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Thermo-optical properties of copper oxide nanofluids for direct absorption of solar radiation

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ABSTRACT

In this paper, the optical and thermophysical properties of CuO nanofluid as the working fluid of low temperature direct absorption solar collector which is prepared by dispersing the CuO nanoparticles into mixture of distilled water and ethylene glycol (70%:30% in volume) as the base fluid is investigated at the different temperatures for different volume fractions. The results showed that the nanofluids had higher absorption coefficient compared to the base fluid in the whole wavelengths for solar energy, ranging from 200 to 2500 nm. The absorbed energy fraction of CuO nanofluid with only 100 ppm (volume fraction 0.01%) nanoparticle volume fraction is 4 times more than that of the base fluid at solar collector depth of 1 cm. The viscosity increased with the increasing volume fraction and decreased exponentially with the increasing temperature. The thermal conductivity of CuO nanofluids increased with the increase of CuO volume fraction in the base fluid and temperature. At the investigated volume fractions, the thermal conductivity of the nanofluids was found to increase with respect to the base fluid up to about 13.7% for the 100 ppm CuO nanoparticle volume fraction. Higher thermal conductivity and lower viscosity of CuO nanofluids by increasing temperature, together with the appropriate optical properties, introduce this kind of nanofluids as an appropriate candidate to effectively enhance the direct absorption solar collector efficiency.

1. Introduction

Direct absorption solar collector is an approximately new kind of solar thermal collection devices that has been developed in order to overcome drawbacks of conventional solar collectors such as limitations on incident flux density and relatively high heat losses [1]. In this kind of collector, solar radiation can be directly transferred into a fluid medium, which subsequently reduces the concentrated heat at the surface (Fig. 1).

In 1970s, researchers proposed utilizing particle suspensions in liquids to increase the solar direct absorption [2–4]. In these studies, black liquids containing millimeter to micrometer-sized particle were used as working fluid in solar collectors due to their excellent optical properties. However, the applications of these suspensions are limited because of severe abrasion, sedimentation, and plug problems of coarse particles.

More recently, nanoparticle-liquid suspensions have been proposed as a means to enhance solar collector efficiency through direct absorption of the incoming solar energy [1]. Since common solar fluids (water, ethylene glycol (EG), propylene glycol (PG), etc) do not absorb solar energy well [5], the use of nanoparticle enhancement is necessary. In addition, nano-sized particles can be added into conventional liquid pumping and plumbing with little adverse affects such as abrasion or clogging [6,7].

Several researchers have reported that nanofluids could effectively improve the solar energy utilization. In the most recent work by Tyagi et al., the benefit of direct absorption solar collector (DASC) using aluminum nanoparticle suspensions in water have been numerically evaluated [1]. The result of their study showed 10% efficiency improvement of the nanofluid-based DASC than that of the conventional flat plate solar collector using pure water under similar operating conditions. A similar numerical investigation was conducted by Otanicar et al. and the numerical results were validated by experimental data obtained from a micro-solar collector [8]. The nanofluids based on the carbon nanohorns (CNH) from the family of carbon-based nanostructured materials were used as direct sunlight absorbers in work by Sani et al. [9–11]. They demonstrated that only small amount of radiation (~5% of the total extinction) was scattered by SWCNH particles and therefore the absorption effect was strongly prevailing.

Mu et al. investigated the radiative properties of SiO2/water, TiO2/water, and ZrC/water nanofluids. They found that the ZrC

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nanofluid had the highest solar absorbance among the studied nanofluids [12]. Taylor et al. found that for the nanomaterials used in their study, over 95% of incoming sunlight can be absorbed (in a nanofluid thickness ≥ 10 cm) with extremely low nanoparticle volume fractions – less than 1×10^{-5}[13].

The presence of suspending nanoparticles inside the fluid changes also the transport properties and heat transfer characteristics of the fluid. Thermal conductivity is an important parameter for heat transfer systems and affects the collectors' efficiency. Viscosity and rheological behaviors not only are essential parameters for nanofluid stability and flow behaviors but also affect the heat transfer efficiency of direct solar absorbers. Great efforts have been made to the rheological behaviors and thermal conductivities of nanofluids [14–20]; however, there are only few researches on copper oxide nanofluids [21–24], which mainly concern about the viscosity, dispersion stability, and tribological behavior. In addition, there are no researches committed to the optical properties of metal oxide nanofluids with the aim of absorbing solar radiation.

In this study, copper oxide nanofluids were prepared by dispersing the copper oxide powder into mixture of distilled water and EG (70%:30% by volume).The optical properties, viscosity, and thermal conductivities of the nanofluids as the working fluid of low temperature direct absorption solar collector (operating temperature between 0 °C and 100 °C) were also investigated to study the potential of using the nanofluids for absorbing solar radiation in solar thermal collectors.

