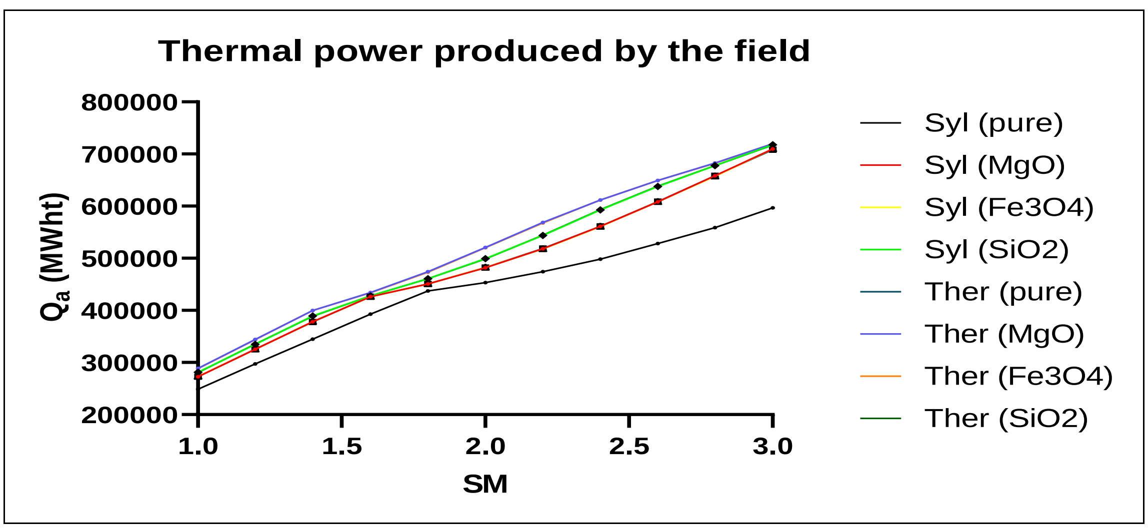


Figure.7 : Thermal power produced by the field as a function of nanofluids and SM

Table 2 show the comparison of the results obtained in this study with the studies a little similar and either with storage or without storage. We found that the results obtained are really reliable and encouraging.

Table 2: Comparison of the results with other studies

	HTF fluid	CSP technology	Storage	Plant capacity (MW)	SM	CF (%)
This study	Nanofluids	Solar-gas hyrid	No storage	50	2	27-42
(Mihoub, and Beltagy 2017)	Therminol VP-1	Solar-gas hyrid	8H	50	3.1	43
(Liu et al. 2016)	Synthetic oil	Current trough	6H	100	-	20-25 40-53
(Ikhlef and Larbi 2020)	Therminol VP-1	Solar-gas hyrid	No storage	25	1.6	47

Conclusion

A new term has come into the limelight that has weighed on the world and is the subject of a great deal of attention: this term is nanofluid.In this work, we presented and interpreted the simulation results obtained on the thermo-physical properties of nanofluids,for use as heat transfer fluids (HTF) in concentrated solar thermal power plants. For the nanofluids used in this study, we used different fluids based on synthetic oils. The effects of temperature and nanoparticle concentration on the properties were determined.In this numerical work using the MATLAB code, the effect of nanoparticle concentration and temperature on the thermophysical properties of nanofluids was investigated, and we concluded that: the integration of MgO, SiO_2, Fe_3O_4 nanoparticles in Syltherm 800 and Therminol VP-1 oily base fluids shows a considerable improvement in thermal conductivity, density and specific heat. The results show that the Fe_3O_4 / Therminol VP-1 nanofluid is most suitable for use as a heat transfer fluid in concentrated solar power plants, given its higher value.

The most important conclusions of this study are :

- Thermal conductivity is a fundamental parameter for heat transfer. Heat is conducted more quickly by solid particles compared with liquid, especially as we used the oxide-metallic nature,
- Nanofluids are ready for applications in solar thermal power plants, because they have not lost or destroyed their thermophysical properties despite the high temperature. Almost all the research is agreed that nanofluids will improve the thermal properties of HTF. Nanofluids are expected to trigger a series of industrial revolutions over the next two decades,
- The maximum annual energy produced is 588164 MWht and 588263 MWht for Fe_3O_4 / Therminol VP-1 and MgO / Therminol VP-1, respectively.
- The presence of nanaparticles reduces the specific heat, which is not acceptable for heat transfer. Therefore, these nanofluids are better as HTF and are not suitable for thermal energy storage.
- The efficiency of nanofluid-based concentrated solar power plants is better than that of pure working fluids.
- The nanofluid play a major role in improving the conductivity and density.

