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Effect of CuO-H_20 and ZnO-H_20 nanofluids on the Performance of Solar Flat Plate Collector

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Keywords
Solar Flat Plate Collector •
Nanofluid •
Efficiency •
Forced Convection.

Abstract

The solar flat plate collector is commonly used in low-temperature domestic applications for water heating. In this paper, copper oxide (CuO) and zinc oxide (ZnO) nanofluids were synthesized and prepared with water as base fluid, and its thermal efficiency is examined by conducting experiment on a solar flat plate collector. The experiment was conducted under forced flow conditions by varying the volume concentration and flow rates of both the nanofluids. For higher flow rates and volumetric fraction considered, substantial performance improvement was observed. The inclusion of EBT (eriochrome black T) and OA (olylamine surfactant, for CuO and ZnO nanofluid provided the best dispersion stability compared to pure water suspension.

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1. Introduction

The quest for efficient energy continues even today with scientists and engineers inventing new technologies and more efficient devices to harness energy (Abdul Razak et al., 2018; Afzal et al., 2017, 2019; Afzal, Kareemullah, et al., 2018; Afzal, Mohammed Samee, Abdul Razak, & Ramis, 2020; Afzal, Mohammed Samee, Abdul Razak, Khan, et al., 2020; Afzal, Samee, et al., 2018, 2020, 2020; Akthar et al., 2015; Kaladgi et al., 2020; Rahiman et al., 2014; Samee AD et al., 2018). To exemplify an innovative option, nanofluids have revolutionized energy extraction, transmission and storing systems over the years. As the substance transfers from micro to nano shape, different variables necessary to augment thermal efficiency dramatically changes. The variables are viscosity, thermal and electrical conductivity, and heat transfer coefficient (HTC). Solar thermal collector is a distinctive kind of heat exchanger that absorbs and partially converts solar irradiation to usable heat that is transferred to a liquid. Together with evacuated tube collector (ETC), flat plate collectors (FPCs) are extensively used for solar energy absorption owing to their simplicity, compact size, ease of maintenance, low production cost and reliability established over the years. Muhammad et al. (2016) reviewed the performance, and energy and ecological aspects of nanofluid implementations in ETC and FPC's, and concluded that nanofluids provide a better substitute to traditional fluids. Sabiha et al. (2015) analyzed the impact of Multi walled carbon nanotubes (MWCNTs) as nanofluid on ETCs efficiency enhancement. At 0.025 kg/s mass flow and 0.2 % volume concentration, the authors observed the highest performance improvement of 93.43%. Tong et al. (2015) analyzed experimental results by replacing the gap resistance with MWCNTs as a working fluid. A performance improvement of 4% was observed in their ETC system (Afzal et al., 2017; Pinto et al., 2017).

Numerous options have been opened up by the invention of nanofluids, a new-age thermal energy fluid. Numerous researchers are now focusing on different aspects of heat transfer over the last few decades. Pak and Cho (1998) registered a 75% increase in the convective HTC of Al_2O_3 with a nanofluid concentration of 2.78%. Natrajan and Sathish (2009) reported enhancement of thermal conductivity of base fluids by the use of CNTs. A theoretical analysis on a non-concentrating direct absorption solar collector was performed by Tyagi et al. (2009) and compared its output with FTC. The impact of nanofluids on the ecology and economy was explored by Otanicar and Golden (2009) when utilizing them to increase solar collector performance. Godson et al. (2009) reviewed the basic characteristics of nanofluids, including improvement of heat transfer and thermal conductivity, rise in surface to volume ratio and Brownian motion. Wang et al. (2009) stressed that the uniformly distributed immersion of nanoparticles in the base fluid greatly affects the characteristics of transport and heat transfer. Using nanoparticle suspension, Kameya and Hanamura (2011) recorded an increase in solar radiation absorption. An improvement in thermal conductivity of ethylene glycol nanofluids was reported by Yu et al. (2011) via experiments. The influence of Al_2O_3 / water nanofluid was examined by Yousefi et al. (2012). They recorded an improvement of 28% in FPC's performance. In another research, Tiwari et al. (2013) recorded 31% improvement in the efficiency of Al_2O_3 nanofluid solar collectors at an ideal 1.5% concentration compared with water nanofluid fluid. Mwesigye et al. (2015) investigated the impact of Al_2O_3 / oil in reducing the entropy.

