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# Comparative Assessment of the Effect of Thermo-Physical Properties on the Performance of Parabolic Trough Solar Collector

***Sangotayo, Emmanuel Olayimika[1], Ph.D. and Peter, Benjamin Aina[2], Ph.D.**

1.Department of Mechanical Engineering, SEAS, Kampala International University,
Ggaba Road, Kansanga, P. O. Box 20000 Kampala, Uganda, sangotayo.emmanuel@kiu.ac.ug
2 Department of Physical Science, SEAS, Kampala International University, Ggaba Road, Kansanga, P. O. Box 20000, Kampala, Uganda, benjamin.aina@kiu.ac.ug

**Abstract**

The harmful effects of fossil fuels on the environment and continuous growth in the energy demand across the world due to the prosperous population have made it essential to harness renewable energy through different technologies. The heat transfer fluids used in solar thermal systems are fundamental to enhance the higher effectiveness of solar thermal systems. This paper presents a comparative analysis of the influence of the thermo-physical properties of CuO, $Al_2O_3$, and $TiO_2$ water-based nanofluids on the thermal performance of the Parabolic Trough Solar Concentrator, PTSC. The energy governing equations of nanofluids, coupled with the concentrator's effectiveness equations were solved using iterative relaxation approach. C++ program is developed to examine the impact of the thermal characteristics of the three water-based nanofluids on the heat distribution and performance of the concentrator with varying sizes of nanoparticle in the range $1\% \leq \varphi \leq 10\%$ at 0.2 kg/s mass flow rate value. The results reveal that the heat transfer coefficient is expanding by 20%, 21%, and 14%, and thermal efficiencies are diminishing by 9%, 56% and 33% using $TiO_2$, CuO and $Al_2O_3$ respectively, with the density increase by 28 %, the thermal conductivity increase by 23 %, and the specific heat capacity reduce by 30 %. The influence of the thermophysical properties of the water-based nanofluids on the heat transfer coefficient and the efficiency of the PTSC are significant. This work indicates that the suspended nanoparticles significantly change the thermal characteristics of the suspension which determines its applications

**Keywords:** Heat transfer enhancement, Solar Energy, Parabolic Trough Collector, Heat transfer fluid, Nanofluids.

**NOMENCLATURE**

| Symbols | Definition | Unit |
|---|---|---|
| Nu | Nusselt number | [-] |
| Re | Reynolds number | [-] |
| Pr | Prandtl number | [-] |
| D | Receiver tube diameter | m |
| h | Heat transfer coefficient | $W/m^2.K$ |
| K | Thermal conductivity | W/m.K |
| $Aa$ | Collector aperture area | $m^2$ |
| $C_p$ | Heat capacity | J/kg.K |
| $Cp_f$ | Heat capacity of fluid | J/kg.K |
| $Cp_{nf}$ | Heat capacity of nanofluid | J/kg.K |
| $Cp_p$ | Heat capacity of nanoparticle | J/kg.K |
| $Ib$ | Beam solar radiation | $W/m^2$ |
| $K_f$ | Thermal conductivity of fluid | W/m.K |
| $K_{nf}$ | Thermal conductivity of nanofluid | [W/m.K] |
| $K_p$ | Thermal conductivity of nanoparticle, | [W/m.K] |
| m | Mass flow rate | kg/s |
| $Qu$ | Useful energy | W |
| $T_{f,i}$ | Inlet fluid temperature | $^oC$ |
| $T_{f,o}$ | Outlet fluid temperature | $^oC$ |

***Greek symbols***

| Symbols | Definition | Unit |
|---|---|---|
| ηth | Theoretical efficiency | [-] |
| $\varphi$ | nanoparticle size | [-] |
| $\rho_{nf}$ | Density of nanofluid | $kg/m^3$ |
| $\rho_f$ | Density of fluid | $kg/m^3$ |
| $\rho_p$ | Density of nanoparticle | $kg/m^3$ |
| $\mu_{nf}$ | Viscosity of nanofluid | $m^2/s$ |
| $\mu_f$ | Viscosity of fluid | $m^2/s$ |
| μ | viscosity | $m^2/s$ |
| $\rho$ | Density | $kg/m^3$ |

***Subscripts***

| | |
|---|---|
| $bf$ | Base fluid |
| $nf$ | Nanofluid |
| $p$ | Particle |
| $f$ | Fluid |

## 1. Introduction

Solar energy plays an essential role in saving our planet from the effects of climate change caused by fossil fuel utilization to meet our energy requirements. Therefore, improving the performance of solar energy technologies is of vital significance. Solar energy is proving to compete side by side with fossil fuels today. Nanotechnology is a multidisciplinary field that combines technology, engineering, and science at a nanoscale (National Nanotechnology Initiative, 2019). There is a wide range of usage where nanotechnology takes place, such as engineering, material science, and biology. In the solar energy field, nanotechnology participates positively by replacing the working medium with nanofluids. Nanofluid is a new type of heat transfer fluid that allows more heat to be eliminated from the solar system. The theory of using nanoparticles with the base fluids increases the thermal conductivity which can cause a higher heat transfer coefficient as well as higher thermal efficiency. (Sathe and Dhoble, 2017; Ju, *et al*. 2017)

The sun is described as a large sphere of scorching gaseous matter with a diameter of $1.39\times10^{9}$ m and away from earth by $1.5\times10^{11}$ m. It has a total energy output of $3.8\times10^{20}$ MW, however, it is a small portion, $1.7\times10^{14}$ of the total radiation spread to the surface of the earth because the solar radiation is attenuated two times by the clouds and the atmosphere (Tian, and Zhao, 2013) The applications of the different types of solar collectors are cooling, industrial process heating, water heating, space heating, and thermal power systems, and chemistry applications (Chandraprabu et al., 2019). The uniform dispersions of the nanoparticle are called nanofluids (Lee et al., 2011; Chen et al., 2008 and Murshed et al., 2008). Nanofluids have found useful applications and effective heat transfer in industrial cooling applications (Eastman *et al.* 1996), cooling of microchips (Sarkar, 2011), microscale fluidic applications (Kleinstreuer *et al*., 2008), cryopreservation (He *et al*., 2008), and gasification of biomass (Tyagi *et al*. 2009[a]).

