Abstract

Photo-thermal energy conversion in a solar collector is one of the most efficient ways of storing solar energy. In a conventional solar collector, incident radiation is at first absorbed on the walls of the collector which afterward is transferred to the working fluid. Thermal losses associated with heat transfer from the walls to the working fluid are eliminated in a direct absorption solar collector (DASC) where solar energy is directly absorbed in the working fluid. One of the main requirements in a DASC is that the energy should be absorbed in the entire volume of the working fluid. This makes it alternatively known as a volumetric collector. Efficiency of a DASC is greatly enhanced by using a nanofluid which is a stable and homogeneous suspension of nanoparticles (particle size less than 100 nm) in a base fluid.

The work in this thesis is broadly divided into two parts. In one part, investigations on various nanofluids are carried out in the perspective of storage of solar energy through photo-thermal conversion, while in the other part design optimization of a DASC is carried out. Nanofluids considered are (i) 2, 4, 10, and 15 ppm carbon black in ethylene glycol (CB-EG), (ii) 30, 50, 70, and 90 ppm of hexagonal boron nitride in ethylene glycol (BN-EG), and (iii) a hybrid mixture of 4, 10, and 15 ppm of CB in 30, 50, 70, and 90 ppm of BN (BN/CB-EG). These nanofluids were synthesized by the two-step method. Various studies that were carried out include long time suspension stability or homogeneity, optical properties such as absorption, transmittance, extinction coefficient etc., and energy absorption characteristics.

Photo-thermal conversion performances of the nanofluids were investigated in an experimental collector through the measurements of transient temperature profiles under varying concentration of the nanoparticles, and the duration of light exposure. A halogen lamp with a shortwave filter is used as the source of incident radiation. Fluid temperatures were measured through five uniformly placed PT100 temperature sensors. A fluid height of 16 mm and an incident radiation of 437 W/m^2 having wavelength 450 to 820 nm were used in all the experimental studies using the collector.

The optical absorption at 650 nm wavelength for 15 ppm CB-EG nanofluid is obtained 82.2 times higher than that of the base fluid. The absorbed energy fraction computed over 20 mm penetration depth are 37.8% and 87.3% for 2 and 15 ppm CB-EG respectively. About 27.9% increase in storage efficiency (after 1200 s exposure) over that of EG is observed using 15 ppm CB-EG nanofluid. Comparing with the base fluid EG, studies on 90 ppm BN-EG nanofluid indicate 89.4 times higher optical absorption (at a wavelength of 650 nm), 38.8 times higher absorbed energy fraction at a penetration depth of 20 mm and 16.2% enhancement in photo-thermal conversion efficiency after 1200 s of exposure.

The hybrid nanofluids were also investigated under varying concentration mixing ratios (CMRs). At 650 nm wavelength, the optical absorption of 90 ppm BN-EG improves by 100% when 15 ppm CB is added to the nanofluid. The enhancements in energy storage efficiency for 90 ppm BN-EG nanofluid and that mixed with 4 ppm CB are 16.2% and 30.2% respectively after 1200 s of exposure. An enhancement of 34.6% in photo-thermal conversion efficiency (after 1200 s exposure) over that of EG alone is obtained using 90 ppm/15 ppm BN/CB hybrid nanofluid.

A time dependent finite difference model for performance prediction of a DASC is developed using a mean extinction coefficient (MEC) of the working fluid. The model considers heat transfer in the fluid, convective and radiative heat losses at the top surface, and reflected radiation from the bottom of the collector. The model is validated with our own experimental data. Using the model, parametric studies are carried out for understanding the behaviour of DASCs. There is an optimized MEC at which storage efficiency is maximum. Through regression analyses over these maxima points, correlations are developed for determining the optimized MEC and the corresponding storage efficiency as functions of fluid height and time of exposure under one sun incident radiation. A simplified time-averaged correlation for obtaining an optimized MEC only as function of fluid height is also derived. An optimized optical thickness, a non-dimensional parameter defined as the product of MEC and fluid height, of 2.35 is recommended for the fluid height between 20 and 80 mm.

This work would be useful in understanding (i) the behaviour of CB, BN, and their hybrid nanofluids for DASCs, (ii) the behaviour of DASCs under varying parametric conditions, and (iii) obtaining an optimized MEC for designing a collector.

Keywords: nanofluid; carbon black; hexagonal boron nitride; hybrid nanofluid; direct absorption solar collector; absorbed energy fraction; photo-thermal conversion efficiency; parametric behaviour; mean extinction coefficient