The literature review indicates that, over the years, several scientists have improved solar FPC performance to the current level. However, relative to other traditional techniques, the present performance of the solar FPC is lower. The inclusion of nanoparticles in the base fluid leads to a major increase in thermal efficiency. Hence, in this paper, two types of nanofluids namely CuO and

ZnO nanofluids were prepared and checked for its performance. The results of these studies will help to gain a broad understanding of the feasibility of solar power devices with nanofluids.

2. Methodology

The test was carried out in a readily available 100 LPD solar FPC by producing copper nanoparticle, processing the CuO / H_2O nanofluid, and relating the efficiency of the processed CuO / H_2O nanofluid with water.

2.1 Preparation of Nanofluids

The ZnO nanoparticles with a mean 90nm particle size and 99% purity, and CuO nanoparticles in spherical form having a diameter of 20-50 nm and purity of 99% were brought from Nanoshel, USA and Nano Labs, INDIA respectively. From the FTIR spectroscopy, (figure 2), the decreased transmittance and absorption coefficient, and higher wavelength signal, it was found that there is really no carboxylic group connection to zinc oxide for nanoparticle diffusion in the working fluid and that it can take as much as 100 hours for diffusion without the use of surfactant if ultra-sonication is performed [15]. In this research, EBT is employed as surfactant and de-ionized water as base liquid for distribution. For optimal diffusion of nanoparticles in base fluid, 0.1% by weight of ZnO nano particles in de-ionized water are blended and agitated for 25 minutes using a magnetic agitator. Then, introducing 0.1 percent of EBT surfactant to this solution, it was agitated again for almost 20 minutes to get a uniform mixture. The mixture with ZnO nanoparticles and EBT surfactant was carefully stirred for additional mixing using a glass rod. As OA provided clear dispersion and stable nanofluids, it was employed for CuO in the current analysis. The mixture was prepared by employing a magnetic stirrer and 0.1% by weight of CuO nanoparticles and 0.1% by weight of OA surfactant, to produce CuO nanofluid as stated earlier. At this stage, the prepared solution was ultrasonicated separately for 2, 4, 6, and 8 h using a bath sonicator. Twelve different nanofluids of 1 liter each were processed cautiously and were placed in glass jars for further testing. The ultra-sonicator was used for sonification, and the prepared nanofluid is shown in Fig. 1.

2.2. Experimental configuration overview

In this research, a 100 LPD thermo syphon-based solar flat plate collector was used. The temperatures of a number of locations were measured using copper-constantan K-type thermocouples of radius 0.4mm, while the inlet and outlet temperatures of the fluid were measured by using chromel-alumel T-type thermocouples of radius 0.06 mm. A handheld (-400C to 10000C) digital thermometer with the accuracy of ± 0.1 ^{o}C was used to read all the temperatures from thermocouples. Pyranometer (Hukseflux LP02) was used to determine the radiation on the flat plate collector. All the sensors were linked to a DQS and were monitored regularly to plot the graphs. A rotameter having a precision of 0.1LPM was used to maintain a constant flow of fluid in to the tubes. A centrifugal pump (0.5 HP and 3m head) was used for forced circulation testing. Fig.3

displays the full experimental design and the graphic illustration of the FPC and properties of fluids used in the experiment si shown in Table 1.

Ultrasonicator ZnO Nanofluid

Figure 1. Preparation of Nanofluid.

