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Enhancement of heat absorption rate of direct absorption solar collector using graphite nanofluid

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Abstract : Metal absorbers are prone to conductive, convective and radiation heat losses. Direct absorption of solar energy by a fluid is possible with and without concentration of solar energy. The addition of higher thermal conductivity materials to the base fluid is vital to improving the rate of heat absorption. An experimental study was performed with and without nanoparticle dispersion in the water under similar operating conditions. The agglomeration of nanoparticles was found high at the volume fraction in the order of 0.1% and the low at a volume fraction of 0.002%. The lower volume fraction of nanoparticles to the base fluid increased the temperature gradient with respect to time.
Keywords: Direct solar absorption, volumetric receivers, nanoparticle dispersion.

1. Introduction

Metal surface solar collectors involve the higher heat losses. A direct absorption solar receiver (DASR) is one of the choices to overcome the heat losses from the surface absorption collectors. Instead of an irradiating surface, solar radiation is absorbed directly on the fluid in DASR. However, the base fluids have low absorptivity and transparent to solar spectrum. So there is a need of increasing the absorptivity of the fluid. It is preferred to add highly conductive solid particles to enhance the absorptivity. Gravity and Brownian motion are the forces acting on solid particles in fluids. If the particle size is large, then the gravitational force is predominant, and the particles get agglomerated without fine dispersion, which leads to inefficient absorption process. The size of particles is in nanometres then the gravitational force will become insignificant, and the Brownian motion will become predominant, which makes particles disperse throughout without agglomeration. The fluids are used in the solar collectors to capture incident energy. The selective fluids can be water, heat transfer oils and mineral salt. For high temperature applications, thermal oils can be used to sustain high-temperature and heat transfer stays in sensible heat region.

Nanofluid is the fluid comprising of base fluid and suspended nanoparticles. Nanoparticles have desirable properties to absorb energy effectively. Typical nanoparticles are MWCNT, graphite, Silver and Al_2O_3 nanoparticles etc. Tyagi and Phelen[1] predicted the 10% higher efficiency of nanofluid DASR when compared to flat plate collector. Taylor et al.[2] presented nanofluid for a concentrated solar collector with enhancement if efficiency up to 10% when compared to surface absorption receivers. Andrej and Wang[3] found the efficiency of nanofluid absorbers were increasing with solar concentration and nanofluid height. The receiver-side efficiency was predicted to exceed 35% when coupled to power cycle. Ladjevardi et al.[4] demonstrated a graphite nanofluid with a volume fraction around 0.000025% absorbs 50% of incident solar energy while pure water absorbs only 27%. Omid et al.[5] reviewed properties of several nanoparticles with focus on efficiency, economic and environmental viewpoints. Subramaniyan et al.[6] proposed a laser intensity technique was proposed to test the stability of nanofluids. Vikrant et al.[7] discussed the importance of nanofluid and drawbacks of surface based absorption. The radiation losses over surface based absorption and direct absorption are specified. The addition of solid particles leads to instability, sedimentation, erosion of the flow passages etc if particles are micron size. Brownian motion and Gravitational force are the forces involved. In micron particles gravitational force effects reasonably. Reduction in size of particles leads to complete Brownian motion and insignificant gravitational force, which leads to high stability and good transmission of energy.

Azwadi et al.[8] reviewed nanofluids and their properties like stability, high thermal conductivity, low specific heat and low viscosity etc. Deepak and Sanjeev[9] demonstrated the multilayer nanowires with more optical scattering than a single metal nanowire. Tora[10] optimized the nanofluid velocity and nano particle concentration for the minimum pumping power and maximum heat convection as 0.5 m/s and 0.005 respectively. Kannan and Vijayakumar[11] used Taguchi method to optimize the flow rate of nano fluid, nano particle concentration and inlet temperature. Thermal conductivity of water/ethylene glycol was increased by 58% with CuO nanofluid[12]. Optical and electrical properties of nano powders were determined by Thiruramanathan et al.[13]. Dinesh Babu et al.[14] synthesized nanopowders by chemical combustion method and determined the surface area of nano powders.

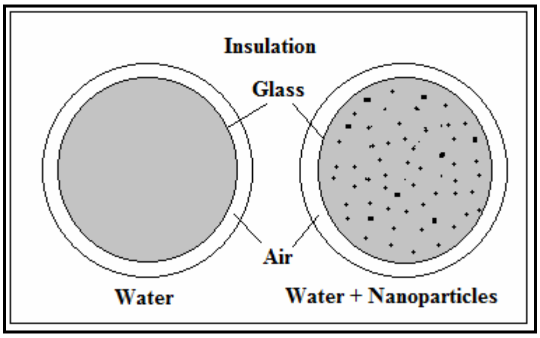


Figure 1. Base fluid and nanofluid in volumetric absorber

Thermal conductivity enhancement techniques of phase change materials using nano particles were summarized by Senthil and Cheralathan[15]. Corrosion resistance of mixed metal oxide based nano particles was demonstrated by Muthuchudarkodi and Kalaiarasi[16]. The CuO nanofluid based heat pipe showed 20-30% better thermal performance when compared to the heat pipe without nanoparticles[17,18]. The present study focussed on the preparation of nanofluid with water as base fluid and graphite nano particles. Nanofluid has excellent thermo-physical and optical properties. The outdoor testing of water-graphite nanofluid based DASC and the thermal performance was reported in this work.

