Solar absorption capacity of zinc oxide nanofluids

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Nanofluids have been studied since 1995 for their enormous thermal conductivity enhancement. Applications of nanofluids include electronic, automobile and nuclear reactor cooling. Nanofluids have also been explored as potential fluids for direct absorption solar collectors. In the present work, zinc oxide nanofluid (ZnO) has been synthesized by a two-step process without any surfactant. ZnO nanoparticles are characterized by XRD and SEM to reveal ZnO nanorods with average diameter and length of 50–500 nm. The stability of the nanofluid has been studied by zeta potential measurement for 0.1, 0.2, 0.3 and 0.4 wt%. ZnO/water nanofluid showed good solar absorption (12.2%) and can act as better solar absorbers like Ag nanofluids.

Keywords: Direct absorption solar collector, nanofluid, solar absorption, ZnO.

A major thrust on nanotechnology is on energy harvesting applications. Deploying non-renewable energy resources has put pressure on the scientific, academic and energy engineers to innovate new energy absorption and generation mechanisms. ZnO nano products in the form of nanowires[1], nanosheets[2], nanofilms[3] have been studied to achieve high solar absorption. ZnO is a semiconducting material with a wide band gap of 3.37 eV and a large excitation binding energy of 60 meV. It is also biosafe and biocompatible[4]. The use of ZnO as a solar cell material has been reported in earlier studies[5]. Recently ZnO is reported as an active *n*-layer and antireflective coating for silicon-based heterojunction solar cell[6].

The term nanofluids, coined by Stephen S. Choi, can be defined as a colloidal suspension of nanoparticles in a suitable base fluid[7]. Nanofluids show enhanced thermal and electrical conductivity with tunable properties based on volume fraction of nanoparticles in the base fluid[8,9]. ZnO nanofluids have been studied for electrical conductivity with propylene glycol base fluid and insulating oil and have shown 10^5 fold increase in conductivity for a volume fraction of 0.75% (refs 10, 11). Enhanced thermal conductivity results of ZnO/ethylene glycol nanofluid (27% for 5 vol%) are reported by Wei Yu[12]. ZnO nanofluids have been studied extensively for their thermal and heat transfer properties through round robin test and the results confirm the discrepancy between experimental and theoretical values[13]. ZnO nanofluids have shown hysteresis during heating and cooling cycles[14] and extensive studies have been performed an their physiochemical properties[15,16]. Singh made on ultrasonic study of ZnO nanofluids[17]. Results of nanofluid thermal conductivity enhancement may depend on the shape, pH and viscosity[18].

Nanofluids have been explored for their optical properties over the past five years and have been proved as efficient liquids in direct absorption solar collectors (DASC) for thermal applications. Nanofluids are potential fluids to enhance efficiency in flat plate solar collectors[19] and parabolic solar thermal collectors[20]. Solar energy harvesting with nanofluids has been reported especially in DASC[21–28]. TiO_2 and carbon black nanofluids have been exploited to achieve better photothermal absorption. Nanofluids have also been used as selective optical filters[29] and the optical properties of metal oxide nanofluids[30] have been studied to prove their suitability in solar absorption. Despite extensive research in ZnO nanofluids and their application to DASC, the comparison of solar absorption between the base fluid and ZnO/water nanofulid is yet to be made. The present work focuses on the absorption characteristics of ZnO nanofluid and their enhancement in comparison to base fluid for 0.1, 0.2, 0.3 wt% of ZnO in water. The results are reported for a moderate day temperature of 33–35°C (location Madurai, India, lat. 9.9000°N, 78.1000°E).

Nanoparticles were prepared by sol–gel route. Zinc acetate dihydrate (10 g) was mixed with 50 ml of absolute ethanol in a beaker[31]. The resulting mixture was stirred using a magnetic stirrer for about 60 min until a colloidal precipitate was formed. NaOH was used to control the pH. The solution changed to milky white colour after 2 h. The solution was dried in an oven at 110°C for 3 h leaving behind ZnO nanopowders. The dry powders were further ground into finer particles using a mortar and pestle.