Jin *et al. (2017)* suggested a unifying technique of analyzing parabolic trough collectors with different dimensions using similarity principle and dimensional analysis. The results revealed that there was a substantial correlation between the key parameters of different types of parabolic trough collectors, and the relative self-determination of solar thermal system performances is on dimensions. The feasibility test of parabolic trough collectors in large scale solar heating plants in Denmark for district heating was validated in the pilot thirsted plant. The results showed that the parabolic trough collector was used effectively for solar district heating plants at operating temperatures ranging from 85-95°C (Perers et al., 2013). Bellas and Lidorikis (2017) developed a high-temperature solar-selective coating for application in solar collectors. It was reported an increase in the efficiency of the collector was attained with excellent spectral selectivity, high transparency in the solar spectrum, and high reflectance. An increase in the heat transfer absorption of solar intensity and development in the receiver tube is attained by using nano-fluids as a heat transfer fluid for parabolic trough collectors. The solar beam intensity affected the thermal efficiency of the collector while comparing the different working fluids of the collector. It was stated that $Al_2O_3$ nano-fluid had a high heat transfer rate compared to SiC nano-fluid but, CuO nano-fluid had a higher heat transfer rate compared to $Al_2O_3$ (Marefati *et al*. 2018; Chandraprabu *et al.* .2013 and Chandraprabu *et al*. 2014).

Guo *et al*. (2016) carried out a parametric assessment of parabolic trough collectors, PTC for different receiver diameters, ambient temperatures, inlet temperatures, wind velocities, and incident angles. The results showed that there is an optimum mass flow rate exergetically, and a need to reduce the high optical losses is one way to improve PTC's exergetically. Qu *et al.* (2017) carried out an experimental evaluation of a solar parabolic trough collector with rotatable axis tracking. Results showed that adopting the rotatable axis tracking increased the daily average collector efficiency by 5.0% and reduced the daily average cosine loss by 10.3% compared with the north-south axis tracking. Su *et al*. (2017) described the modeling and simulation of ray tracing for the compound parabolic thermal solar collector. The thermal efficiency was found by using the transmittance, the absorption, and the reflection at a different incident angle for each ray tracing. Sheel *et al*. (2018) performed a numerical examination of Parabolic Trough Solar Collector (PTSC) using $TiO_2$ water-based Nanofluid. The results revealed that the collector efficiency increased up to 8.56%, and 54 % is the highest overall efficiency in Parabolic trough solar collector, which 7% more than base fluid.

Sangotayo and Waheed (2011) performed a numerical examination of heat transfer attributes of the working fluid in the Cylindrical Parabolic Concentrating Solar Collector in Ogbomoso Climatic Conditions. The effects of twist tape ratio in various liquids on the system performance as a function of efficiency to achieve the optimum performance of the system were analyzed. The results showed that oil has the highest heat transfer characteristics. It is observed that the tape twist factor enhances the heat transfer characteristics of the fluids in a cylindrical parabolic concentrating solar collector, and the performance of the cylindrical parabolic trough collector with twisted tape has been improved appreciably. Khan *et al*. (2020) presented a comparative analysis of different absorber tube geometries for parabolic trough solar collectors using nanofluid. The use of nanofluid and twisted tape inserts led to higher thermal enhancement, followed by the nanofluid and internal fins inserted tube.

The performance of the PTSC is enriched with the better basic geometrical and design aspects of the solar collectors, which include aperture area, focal length, concentration ratio absorber diameter, rim angle, and optical parameters. Gee *et al. (*1981) suggested several improvements on the PTC by growth in the subsystem like a receiver tube, collector area, and aperture. An increase in receiver tube assembly, the reflectivity of the mirror, and the glass cover with coating were suggested because of all these considerations. It was found that optical efficiency increased by up to 70 to 81%. Xuan and Li, (2003) concentrated on the use of nanoparticle to improve the collector efficiency and the heat transfer characteristics. Metal oxide nanoparticle is mixed with a different base fluid like water, ethanol, and glycol.

Tyagi *et al. (*2009[b]) presented a theoretical evaluation of the solar collector, which non-concentrating type compared its performance with a flat plate collector, and $Al_2O_3$/water based nanofluid is used as heat transfer working fluid. It was found that the nanofluid absorption is increased by nine times than the water and the efficiency of increased by 10%. Khullar *et al. (*2012) used Aluminum nano-particle water-based in parabolic trough solar collector (PTSC). The result of nano-fluid based solar parabolic concentrator performance and efficiency was 5-10% higher than the flat plate. Nagarajan *et al*. (2014) used $Al_2O_3$ water-based nanofluid in parabolic trough solar collectors. It was found that the collector efficiency was enhanced and the volume concentration and particle size play a significant role in the effectiveness of the system. Kasaeian *et al. (*2015) designed the PTSC with 0.7 m width and 2 m height, reflector made up of steel mirror with four different receivers. It was noted that the vacuum tube efficiency is 11% higher than the bare tube and the thermal efficiency is enhanced up to 4% to 7%. Kaloudis *et al*. (2016) evaluated the effectiveness of PTSC with the volume concentration numerically by using $Al_2O_3$ nanoparticle in synthetic oil as base fluid. The result was noted that the collector efficiency enhanced up to 10% with a 4% volume concentration of $Al_2O_3$. Bellos *et al. (*2016) analyzed the thermal efficiency of parabolic solar collectors of commercial type with the use of working fluid and second by absorber geometry. It was found that the absorber geometry parameter improved the efficiency with 4.55% and the collector efficiency increased by 4.25% by using nanofluid. Arani and Amani, (2013) examined the heat transfer behaviours of PTSC in the straight double-tube type counter-flow heat exchanger of $TiO_2$/water nanofluid. It was found that diameter particle-sized gave optimal results.