2. Materials and Methods

The thermal conductivity of nanofluid depends on base fluids, nanoparticles and the solid–liquid interface. Experiments on volumetric absorber with nanofluid and base fluid were carried out to test the thermal performance. High purity graphitized, porous carbon nanoparticles have large mesopores and some microporosity. The assay of graphite nanoparticle powder (Sigma-Aldrich) is 99.95% trace metal basis and it has pore size of 0.25 cm^3/g pore volume. The specific surface area of the particle is 50-100 m^2/g. Graphite lattice structure content of approximately 10% and an agglomeration of 30 nm mesoporous nanoparticles. The TEM image of nanoparticle is shown in Fig. 2. The SEM image of nano particles at different magnifications are given in Fig. 3 (a) – (c).

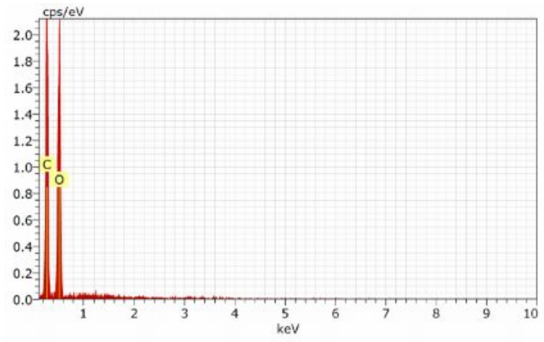
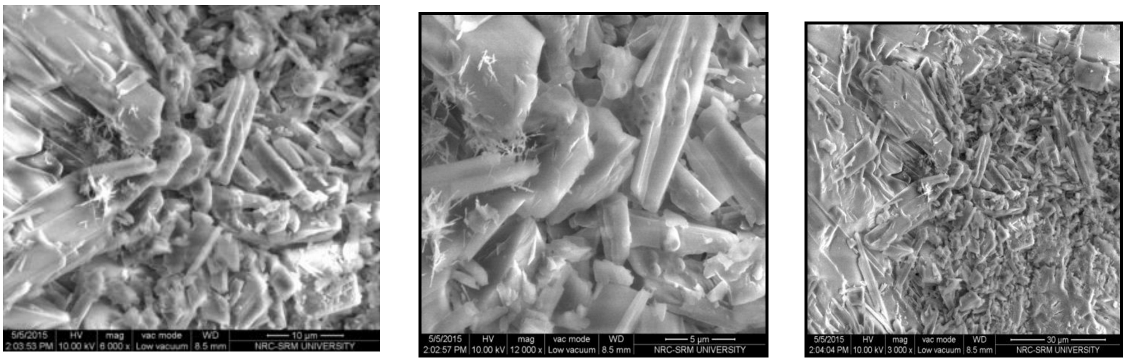


Figure 2. EDS spectra of graphite nano particle

Figure 4. Ultrasonicator **Figure 5. Nanofluid sample**

The beaker with nanoparticles dispersed in water was kept in a small open box and filled with ice cubes around it. The fluid was ultrasonicated in an ultrasonicator by setting the frequency of 20 kHz and time of 30 minutes for the homogenization of the solid particles. The ultrasonicator is shown in Fig. 4.



(a) (b) (c)

Figure 3. (a-c) SEM images of graphite nanoparticles with different magnifications

The outdoor testing was conducted for the test samples (Fig. 5) in flat-surfaced glass tubes. The temperatures at 2, 4 and 6 cm from top of the tube were measured with K-type thermocouples and the average value of temperature was used in the thermal calculations. The outdoor temperature readings were noted at every 10 minutes and the temperature trends were obtained for the 0.001% and 0.0015% nanofluids. The ambient temperature was measured at the site in the range of 34-36 °C. The measured wind speed was well below 1.8 m/s at the site. Solar radiation is measured with pyranometer at the test site for every ten minutes averaged values are recorded. The collector efficiency is calculated using Eq. (1).

$$\eta = \frac{m \cdot C_p \cdot (T_f - T_i)}{A_c \cdot Q_i \cdot t} \qquad (1)$$

Where, m is the mass of nanofluid, C_p is the specific heat, T_f and T_i are the average final and initial temperature of the fluid, A_c is the aperture area of collector, Q_i is the incident solar radiation and t is the time of operation.

3. Results and discussion

The graphite nanofluid of 0.001% to 0.002% volume fractions is experimentally evaluated by outdoor experiments with glass tubes of 25 mm diameter and 80 mm depth. The aperture area of the solar collector is 1.9635×10^{-3} m^2. The average solar radiation during the test period is around 650 W/m^2. Figure 6 shows the trend of temperature for water and nanofluid.