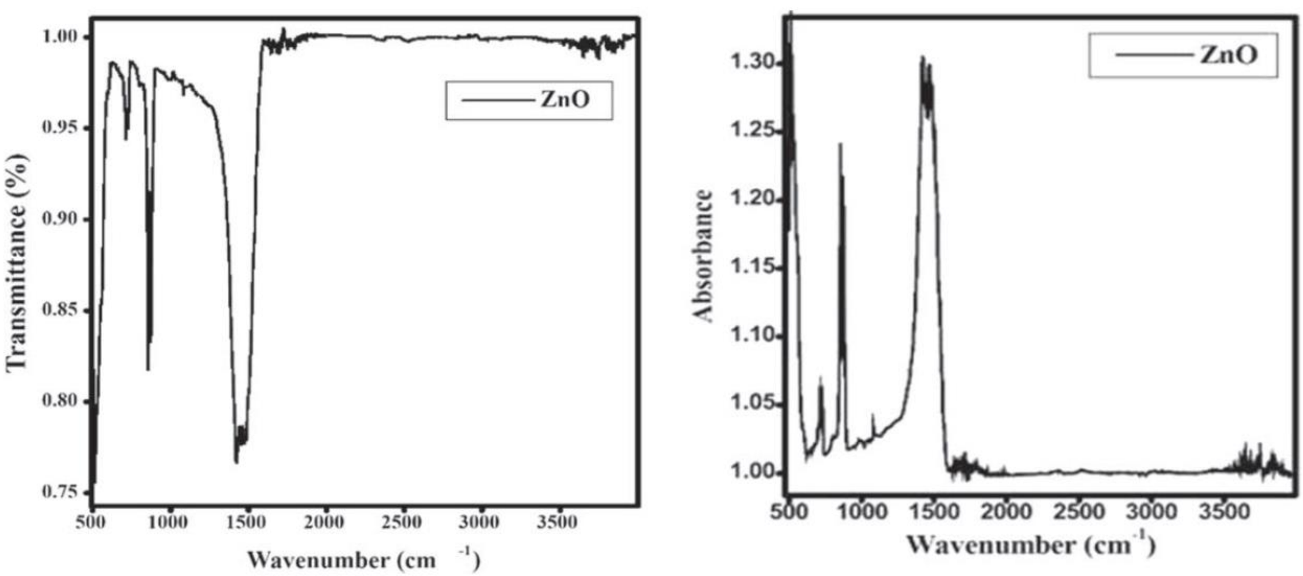

Figure 2. Transmittance% and absorbance of ZnO nanoparticles.

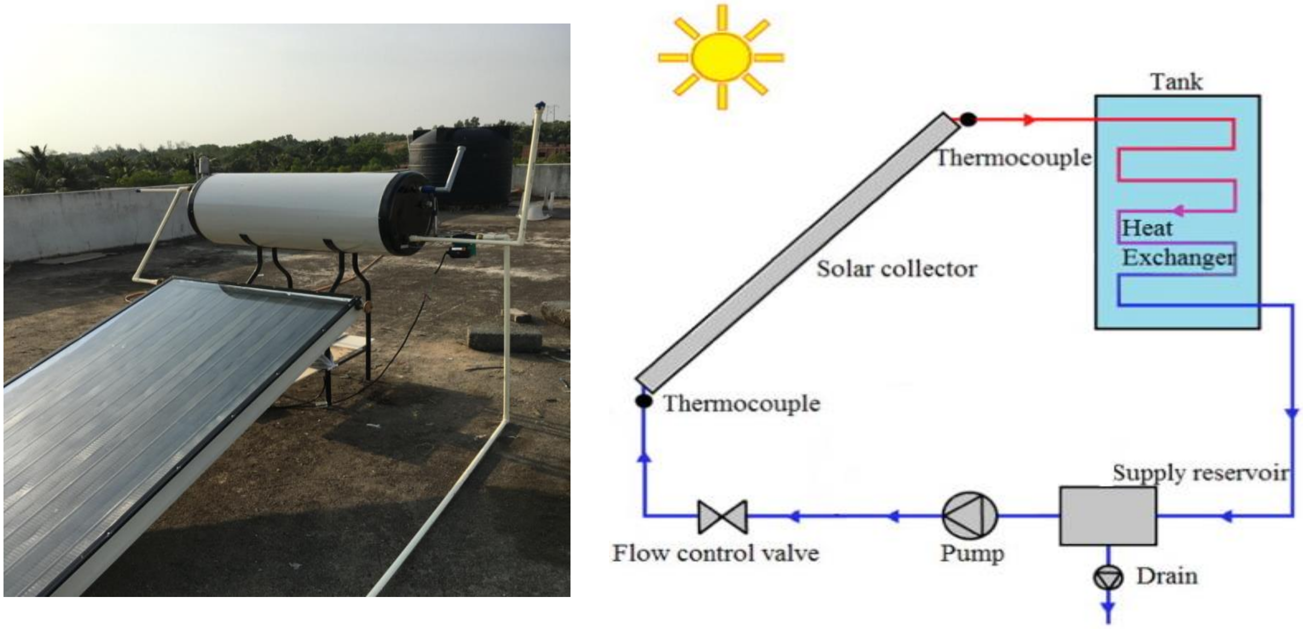

Figure 3. Experimental setup and Schematic diagram

Table 1. Properties of fluids used in the experiment [15]

Fluids	Thermal conductivity, K (W/m.k)	Density q (kg/m^3)	Viscosity m (Pa.s)	Specific heat Cp (J/kg.k)
Water	0.6072	997.04	8.94 104	4183
ZnO /water	0.52	7133	–	383
CuO/water	0.672	1260	0.945	399

2.3. Uncertainty analysis

The important thermal performance parameters were determined after measuring temperature, mass flow rate, etc. The uncertainty in the experiment was estimated by considering the accuracies of all the measuring equipment's by using the method described by Moffat [16].