Subramani *et al. (*2017) examined the heat transfer behaviours of the ($TiO_2$/water) based nanofluid in solar parabolic trough collectors with volume concentration in the range of 0.2% to 0.5% by using three different mass flows rate. The results revealed that $TiO_2$/water nanofluid has a 9.5% higher absorbed energy factor at 0.2% volume concentration at 0.0667 kg/sec mass flow rate. The overall efficiency was 57%. The impact of the thermophysical properties of nanofluid on the performance of the parabolic solar concentrator has not been considered. However, this paper presents the effect of the thermo-physical properties of three different nanofluids and the volumetric concentration of nanoparticle on the heat transfer rate and system performance of a parabolic trough concentrating system.

## 2. Materials and Methodology

### 2.1 Model development

Parabolic trough collectors are the long, trough-shaped reflector of the parabolic cross-section with a slope controlled by the rim angle, which focuses the reflected sunlight radiation on to the receiver tube (heat pipe). The receiver is placed at the focal length of the trough to absorb most of the energy concentrated onto it, and it transfers the heat to the heat transfer working fluid, which gets heated to the elevated temperature when moved through the receiver tube to accept the heat absorbed by it. The receiver is made of black-coated copper tubing. The efficiency is improved by using the anti-reflective coating on the outer glass surface. The parabolic trough has a tracking system and It is mounted on structural supports that allow the tracking of the sun from east to west direction during the day time. The supports for parabolic trough are made of steel and other material with higher strength (Hafez *et al*. 2018).

A developed prototype of a parabolic trough solar concentrator (PTSC) is presented in Figure 1.0 (Sangotayo *et al*., 2019). The effect of the thermophysical properties of nanofluid on the performance of the parabolic solar receiver is being investigated using the design parameters of the PTC system. The design parameters and dimensions of the parabolic-trough system are listed in Table 1.0. The solar collector is formed in the shape of a parabola, which is formed from segmented mirrors (reflector) to concentrate the radiation rays of the sun on the receiver (adsorber) pipe placed in the focal line of the collector. The material of the adsorber pipe is copper and it is painted with black paint to improve the performance. The adsorber pipe transforms the radiations into thermal energy which is carried by the heat transfer fluid that passes through the pipe and uses it in the required application. This collector was designed, constructed, and tested in the Ogbomoso weather condition to obtain 114 º C receiver temperature. The effectiveness of the PTSC depends upon the material used as a reflecting surface, receiver (adsorber) pipe materials, and heat transfer fluid. The concentrating collectors have a significant factor called concentration ratio, and it is the ratio of the aperture area of a collector to the area of the receiver pipe. The dimensions of the system setup and operating conditions used in this research work are listed in Table 1.0.

### 2.2 Nano-fluid

A nano-fluid is a fluid containing nanometer-sized particles, named nanoparticles. These fluids are brought about as a mixture of suspensions of nanoparticles in the base fluid. The nano-particles used in nano-fluid are made of metals, oxides, carbides, or carbon nano-tubes. The knowledge of the rheological behaviour of nanofluids is found to be essential in deciding its suitability for convective heat transfer applications.

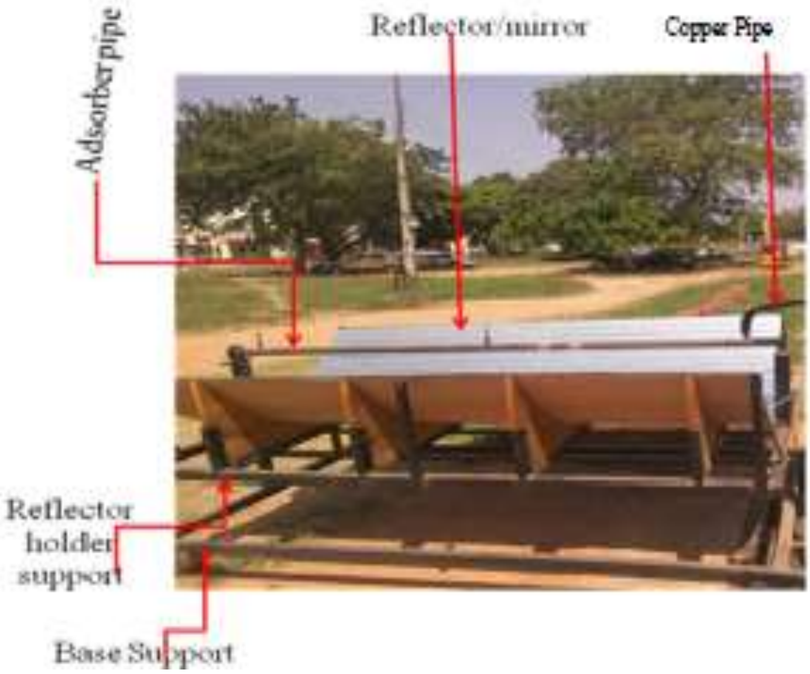


Figure 1.0: Photograph of parabolic trough solar concentrator
(Source: Sangotayo *et al*. 2019)