ZnO nanofluid was prepared by a two-step method with water as the base fluid using ultrasonication. ZnO

Table 1. Variation of pH and electrical conductivity

Weight fraction of ZnO	pH	Electrical conductivity (milli simens)
0.1	7.50	5.30
0.2	7.20	7.50
0.3	7.0	9.0
0.4	6.90	10.60

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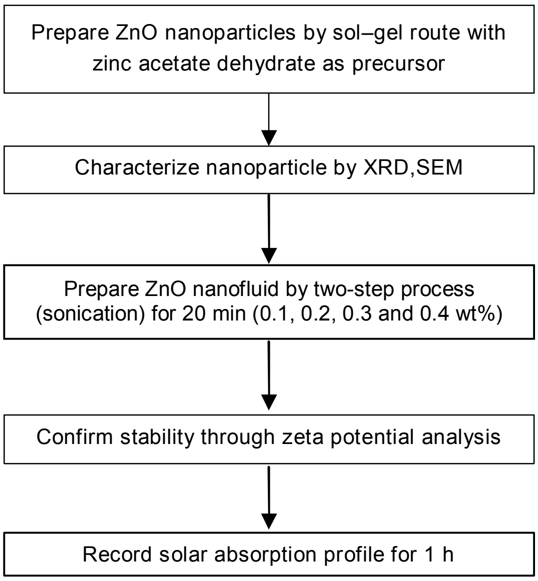
*For correspondence. (e-mail: rilangovan@gmail.com) nanofluids (0.1, 0.2, 0.3, 0.4 wt%) were dispersed with water as base fluid in two volumes (10 and 50 ml) to get eight possible combinations. The nanofluids (10 ml) were stored in cylindrical bottles of 1 cm diameter and the 50 ml nanofluids stored in 5 cm diameter beakers (Figure 1).

Figure 1. Prepared nanofluids.



Prepare ZnO nanoparticles by sol–gel route with zinc acetate dehydrate as precursor

Characterize nanoparticle by XRD,SEM

Prepare ZnO nanofluid by two-step process (sonication) for 20 min (0.1, 0.2, 0.3 and 0.4 wt%)

Confirm stability through zeta potential analysis

Record solar absorption profile for 1 h

Figure 2.

The ZnO nanoparticles prepared were characterized by XRD, SEM and BET to reveal the crystallite size, morphology and surface area. The stability of nanofluids was characterized by zeta potential tests. The pH and electrical conductivity of ZnO nanofluid were measured. The prepared nanofluid samples were analysed for their solar absorption capacity by placing them in open sunlight for 75 min. The temperature of base fluid and different nanofluids was recorded by an IR thermometer. In order to differentiate the thermal properties, the base fluid and nanofluid were heated to 80°C and further cooled to obtain the cooling curve of the nanofluid and base fluid. The results are shown in Figure 2.

Figure 3 shows the powder XRD pattern for ZnO nanopowders. Comparison with standard JCPDS card 36-1451 confirmed that the synthesized ZnO materials are in hexagonal phase, wurtzite structure. The three diffraction peaks between 30 and 40 angles confirm the presence of

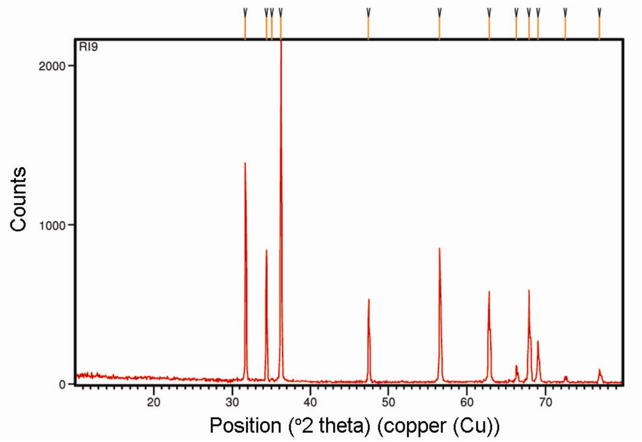


Figure 3. XRD of the prepared sample.