The research prospects are vast, and we can mention just a few, such as the integration of nanofluids into another type of solar power plant, namely the Fresnel mirror solar power plant or the tower solar power plant.Conducting an experimental study of nanofluid-based solar power plants. Simulations can also be carried out on the behaviour of flat solar thermal capture based on nanofluids. Study the fluid in a heat exchanger to reduce its viscosity with calculation software"Fluent" and GAMBIT.

Declaration

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Authors contribution: Conceptualization, F.B., S.M.; methodology, S.Z.;Simulation, S.M,; investigation, F.B.; writing—original draft preparation, S.Z,;writing—review and editing, F.B

Data availability: The data presented in this study are available on request

References

Norberto Fueyo, Salvador Izquierdo, and Carlos Montan. 2010. "Analysis of CSP Plants for the Definition of Energy Policies : The Influence on Electricity Cost of Solar Multiples , Capacity Factors and Energy Storage." 38: 6215–21.https://doi.org/10.1016/j.enpol.2010.06.009

Abid, Muhammad, Tahir A H Ratlamwala, and Ugur Atikol. 2017. "ScienceDirect Solar Assisted Multi-Generation System Using Nanofluids : A Comparative Analysis." *International Journal of Hydrogen Energy*: 1–14. http://dx.doi.org/10.1016/j.ijhydene.2017.05.178.

Allouhi, A et al. 2018. "Energy and Exergy Analyses of a Parabolic Trough Collector Operated with Nano Fl Uids for Medium and High Temperature Applications." *Energy Conversion and Management* 155(August 2017): 201–17. http://dx.doi.org/10.1016/j.enconman.2017.10.059.

Alnaqi, Abdulwahab A. et al. 2019. "Effects of Magnetic Field on the Convective Heat Transfer Rate and Entropy Generation of a Nanofluid in an Inclined Square Cavity Equipped with a Conductor Fin: Considering the Radiation Effect." *International Journal of Heat and Mass Transfer* 133: 256–67. https://doi.org/10.1016/j.ijheatmasstransfer.2018.12.110.

Bekhti, MOHAMMED, and Rachid Saim. 2022. "Numerical Study of Convective Heat Transfer and of Turbulent Forced of Differents Nanofluids in Channel." *Journal of Technology Innovations and Energy* 1(1): 1–8. https://doi.org/10.56556/jtie.v1i1.127

Boufoudi, Fatah, Sofiane Mihoub, Salah Zouaoui, and Abdelillah Benahmed. 2023. "Receiver Parameter Optimization for Nanofluid-Based Parabolic Trough Concentrating Plant: A Case Study." *Energy Sources, Part A: Recovery, Utilization and Environmental Effects* 45(2): 5559–76. https://doi.org/10.1080/15567036.2023.2209036.

Boufoudi, Fatah, Salah Zouaoui, Sofiane Mihoub, and and Tahar Tayebi , Abdelillah Benahmed. 2023. "Numerical Investigation of the (Mono-Hybrid) Nanofluid Thermophysical Properties For." 12(5): 1233–41. https://doi.org/10.1166/jon.2023.2015

Cho, Pak et, HYDRODYNAMIC AND HEAT TRANSFER STUDY OF, DISPERSED FLUIDS WITH SUBMICRON METALLIC OXIDE, and 1980 PARTICLES. 2013. "Hydrodynamic and Heat Transfer Study of Dispersed Fluids With Submicron Metallic Oxide." *Experimental Heat Transfer : A Journal of , Thermal Energy Transport , Storage , and Conversion* (January 2013): 37–41.

Desideri, U., F. Zepparelli, V. Morettini, and E. Garroni. 2013. "Comparative Analysis of Concentrating Solar Power and Photovoltaic Technologies: Technical and Environmental Evaluations." *Applied Energy* 102: 765–84. http://dx.doi.org/10.1016/j.apenergy.2012.08.033.

Ghalambaz, Mohammad, Ali Doostani, Ehsan Izadpanahi, and Ali J. Chamkha. 2020. "Conjugate Natural Convection Flow of Ag–MgO/Water Hybrid Nanofluid in a Square Cavity." *Journal of Thermal Analysis and Calorimetry* 139(3): 2321–36. https://doi.org/10.1007/s10973-019-08617-7.

Ghasemi, Seiyed E, and A Ranjbar. **"** Thermal performance analysis of solar parabolic trough collector using nanofluid as working fluid: A CFD modelling study **."** *Journal of Molecular Liquids*.
. http://dx.doi.org/10.1016/j.molliq.2016.06.091.