The solar collector's efficiency was computed using the following formula:

$$\boldsymbol{\eta} = [\boldsymbol{m} \times \boldsymbol{C_p} \times (\boldsymbol{T_0} - \boldsymbol{T_i})]/[\boldsymbol{A_c} \times \boldsymbol{I(t)}] \text{ ----- (1)}$$

Where the useful heat, $\boldsymbol{Qu} = \boldsymbol{m} \times \boldsymbol{C_p} \times (\boldsymbol{T_0} - \boldsymbol{T_i})$ -----(2)

$\boldsymbol{A_c}$- Area of the collector, Ti = temperature of inlet fluid (°C),

I(t) = Total solar radiation incidence on the absorber plate ($\boldsymbol{W/m^2}$),

$\boldsymbol{T_a}$ = ambient temperature (°C).

3. Results and Discussion

In this paper, the various thermal performance parameters of interest of a solar FPC was calculated using zinc and copper oxide as a nanofluids. The test was performed by changing the rate of flow of nanofluids under conditions of forced flow. The effect of these nanofluids' flow rate on the performance of the FPC was also compared with that of water.

3.1. Reservoir temperature at various flow rates

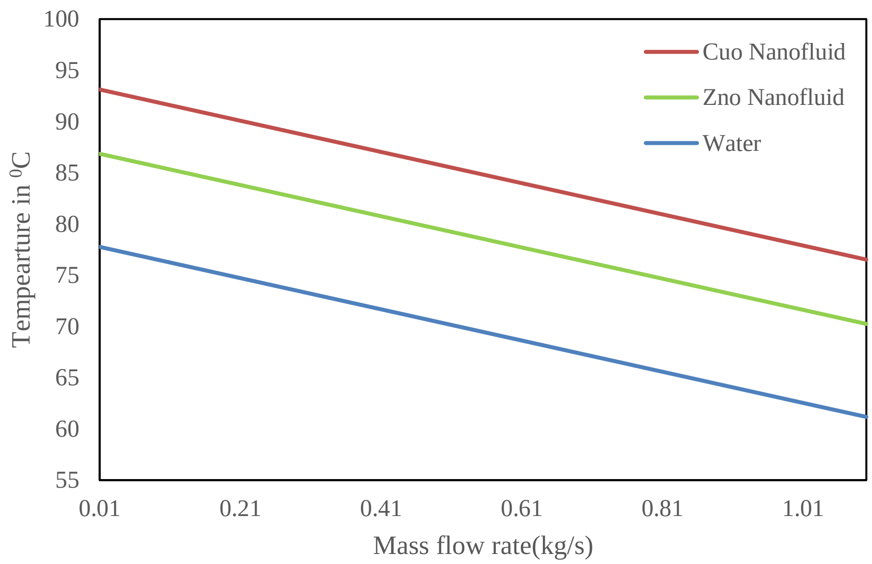

Figure 4. Thermal reservoir temperature at various flow rates.

Figure 4 displays the disparity of thermal reservoir temperature with flow rates. The concentration of both the nanofluids was kept constant at 0.06% by volume. The temperature of the water in the thermal reservoir relies heavily on the efficacy of the heat exchanger and the temperature differential between the exit and the intake of the fluid. It was observed that the reservoir temperature decreased with increase of flow rate for both nanofluids and water. However, the reservoir temperature was the highest for CuO nanofluid followed by ZnO nanofluid and water, which is consistent with the respective thermal conductivity values. Lower flow rates provide more heat transfer to the reservoir, and it decreases with increase of flow rate owing to the less contact time with the heat exchanger.

3.2. Thermal Reservoir temperature at various concentrations

The variation of the thermal reservoir temperature with concentration is depicted in Figure 5. In general, the reservoir temperature increases with the rise in concentration, which is attributed to the higher thermal conductivity at higher concentration. Moreover, as previously seen, the temperature was the highest for CuO nanofluid as compared to ZnO nanofluid and water.