**Table 1.0: Specifications of Parabolic Trough Concentrator (Sangotayo *et al.* 2019)**

| S/N | Descriptions | Specifications |
|---|---|---|
| **1** | Rim Angle ($\phi_r$) | 90° |
| **2** | Focal Length (f) | 0.30 m |
| **3** | Aperture width ($W_a$) | 1.20 m |
| **4** | The outer diameter of the copper tube ($D_o$) | 0.018m |
| **5** | The inner diameter of the copper tube ($D_i$) | 0.016m |
| **6** | Length of the cylindrical trough (L) | 2.1 m |
| **7** | Effective Aperture Area (Aa) | 2.42 $m^2$ |
| **8** | Concentration Ratio (C) | 11.7 |
| **9** | Reflectivity of the collector (ρ) | 0.9 |
| **10** | Absorptivity of the copper tube (α) | 0.8 |
| **11** | Transitivity of the copper tube (γ) | 0.8 |
| **12** | Intercept factor (ϒ) | 0.92 |

**2.3 Formulation of the heat transfer mechanism**

The heat transfer coefficient of the nanofluid of the parabolic-trough receiver tube is calculated in Equation (1) (Brinkman, 1952):

$$h_{nf} = \frac{Nu_{nf} K_{nf}}{D_i} \qquad (1.0)$$

The Nusselt number $Nu_{nf}$ is analyzed using Equations (2 & 3) for laminar and turbulent flows (Yu and Choi, 2003):

$$Nu_{nf} = 4.364 \qquad (2.0)$$

with the constant heat flux considered and $Re_{nf} \leq 2300$.

$$Nu_{nf} = 0.023 \mathrm{Re}_{nf}^{0.8} \mathrm{Pr}_{nf}^{0.4} \qquad (3.0)$$

Where $2300 < Re_{nf} < 1.25 \times 10^5$ and $0.6 < Pr_{nf} < 100$

In Equation (3), $Re_{nf}$ *and* $Pr_{nf}$ are the nanofluid's Reynolds and Prandtl numbers respectively; $Re_{nf}$ *and* $Pr_{nf}$ are examined using Equations (4 and 5) (Brinkman, 1952):

$$Re_{nf} = \frac{4m_{nf}}{\pi D_i \mu_{nf}} \quad (4.0)$$

$$Pr_{nf} = \frac{Cp_{nf}\mu_{nf}}{K_{nf}} \quad (5.0)$$

The thermo-physical properties of the nanofluids (density, viscosity, specific heat, and thermal-conductivity) were calculated using equations (6 – 9) (Yu and Choi, 2003; Shahrul *et al*., 2014; Leong et al., 2006):

The nanofluids density is calculated using equations (6)

$$\rho_{nf} = \phi\rho_p(1-\phi)\rho_{bf} \quad (6)$$

The nanofluids viscosity is computed using equations (7)

$$\mu_{nf} = \mu_{bf}(1-\phi)^{-2.5} \quad (7)$$

The nanofluids specific heat is assessed using equation (8)

$$Cp_{nf} = \frac{\phi\rho_p Cp_p + (1-\phi)\rho_{bf} Cp_{bf}}{\rho_{nf}} \quad (8)$$

The nanofluids thermal-conductivity is determined using equations (9)

$$K_{nf} = \frac{k_f k_p + 2k_f + 2\phi(k_p - k_f)}{k_p + 2k_f - \phi(k_p - k_f)} \quad (9)$$

The Nusselt number is calculated at 0.2 kg/s mass-flow rate and different volumetric concentrations (1% to 10%).

### 2.4 Efficiency Evaluation:

The actual useful energy ($Q_u$) of the parabolic trough solar collector is examined using Equation (10):

$$Q_u = m_{nf} Cp_{nf}(T_{f,o} - T_{f,i}) \quad (10)$$

The thermal efficiency $(\eta_{th})$ is calculated using Equation (11) (Duffie and Beckman, 1991)**:**

$$\eta_{th} = \frac{m_{nf} Cp_{nf}(T_{f,o} - T_{f,i})}{I_b A_a} \quad (11)$$

The energy balance equations (1 – 11) are solved using a simulation program developed in C++ programming language. The effectiveness of the PTSC and heat transfer coefficient of three different water-based nanofluids with different thermo-physical properties at a mass flow rate of 0.2 kg/s is analyzed. The study was carried out using CuO, $Al_2O_3$ and $TiO_2$ water-based nanofluid at various nanoparticle concentrations in the range 1% ≤ φ ≤ 10% at mass flow rate value of 0.2 kg/s to study the heat transfer coefficient and efficiency of the PTSC. The effect of the thermo-physical properties of three different nanofluids and the volumetric concentration of nanoparticle on the heat transfer rate and system performance of a parabolic trough concentrating system (PTCS) is being investigated in the present research.

## 3. Results and Discussions

The energy governing equations of nanofluids, coupled with the concentrator's efficiency were solved using iterative relaxation method. C++ program is developed to study the impact of the thermal characteristics of CuO, $Al_2O_3$, and $TiO_2$ water-based nanofluid as heat transfer working fluids on the performance of the concentrator with varying sizes of nanoparticle in the range 1% ≤ φ ≤ 10% and mass flow rate value of 0.2 kg/s. The results show that the thermophysical properties have a significant impact on the heat transfer coefficient and the performance of the PTSC. The detailed results are depicted in Figures 2.0 – 11.0

Figure 2.0 presents the variation of the heat transfer coefficient with a change in density at 0.2 kg/s mass flow rate. It displays the plot of the heat transfer coefficient versus the thickness of nanofluid in the range of 1000 – 1375 kg/m$^3$. The result shows that the heat transfer coefficient is increasing by 21%, 20%, and 14% in CuO, $TiO_2$, and $Al_2O_3$ respectively, with the density increase by 28 %. Hence CuO has higher heat transfer behavior; $TiO_2$ and $Al_2O_3$ have the least value as density increase. The result agreed with the findings of Marefati *et al*. 2018 and Chandraprabu *et al.* .2013. The result reveals that there is an increment in the heat transfer coefficient as the density of nanofluid is increased. It is deduced that convective heat transfer in the PTSC is expanding as the thickness of nanofluid is rising.