2. Preparation of nanofluids

In the present work, CuO nanoparticles with an average diameter less than of 40 nm and density of 6.3 gr/cm^3 were used. The

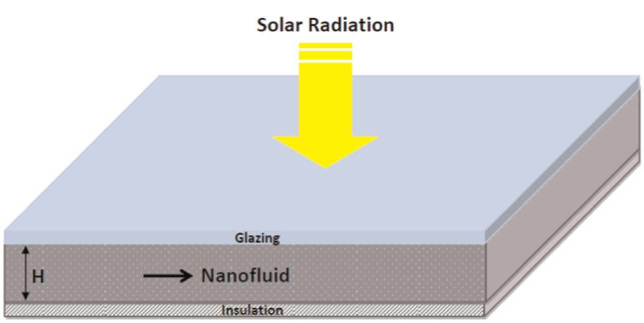

Fig. 1. Schematic of a direct absorption solar collector.

SEM Photography of CuO nanoparticles is shown in Fig. 2(a). As the dispersant, PVP (Polyvinylpyrrolidone) with the weight ratio of 0.25:1 (PVP:CuO) was used to prepare the CuO nanofluid [25]. Nanoparticles with different volume fractions were dispersed in a 70%:30% (in volume) water and EG mixture as the base fluid. Sample preparation was carried out using a very sensitive mass balance with an accuracy of 0.0001 g.

The amount of CuO nanoparticles required to prepare nanofluids of different volume fractions in a 100 ml of the base fluid is summarized in Table 1. The nanofluid mixture was then stirred and agitated thoroughly for 30 min. with an ultrasonic agitator similar to the preparation of nanofluids by Karami et al [26]. This ensures uniform dispersion of nanoparticles in the base fluid. Additionally, the mixture is ultrasonicated intermittently to avoid overheating. The breaks duration is typically about 2 min which provides the opportunity for the energized CNTs to dissipate the energy. Comparative photographs of the nanofluid samples C2 and C4 is shown in Fig. 2(b).

3. Experimental characterizations

Optical transmittance spectra have been measured using a double-beam spectrophotometer (Perkin Elmer Lambda 1050) at room temperature for whole wavelengths, important for solar energy, ranging from 200 to 2500 nm. The transmittance measurement accuracy of this instrument is $\pm 0.0004\%$. The effect of multiple reflections at the interfaces between air, glass and fluid is assumed to be negligible. Effective medium theory shows that this assumption is valid for small volume fractions [27], as was the case in this paper. A 10 mm quartz cuvette was filled with the CuO nanofluids. In filling the cuvettes, care was taken to avoid bubbles. Each measurement was repeated for three times to achieve the best precision.

Using the transmittance spectra, the extinction coefficient $K(\lambda)$ was calculated according to the Beer–Lambert law ($T(\lambda) = e^{-K(\lambda)H}$). In this law, H is the collector depth within the medium.

The thermal conductivity was measured using a KD2 Pro thermal properties analyzer (Decagon devices, Inc., USA), which is shown in Fig. 3(a), equipped by a single-needle sensor for heating and monitoring of the temperature, which is based on transient hot-wire technique [28] widely employed to measure thermal conductivity of nanofluids [29,30]. In order to study the effect of temperature, a thermostat bath was used, which meets the standards of ASTM D5334 [31] at temperature range of 20 °C to 60 °C. All the measurements (with the accuracy of $\pm 5\%$) were performed

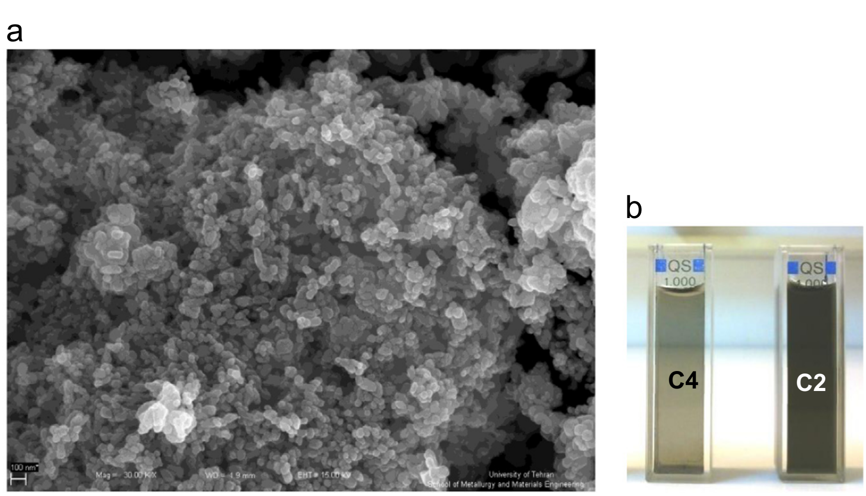

Fig. 2. (a) SEM image of CuO nanoparticles and (b) Comparative image of CuO nanofluids.