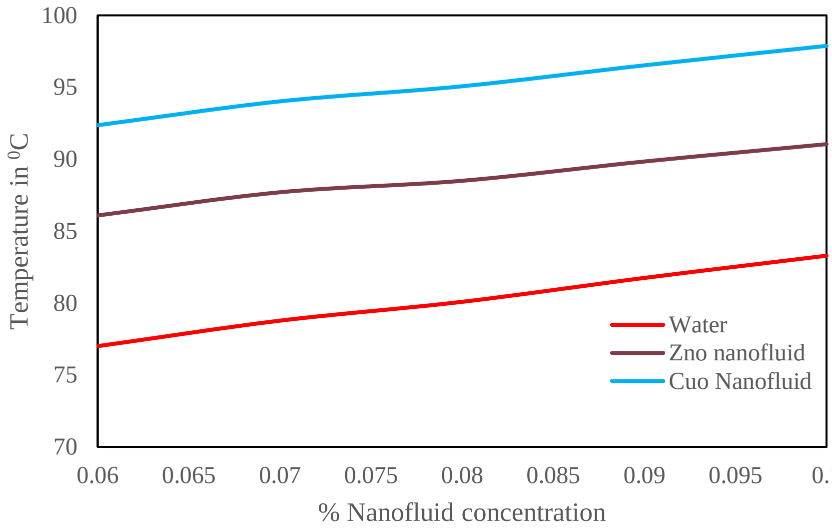

Figure 5. Thermal reservoir temperature at various concentrations.

3.3. Influence of flow rate and Nanofluids Concentration on Fluid Exit Temperature

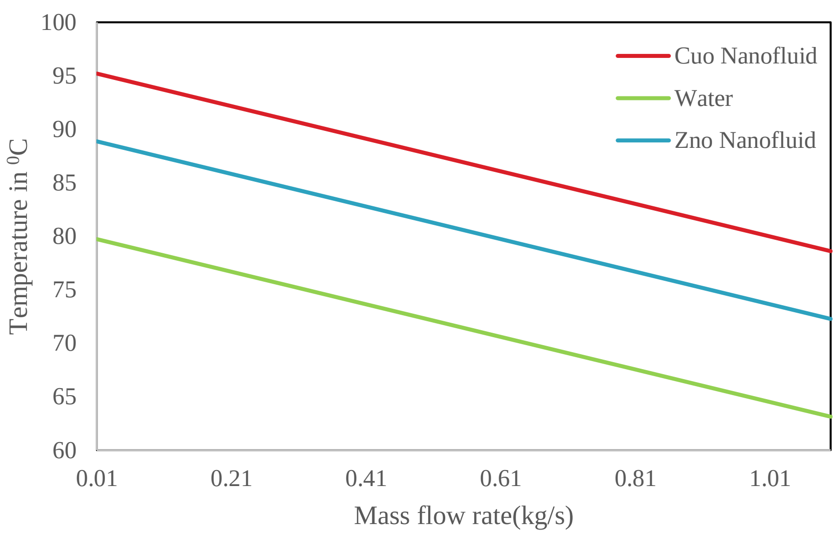

Figure 6. Variation of outlet temperature of the fluid with flow rates.

The effect of flow rate on the outlet temperature of the fluid is depicted in Figure 6. The concentration of both the nanofluids was kept constant at 0.06% by volume. The temperature of the fluid outlet from a solar FPC relies heavily on the flow rate, solar insolation and ambient temperature. This temperature was observed to be higher in the lower flow rate region and lower at higher flow rates. This is because the coefficient of heat transfer would be greater at lower flow rates.

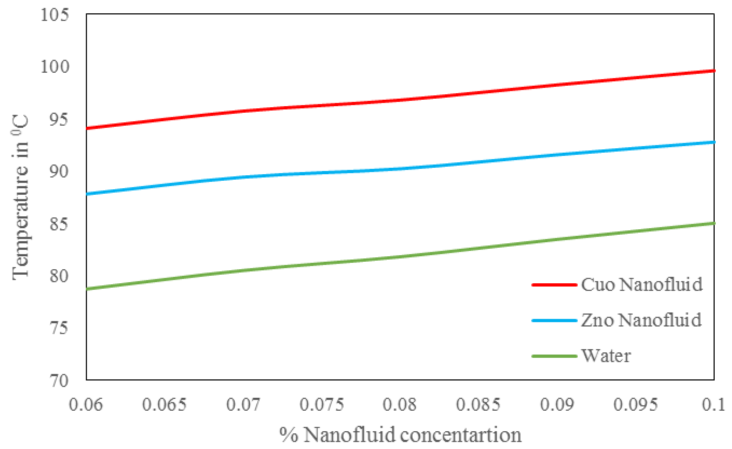

Figure 7. Variation of outlet temperature of the fluid with nanofluid concentration.