Ghasemi, Seyed Ebrahim, and Ali Akbar Ranjbar. 2017. "ScienceDirect Effect of Using Nanofluids on Efficiency of Parabolic Trough Collectors in Solar Thermal Electric Power Plants." *International Journal of Hydrogen Energy*: 1–9. http://dx.doi.org/10.1016/j.ijhydene.2017.07.087.

Huang, Ming-hua et al. 2020. "Experimental and Numerical Studies for Applying Hybrid Solar Chimney and Photovoltaic System to the Solar-Assisted Air Cleaning System." *Applied Energy* 269(May): 115150. https://doi.org/10.1016/j.apenergy.2020.115150.

Ikhlef, Khaoula, and Salah Larbi. 2020. "Techno-Economic Optimization for Implantation of Parabolic Trough Power Plant : Case Study of Algeria." 063704(November).https://doi.org/10.1063/5.0013699

Jan, Kowser Ali, Shubarat Shameem, and R Balaji. 2022. "An Empirical Analysis of Climate Change Mitigation by Solar Energy." Journal of Technology Innovations and Energy : 37–41. https://doi.org/10.56556/jtie.v1i4.411

Kadhim, Zena K., Muna S. Kassim, and Adel Y. Abdul Hassan. 2016. "Effect of (MGO) Nanofluid on Heat Transfer Characteristics for Integral Finned Tube Heat Exchanger." *International Journal of Mechanical Engineering and Technology* 7(2): 11–24.

Kundan, Lal, and Prashant Sharma. 2013. "Performance Evaluation of a Nanofluid (CuO-H 2 O) Based Low Flux Solar Collector." *International Journal of Engineering Research Volume* 112(2): 108–12.

Leong, K Y et al. 2017. "Synthesis and Thermal Conductivity Characteristic of Hybrid Nano Fl Uids – A Review." *Renewable and Sustainable Energy Reviews* 75(November 2016): 868–78. http://dx.doi.org/10.1016/j.rser.2016.11.068.

Liang, Hongbo et al. 2018. "Study on the Thermal Performance of a Novel Cavity Receiver for Parabolic Trough Solar Collectors." *Applied Energy* 222(April): 790–98. https://doi.org/10.1016/j.apenergy.2018.04.030.

Liu, Ming et al. 2016. "Review on Concentrating Solar Power Plants and New Developments in High Temperature Thermal Energy Storage Technologies." *Renewable and Sustainable Energy Reviews* 53: 1411–32. http://dx.doi.org/10.1016/j.rser.2015.09.026.

Mihoub, Sofiane, Ali Chermiti, and Hani Beltagy. 2017. "Methodology of Determining the Optimum Performances of Future Concentrating Solar Thermal Power Plants in Algeria." *Energy* 122: 801–10.

Mihoub, Sofiane, Beltagy Hani, and Abdelillah Benahmed. 2022. "Sustainable Potential of Concentrating Solar Power Plants : A Comparative Study." 58(5): 675–88.

Mwesigye, Aggrey, Zhongjie Huan, and Josua P. Meyer. 2016. "Thermal Performance and Entropy Generation Analysis of a High Concentration Ratio Parabolic Trough Solar Collector with Cu-Therminol®VP-1 Nanofluid." *Energy Conversion and Management* 120: 449–65. http://dx.doi.org/10.1016/j.enconman.2016.04.106.

Potenza, Marco, Marco Milanese, Gianpiero Colangelo, and Arturo De Risi. 2017. "Experimental Investigation of Transparent Parabolic Trough Collector Based on Gas-Phase Nanofluid." *Applied Energy* 203: 560–70. http://dx.doi.org/10.1016/j.apenergy.2017.06.075.

Serradj, D E Benhadji, and A B Sebitosi S O Fadlallah. 2022. "Design and Performance Analysis of a Parabolic Trough Power Plant under the Climatological Conditions of Tamanrasset , Algeria." *International Journal of Environmental Science and Technology* 19(4): 3359–76. https://doi.org/10.1007/s13762-021-03350-x.

System Advisor Model (SAM)." 2020. Available at: https://www.google.com/search?q=System+Advisor+Model&oq=System+Advisor+Model+&gs_lcrp=EgZjaHJvbWUyCggAEEUYFhgeGDkyBwgBEAAYgAQyCAgCEAAYFhgeMggIAxAAGBYYHjIICAQQABgWGB4yCAgFEAAYFhgeMggIBhAAGBYYHjIICAcQABgWGB4yCAgIEAAYFhgeMggICRAAGBYYHtIBCTMwNjlqMGoxNagCALACAA&sourceid=chrome&ie=UTF-8 (Accessed August 4, 2023).

Xue, Qing Zhong. 2003. "Model for Effective Thermal Conductivity of Nanofluids." *Physics Letters, Section A: General, Atomic and Solid State Physics* 307(5–6): 313–17.