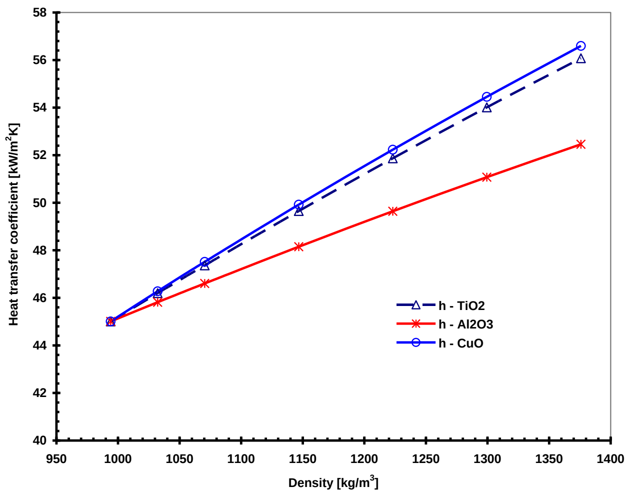


Figure 2.0 Variation of heat transfer coefficient with a change in density at 0.2 kg/s mass flow rate

Figure 3.0 presents the effect in the heat transfer coefficient with different thermal conductivity at 0.2 kg/s mass flow rate. It displays the plot of the heat transfer coefficient versus the thermal conductivity of nanofluid in the range of 0.65 – 0.85 W/mK. The result shows that the heat transfer coefficient is increasing by 20%, 21%, and 14% in $TiO_2$, CuO and $Al_2O_3$ respectively, as the thermal conductivity increase by 23 %. CuO has the highest heat transfer coefficient of 55 kW/m$^2$K, $TiO_2$ has 54 kW/m$^2$K and $Al_2O_3$ has the least value of 51 kW/m$^2$K at a thermal conductivity of 0.8 W/mK. It illustrates that there is an increase in the heat transfer coefficient as the thermal conductivity of nanofluid is increased and It is supported by Sathe and Dhoble, 2017; Ju, *et al*. 2017.

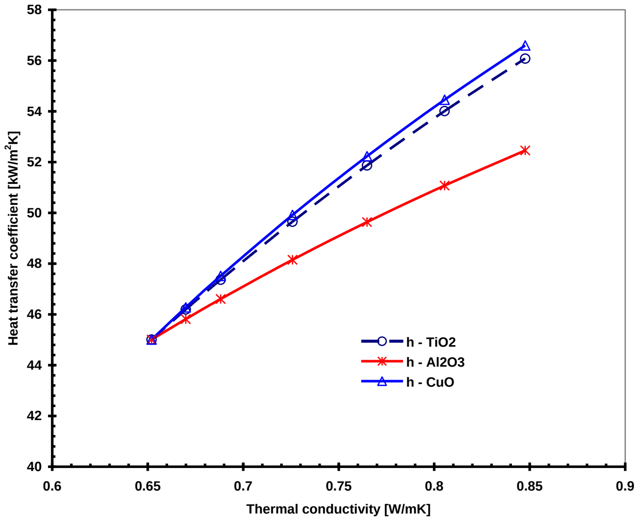


Figure 3.0 Effect in the heat transfer coefficient with different thermal conductivity at a mass flow rate of 0.2 kg/s

Figure 4.0 presents the effect of specific heat capacity on the heat transfer coefficient at 0.2 kg/s mass flow rate. This is the impact of the specific heat capacity of nanofluid (3200 – 4200 J/kg K.) on the heat transfer coefficient. It reveals that the heat transfer coefficient is expanding by 20%, 21% and 14% in $TiO_2$, CuO, and $Al_2O_3$ respectively, with a 30 % reduction in specific heat capacity. CuO has the highest heat transfer coefficient of 55 kW/m$^2$K, $TiO_2$ has 54 kW/m$^2$K and $Al_2O_3$ has the least value of 51 kW/m$^2$K at specific heat capacity of 3400 J/kg K. The result reveals that the specific heat capacity of nanofluid increases as the heat transfer coefficient reduces. It shows that the specific heat capacity of nanofluid is inversely proportional to the heat transfer coefficient. It is deduced that convective heat transfer in the PTSC is diminishing with the rise in specific heat capacity of nanofluid while conductive heat transfer in the PTSC is increasing as the specific heat capacity of nanofluid is reducing

Figure 5.0 presents the variation of thermal efficiency with a change in density. This is the plot of the thermal efficiency of the concentrator versus the thickness of nanofluid in the range of 1000 – 1375 kg/m$^3$ at 0.2 kg/s mass flow rate.