Figure 7 shows the variation of the outlet temperature of the fluid with nanofluid concentration. It could be seen that the outlet temperature was the highest for higher concentration and decreased with decrease in concentration; this is because the conductivity is higher at higher concentration. The lowest temperature was obtained for water because of its lowest thermal conductivity.

3.4. Influence of flow rate and Nanofluid Concentration on solar Efficacy

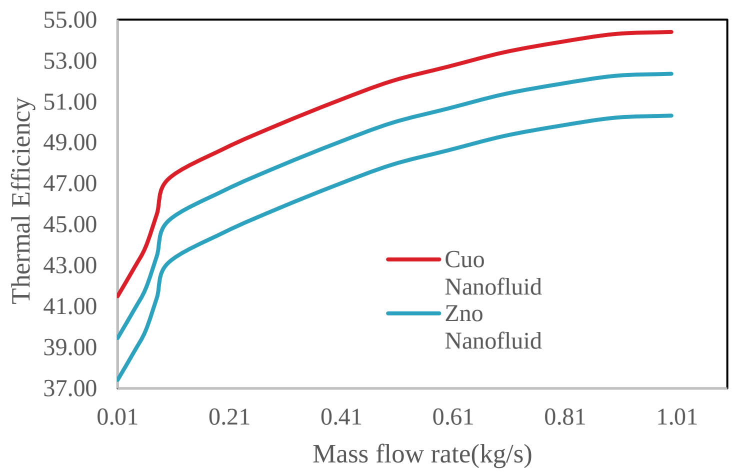

Figure 8. Disparity of solar *efficacy* with flow rates.

The impact of flow rate on solar *efficacy* is depicted in Figure 8. It is obvious that the thermal efficiency increased with increase in flow rate and was the highest (about 54.4%) for a flow rate of 1kg/s for CuO nanofluid. Because, at higher flow rates, Reynolds number is high and due to turbulent flow conditions, the coefficient of heat transfer is also higher.

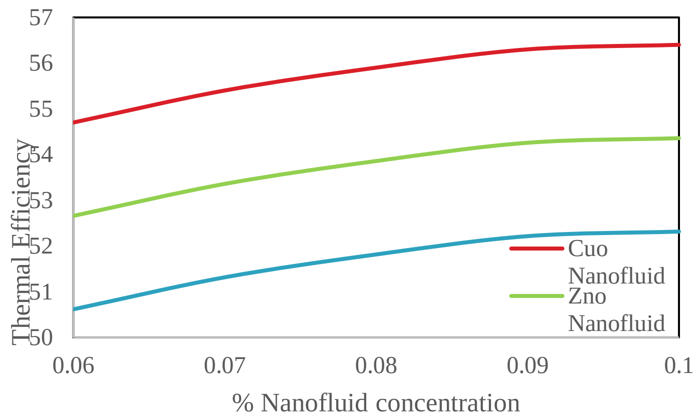

Figure 9. Change of thermal efficiency with nanofluid concentration.

The variation of thermal *efficacy* with nanofluid concentration is depicted in Figure 9. The thermal efficiency increased with increase of nanofluid concentration. It was the highest (about 56.3%) for a concentration of 0.1kg/s for CuO nanofluid and decreased as concentration decreased. The lowest efficiency was observed for water because of its relatively lower thermal conductivity.

4. Conclusion

Two types of nanofluids namely CuO and ZnO nanofluids have been experimented for their potential to improve the performance of solar FPCs. The following conclusions are worth noting:

- Nanofluids, especially CuO and its concentration and flow rate play a very important role in augmenting the reservoir temperature; higher concentrations and lower flow rates enhance the reservoir temperature.
- The exit temperature also increases with nanofluid concentration; higher concentration is desirable for applications where high temperature is required in short duration of time.
- The thermal efficacy upsurges with increase in flow rates and is the highest (about 54.4%) for a flow rate of 1kg/s for CuO nanofluid.
- CuO nanofluid provides higher efficiency (about 20%) as compared to ZnO nanofluid
- The thermal efficacy upsurges with increase in nanofluid concentration. It is the highest (about 56.3%) for a nanofluid concentration of 0.1kg/s for CuO nanofluids and decreases as concentration decreases because of the high conductivity of the nanofluids at higher concentrations.

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