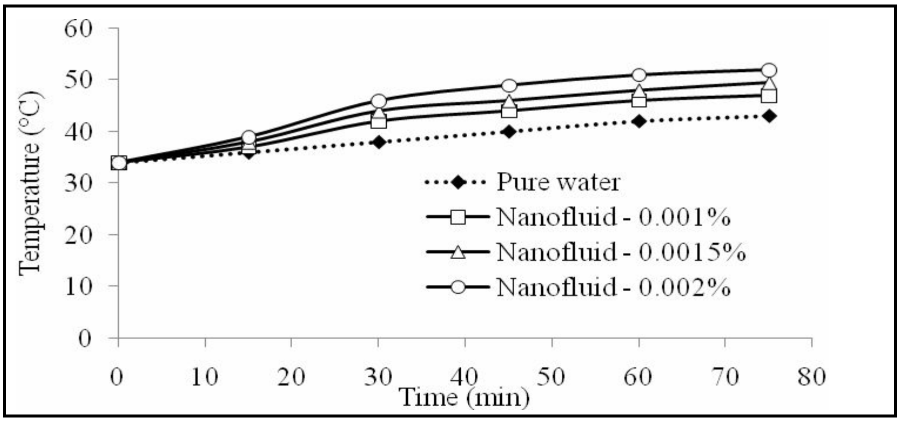


Figure 6. Temperature trend for volumetric absorber for water-graphite nanofluid

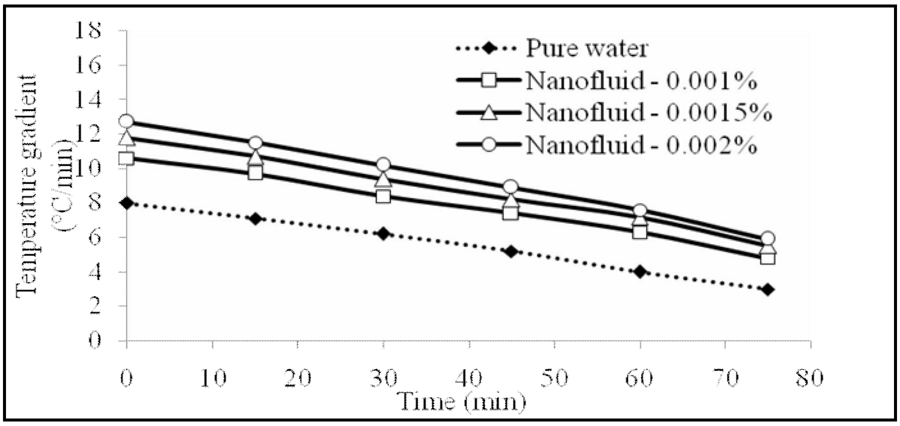


Figure 7. Temperature gradient for water and nanofluid

It can be observed that in Fig. 7, average temperature gradient for three different concentrations are compared to the pure water. The higher concentration of nanofluid shows higher heat absorption while the outdoor experiments are conducted similar incident radiation around 600 to 700 W/m^2. Efficiency over volume fraction is observed from Fig. 8.

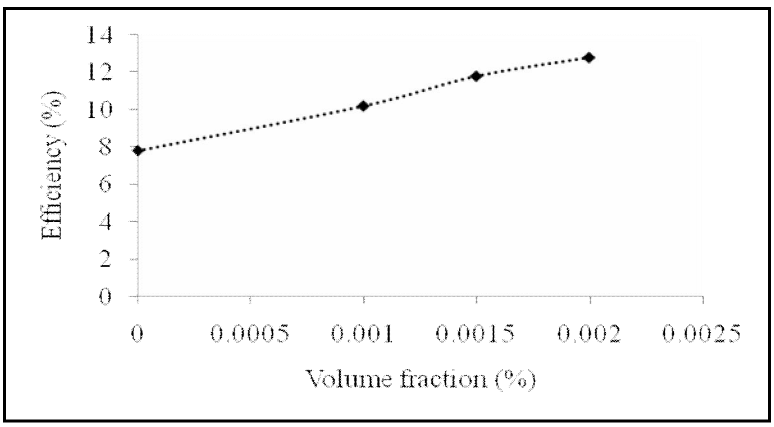


Figure 8. Efficiency variation over the volume fraction of nanoparticles

The lower efficiency is due to the natural convection in the stagnation medium and the heat losses from the container outer walls. Higher volume fractions are not used due to high agglomeration as the density of graphite nanoparticles is very high. The efficiency changes according to the volume fraction.

4. Conclusion

The addition of nanoparticles in certain concentrations can improve the collector efficiency of a volumetric absorption system. It was found that the nanoparticles improve the heat absorption rate and the volume fractions around 0.002% were shown good thermal performance. Further increase in the volume fraction of 0.002% leads to high agglomeration due to the high density of graphite nanoparticles. The optimum concentration of nanoparticles enhanced the rate of heat absorption by the fluid. However, the metal surface based absorption is better than volumetric absorption system at very high operating temperatures. The stability of nanofluid at higher temperatures is one of the major challenges and it has to be studied in future.

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