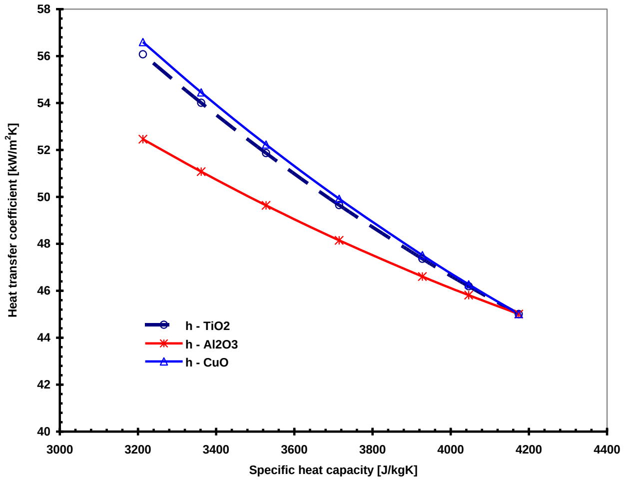


Figure 4.0 Effect of specific heat capacity on the heat transfer coefficient at 0.2 kg/s mass flow rate

Figure 5.0 illustrates that there is a reduction in the thermal efficiency of the concentrator by 9%, 33%, and 56% in $TiO_2$, $Al_2O_3$, and CuO respectively, with a 28% increment in the density of nanofluid. $TiO_2$ has the highest thermal convective ability of 34 %, $Al_2O_3$ has 28 %, and CuO has the least value of 24 % at the density of 1375 kg/m$^3$. It displays that the thermal efficiency is reducing as the density increase. $TiO_2$ is more efficient in convective heat transfer; $Al_2O_3$ and CuO perform efficiently in conductive heat transfer. It can be deduced that less dense fluid plays well for heat transfer fluid in PTCS more than thick liquid.

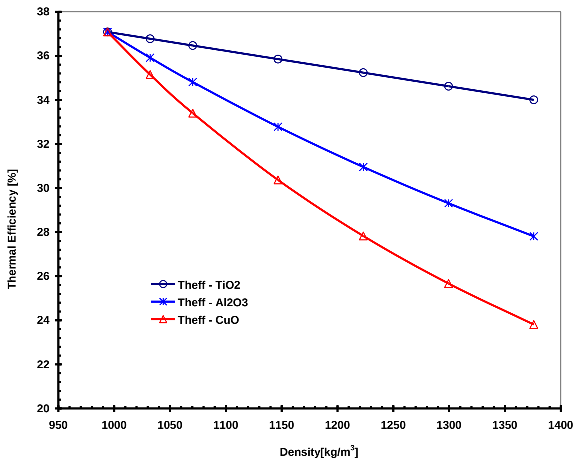


Figure 5.0 Variation of thermal efficiency with a change in density at a mass flow rate of 0.2 kg/s

Figure 6.0 describes the effect of thermal efficiency with different thermal conductivity. This is the plot of the thermal efficiency of the concentrator versus the thermal conductivity of nanofluid in the range of 0.65 – 0.85 W/mK at 0.2 kg/s mass flow rate. It shows that the thermal efficiency is reducing by 9%, 33% and 56% in $TiO_2$, $Al_2O_3$ and CuO respectively, with a 23 % rise in the thermal conductivity. $TiO_2$ has the highest thermal efficiency of 35 %; $Al_2O_3$ has a value of 29 % and CuO has the least value of 26 % at a thermal conductivity of 0.8 J/kg K. $TiO_2$ is more efficient in convective heat transfer rate; $Al_2O_3$ and CuO perform efficiently in conductive heat transfer. It is deduced that the nanofluid with smaller values of thermal conductivity gives the higher thermal convective ability in the concentrator.

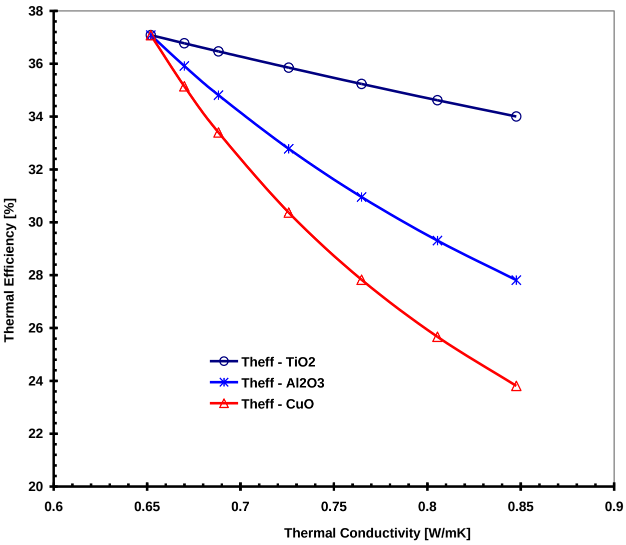


Figure 6.0 Effect in the thermal efficiency with different thermal conductivity at a mass flow rate of 0.2 kg/s

Figure 7.0 presents the effect of specific heat capacity on thermal efficiency. It is the impact of the specific heat capacity of nanofluid (3200 – 4200 J/kg K) on the thermal efficiency of the concentrator at 0.2 kg/s mass flow rate. The result shows that the thermal efficiency is expanding by 9%, 33% and 56% in $TiO_2$, $Al_2O_3$ and CuO respectively, with a 30% rise in specific heat capacity. $TiO_2$ has the highest thermal efficiency of 37 %, $Al_2O_3$ has 36 % and CuO has the least value of 35 % at 4000 W/mK specific heat capacity. It is revealed that the specific heat capacity of nanofluid increases as the thermal efficiency of the concentrator increases. It is deduced that the nanofluid with higher specific heat capacity produces better performance in PTSC. $TiO_2$ is more efficient in convective heat transfer than $Al_2O_3$ and CuO at a smaller value of specific heat capacity.

Figure 8 presents the variation of useful heat gain with a change in density. This is the plot of the valuable heat gain of the concentrator versus the thickness of nanofluid in the range of 1000 – 1375 kg/m$^3$ at 0.2 kg/s mass flow rate.