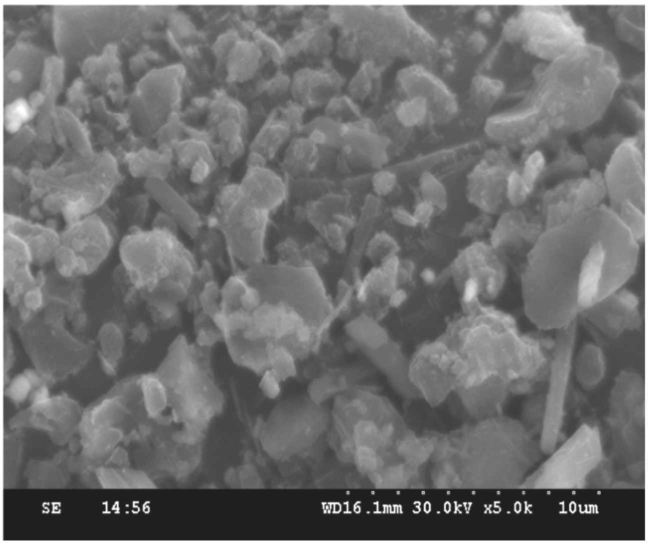


Figure 4. SEM of the prepared samples.

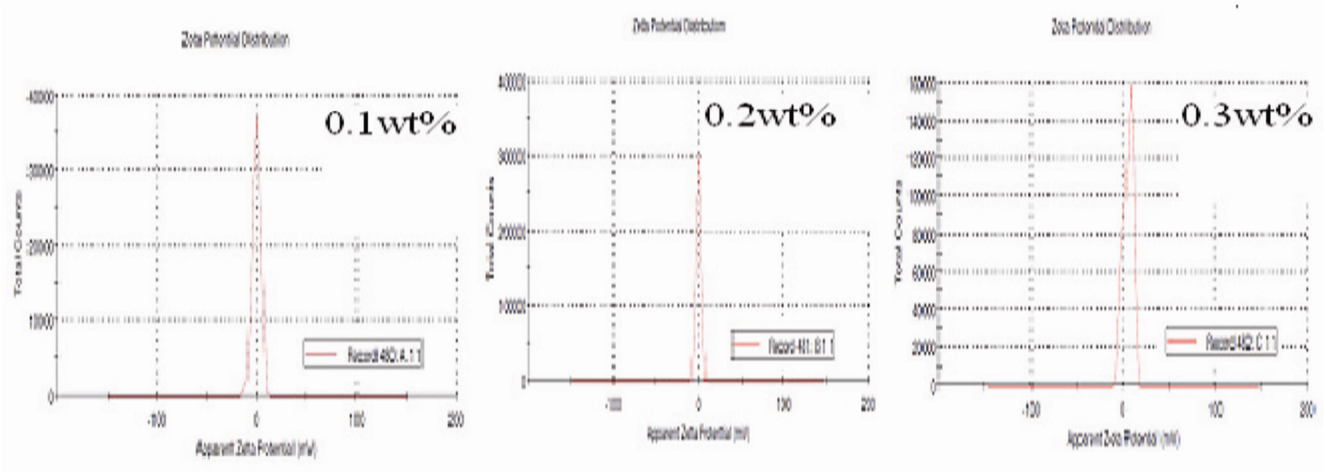


Figure 5. Zeta potential of 0.1, 0,2, 0.3 wt% nanofluids.

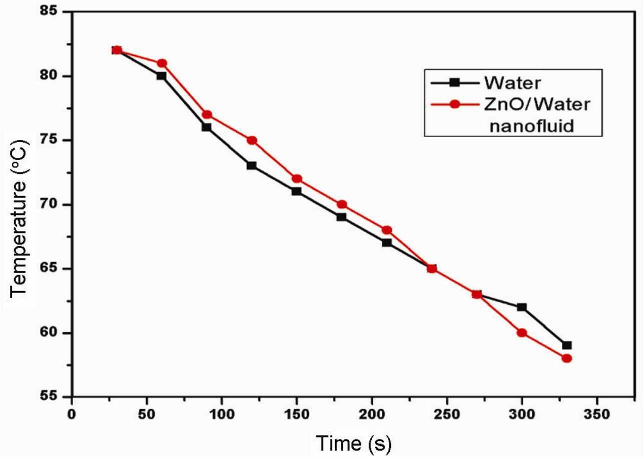


Figure 6. Cooling curve of base fluid and nanofluid.