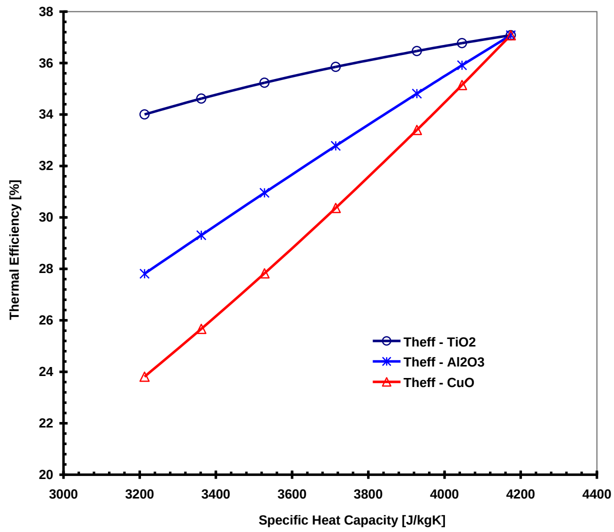


Figure 7.0 Effect of specific heat capacity on thermal efficiency at 0.2 kg/s mass flow rate

Figure 8 shows that the effective heat gain is diminishing by 9%, 33%, and 56% in $TiO_2$, $Al_2O_3$, and CuO respectively, with a 28% rise in density. $TiO_2$ has the highest sufficient convective heat gain of 66 kW, $Al_2O_3$ has 54 kW and CuO has the least value of 46 kW at the mass density of 1375 kg/m$^3$. It illustrates that there is a reduction in the effective heat gain by the concentrator as the density of nanofluid is increased. It is deduced that less dense fluid performs well for heat transfer fluid in PTCS more than thick liquid.

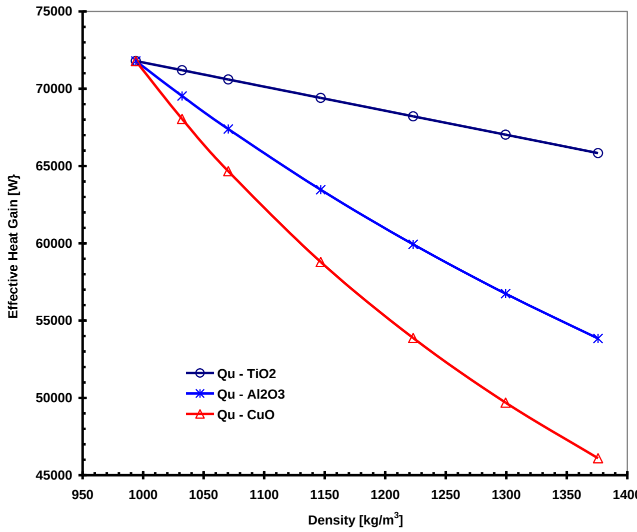


Figure 8.0 Variation of useful heat gain with a change in density at a mass flow rate of 0.2 kg/s

Figure 9.0 describes the effect of the useful heat gain with different thermal conductivity. It is the plot of the valuable energy of the concentrator versus the thermal conductivity of nanofluid in the range of 0.65 – 0.85 W/mK at 0.2 kg/s mass flow rate. It displays that the effective heat gain is reducing by 9%, 33%, and 56% in $TiO_2$, $Al_2O_3$ and CuO respectively, as the thermal conductivity increase 23%/. $TiO_2$ has the highest sufficient heat gain of 67 kW, $Al_2O_3$ has 57 kW and CuO has the least value of 50 kW at a thermal conductivity of 0.8 W/mK. The result shows that there is a reduction in the useful energy of the concentrator as the thermal conductivity of nanofluid is increased. The sufficient heat gain in the PTSC is improving as the thermal conductivity of nanofluid is diminishing, hence the thermal conductivity of nanofluid and useful energy gain in the concentrator has an inversely proportional relationship.

Figure 10.0 presents the effect of specific heat capacity on useful heat gain at 0.2 kg/s mass flow rate. It shows the influence of the specific heat capacity of nanofluid (3200 – 4200 J/kg K) on the useful energy of the concentrator. The sufficient heat gain of the concentrator is increasing, with the increase in the specific heat capacity of nanofluid.

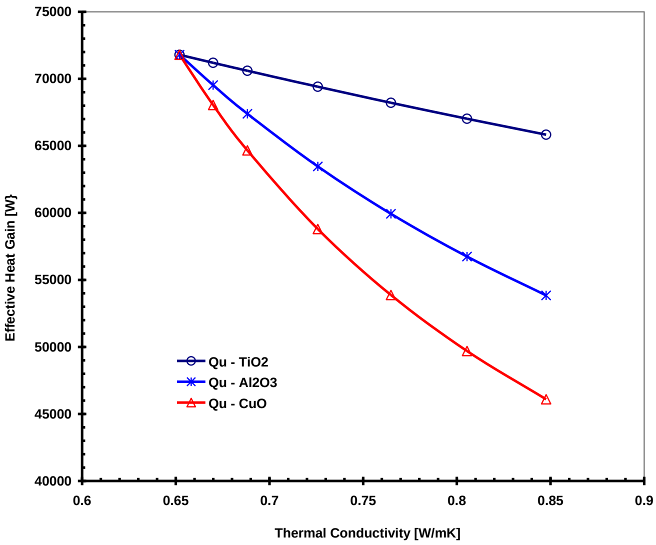


Figure 9.0 Effect in the useful heat gain with different thermal conductivity at a mass flow rate of 0.2 kg/s

Figure 10.0 displays that sufficient heat gain is increasing by 9%, 33% and 56% in $TiO_2$, $Al_2O_3$ and CuO respectively, as the specific heat capacity increase by 30%. $TiO_2$ has the highest sufficient heat gain of 71 kW, $Al_2O_3$ has 70 kW, and CuO has the least value of 68 kW at a specific heat capacity of 4000 J/kg K. The useful heat gain in the PTSC is improving with the higher thermal conductivity of nanofluid.