ZnO. Average crystalline size of ZnO determined by the Debye–Scherer formula $0.9\lambda/\beta\cos(\theta)$ was found to be in the range of 200–500 nm.

SEM test revealed ZnO nanoparticles in the form of rods and flakes (Figure 4). The heterogeneous morphology can be attributed to the lack of uniform temperature following heat treatment or hand milling technique. ZnO nanorods (3–10 μm long and of 200–500 nm) were observed. The solar absorption characteristics can vary with the morphology of nanoparticles. The BET analysis reveals a surface area of 3.75 mÅ^2/g, which corresponds to a nanoparticle size of 285 nm (ref. 32).

The stability of nanofluids is important in nanofluid technology and the use of surfactants can increase the stability to a large extent[33]. In the present work, emphasis was on absorption characteristics of ZnO nanofluid with water and surfactants were not included as they can alter the absorption characteristics of the nanofluid. The stability of ZnO nanofluid was identified for 0.1, 0.2, 0.3 wt% nanofluid. Nanofluids (0.4 wt%) are highly unstable and sedimentation starts after 5 h. Among the prepared nanofluids, ZnO nanofluids with 0.3 wt% show high stability with a zeta potential of –15 mV to +25 mV. The zeta potential of 0.1 wt% and 0.2 wt% is in the range of +15 mV to –15 mV (Figure 5). Visual sedimentation also shows that 0.3 wt% nanofluid is stable for 20–24 h without any trace of sedimentation but all the other fluids settle within 6–12 h.

The pH of the sample decreases with increase in weight fraction of ZnO nanoparticles while the conductivity increases with increase in weight fraction. The increase in pH may change the stability of nanofluid.

The nanofluid and base fluid were heated at 80°C and the cooling of nanofluid is observed till it reaches room temperature to record the cooling curve (Figure 6). Nanofluids are found to cool faster than the base fluid from 80°C to 50°C, which confirm their efficient heat transfer within the boiling point of the base fluid. The efficient heat transfer of nanofluid is due to enhanced thermal conductivity of nanosuspensions as explained by Maxwell model, Hamilton and Crossser model, Patel model and the Lee model. Several static and dynamic thermal conductivity models exist in the literature to explain the increased heat transfer of nanofluids[34].

The efficiency of solar absorption between the base fluid and nanofluid is compared by observing the temperature absorption of the prepared nanofluids with two surface areas (1 and 5 cm diameter) designated as B and BA respectively. The increase in temperature is observed for 75 min at regular time intervals. The solar absorption profile is shown in Figure 7. It is observed that temperature increases by 1.5°C (4.5%) for nanofluid (BA) of 0.4 wt% in a beaker at 300 sec. The same temperature increase 1.5°C (4.5%) is observed for nanofluid (B) of 0.4 wt% in bottle at 300 sec. Thus, the nanofluids' absorption varies within 5 min when compared with a base fluid irrespective of the surface area of the device. The temperature also increases by 5°C for nanofluid (BA) of