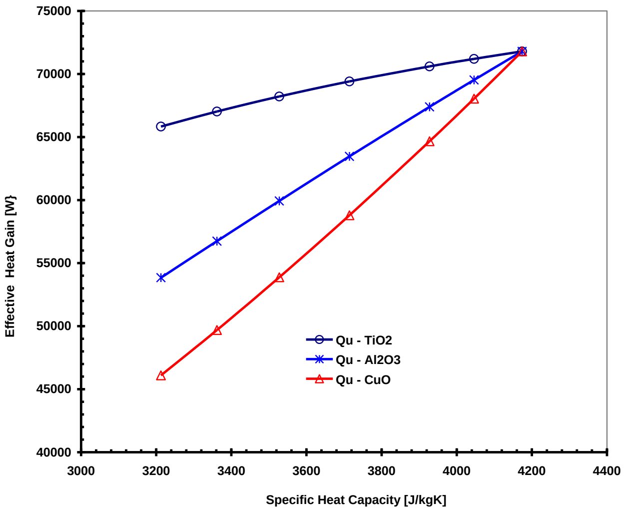


Figure 10.0 Effect of specific heat capacity on useful heat gain at 0.2 kg/s mass flow rate

The plot of the thermal efficiency of the concentrator versus the Nanoparticle size of nanofluid in the range of 1.0 – 10.0 % at 0.2 kg/s mass flow rate is presented in Figure 11.0. Figure 11.0 describes the effect of thermal efficiency with different nanoparticle sizes. There is a reduction in the thermal efficiency of the concentrator as the Nanoparticle size of nanofluid is increased. The PTSC efficiencies at nanoparticle size of 2% are 35%, 36%, and 37% for CuO, $Al_2O_3$ and $TiO_2$ respectively. Also, the PTSC efficiencies at nanoparticle sizes of 10% and mass flow rates of 0.2 kg/s are 24%, 28%, and 34% for CuO, $Al_2O_3$, and $TiO_2$ respectively. Nanoparticle size of nanofluid and thermal efficiency of the concentrator has an inversely proportional relationship. It shows the PTSC has higher performance at the smaller size of the nanoparticle. Hence $TiO_2$ has the highest thermal efficiency, followed by $Al_2O_3$ and CuO has the least value of thermal efficiency at different nanoparticle sizes at 0.2 kg/s mass flow rate.

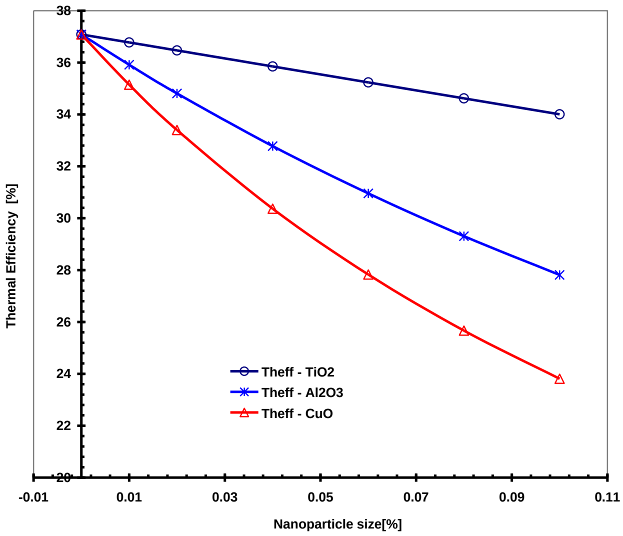


Figure 11.0 Effect in the thermal efficiency with different nanoparticle sizes at a mass flow rate of 0.2 kg/s

## 4. Conclusions

The effect of the thermophysical properties of heat transfer fluid, and the nanoparticle size of CuO, $Al_2O_3$, and $TiO_2$ water-based nanofluid on the heat transfer behaviour and system performance of a parabolic trough concentrating system (PTCS) at 0.2kg/s mass flow rate were analyzed in this research. A numerical method was used to study the influence of the thermal characteristics of the CuO, $Al_2O_3$ and $TiO_2$ water-based nanofluids on the performance of the concentrator with varying sizes of nanoparticle in the range $1\% \leq \varphi \leq 10\%$ at mass flow rate values of 0.2 kg/s and Prandtl number in the range of 4 to 6. The results show that thermophysical properties have a crucial impact on the heat transfer coefficient and the effectiveness of the PTSC. Thermal efficiency increases with a decrease in the nanoparticle size, the density, and the thermal conductivity of the Nanofluid, while the thermal effectiveness of the PTSC is rising with an increase in the specific heat capacity. The PTSC has higher performance at the smaller size of the nanoparticle.

The heat transfer coefficient is expanding by 20%, 21%, and 14% in $TiO_2$, CuO, and $Al_2O_3$ respectively, as the density increase by 28 %, the thermal conductivity increase by 23 %, and as the specific heat capacity reduces by 30 %. Also, the thermal efficiencies are diminishing by 9%, 56%, and 33% in $TiO_2$, CuO and $Al_2O_3$ respectively; as the density increase by 28 %, the thermal conductivity increase by 23 %, and as the specific heat capacity reduces by 30 %. The consequence of the current investigation is imperative for both industrial purposes such as space heating to electricity generation and future analysis. The effective real-life concentrating solar systems can readily apply the findings by making use of the nanofluids, and it will enable to enhance the system performance as well as ensure the commercial suitability of these systems.

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