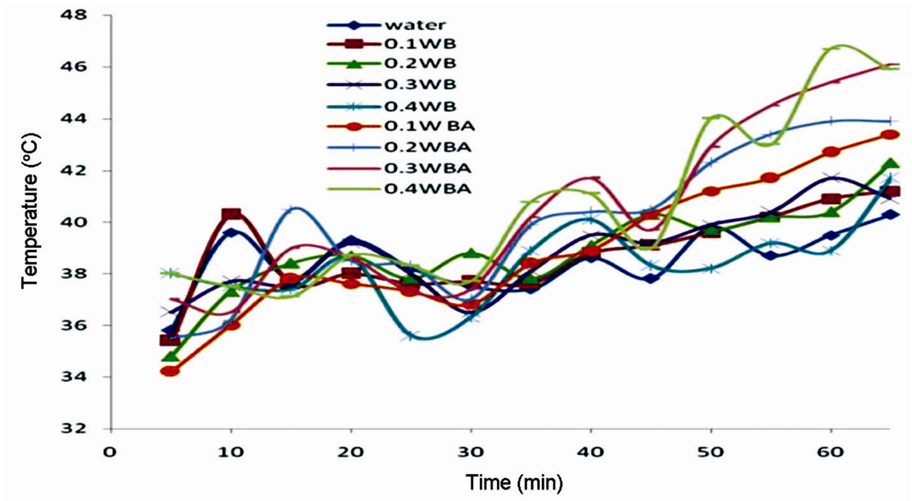


Figure 7. Solar absorption profile of 0.1–0.4 wt% BA and B samples.

0.4 wt% in beaker (12.22%) for 3900 sec. The temperature is increased by 0.8°C (1.9%) for 3900 sec for (B) 0.4 wt%. In comparison, the BA 0.4 wt% sample is 84% effective than B 0.4 wt%.

ZnO nanoparticles prepared by sol–gel route and characterized by XRD, SEM and BET reveal a particle size of 200–500 nm. ZnO nanofluids without surfactants have been prepared with water by a two-step method and characterized by zeta potential measurements. Nanofluids (0.3 wt%) are more stable with a potential of –15 mV to +25 mV for 20–24 h. The best solar absorption is observed for BA 0.4 volume% (12.22%) for 3900 sec. Cooling efficiency of ZnO and water shows that cooling of ZnO is faster when compared to water. Based on the above results of stability and temperature profile, we recommend that ZnO nanofluids can serve as a solar fluid for DASC. Yurong He *et al.*[35] have recommended silver nanofluids in comparison to ZnO and TiO_2 nanofluids for solar absorption. The present work signifies the application of ZnO nanofluids with different volume fractions to achieve better absorption than that predicted by Yurong He. The associated benefits such as savings in cost and the biosafe nature of ZnO show ZnO to be a better candidate or a compatible material to silver nanofluids. Further work is necessary to understand the effect of absorption with different shapes and sizes of ZnO particles in water for enhancing the efficiency of solar collectors.

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Gait parameters in school going children using a marker-less approach

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The burden of course work in Indian schools has exposed the school children to various postural/gait disorders due to heavy backpack. Therefore, it is paramount to develop a low cost, non-intrusive and reliable method for calculation of gait parameters. This study assessed the spatiotemporal parameters such as height of earlobe (HoE), stride length (SL) and stride width (SW) using the markerless sensor Kinect v2 and conventional techniques pursued in Indian clinics. Sixty school children (aged 11 to 15 years) were monitored through both the techniques while performing walking trials. To assess the agreement between the techniques Bland–Altman 95% bias, percentage error (PE), Pearson's correlation coefficients (r_1) and concordance correlation coefficients (r_2) were determined. Each parameter obtained from both techniques possessed strong correlation ($r_{1 \text{ and } 2} > 0.90$). Gait analysis using the Kinect V2 sensor is an acceptable, unobtrusive and economical method. The effect of relative backpack weight (RBW), i.e. (bag weight to body weight percentage) and strategies of backpack packing recommended by the American Occupational Therapy Association on the selected parameters was studied. The effect of RBW on the variation in parameters was evaluated using the regression curve whereas the effect of proper packing was evaluated by paired sample T test. RBW has positive correlation with SW ($r_1 = 0.631$), negative correlation with HoE ($r_1 = -0.387$) but shows no correlation with SL. Recommended packing strategy of schoolbag by AOTA shows results to reduce the unwanted variation in gait parameters.

Keywords: Packing, heavy backpack, spatiotemporal parameters, Kinect V2, school children.

BACKPACKS are the most common form of load carriage used in the world since ages, especially by school-going students. According to the data released by the Ministry of Human Resource Development in 2013 approximately 180 million students in India need a backpack to take away items to and from school every day[1]. School-going children are the invaluable resources of the nation. Hence there has been a growing concern among health practitioners, parents and educators to reduce the increasing load of school backpack that may cause serious effects on the gait of the students[2]. Obesity and stair decent may

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