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Investigations for effect of Al_2O_3–H_2O nanofluid flow rate on the efficiency of direct absorption solar collector

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ABSTRACT

The efficiency of conventional tube- in plate type solar collectors is limited due to higher heat losses for surface based solar energy absorption and indirect transfer of heat from hot absorber surface to working fluid having poor heat transfer properties flowing through tubes. In this paper, a prototype direct absorption solar collector having gross area 1.4 m^2 working on volumetric absorption principle is developed to investigate the effect of using Al_2O_3–H_2O nanofluid as heat transfer fluid at different flow rates. Experimentation was carried using distilled water and 0.005% volume fractions of 20 nm size Al_2O_3 nanoparticles at three flow rates of 1.5, 2 and 2.5 lpm. ASHRAE standard 93-86 was followed for calculation of instantaneous efficiency of solar collector. Use of nanofluid improves the optical and thermo physical properties that result into an increase in the efficiency of the collector in all cases of using nanofluids in place of water. Collector efficiency enhancement of 8.1% and 4.2% has been observed for 1.5 and 2 lpm flow rate of nanofluid respectively. Optimum flow rate of 2.5 and 2 lpm towards maximum collector efficiency have also been observed for water and nanofluid respectively.

1. Introduction

Solar thermal energy is one of the most popular renewable sources of sustainable energy with least environmental impact, no requirement of transportation and free availability for every human being all over the world [1–3]. Solar thermal collector is a widely used system for collection and conversion of solar energy into thermal energy. Among these different types of solar collectors, the conventional 'tube in plate' type flat plate collector absorbs incident solar radiation through a black solid surface, and transfers heat to working fluid flowing in tubes called risers, brazed onto the surface of the absorber plate. The efficiency of a solar thermal collector relies on the effectiveness of absorbing incident solar radiant energy and heat transfer from the absorber to the carrier, which is normally fluid. Due to surface heat absorption and indirect transfer of heat to working fluid, the conversion of sunlight into thermal energy suffers from relatively low efficiencies [4].

In order to improve the efficiency of solar thermal collector, researchers proposed the concept of directly absorbing the solar energy within the fluid volume in the 1970s called Direct Absorption Solar Collector (DASC) [5,6]. However, the efficiency of direct absorption collector is limited by the absorption properties of the conventional working fluid, which is very poor over the range of wavelength in solar spectrum [7]. In the beginning, black liquids containing millimeter to micrometer sized particles were also used as working fluid in direct absorption solar collectors to enhance the absorption of solar

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radiation that had showed efficiency improvement. The applications of micron-sized particles into the base fluid for DASCs lead to pipe blockage, erosion, abrasion and poor stability. Particle sedimentation from the suspensions resulted in clogged channels [5].

Advance material synthesis technologies provide us an opportunity to produce the nano-size materials (nanoparticles), when suspended in conventional fluids considered as nanofluids [8]. The use of nanofluid has a dramatic improvement on the liquid thermo physical properties such as thermal conductivity [9,10]. Studies suggested the thermal conductivity enhancement due to dispersion of nanoparticles [11], intensification of turbulence [12], Brownian motion [13,14] and thermophoresis [15].

Masuda et al. [16] dispersed Al_2O_3 and TiO_2 nanoparticles in water and found thermal conductivity improvement by 32% and 11%, respectively. Grimm [17] dispersed aluminum metal particles (1–80 nm) into water and claimed 100% increase in thermal conductivity of the nanofluid for 0.5–10 wt%. Natarajan and Sathish [18] investigated the thermal conductivity enhancement of base fluids using carbon nanotube (CNT) and suggested efficiency enhancement of the conventional solar water heater by using CNT based nanofluids as a heat transport medium. Nanoparticles also offer the potential of improving the radiative properties of liquids, leading enhanced efficiency of direct absorption solar collectors [19].

Recently Sheikholeslami et al. [20–24] used nanofluid and simulated nanofluid flow and heat transfer by different methods for different kind of problems to enhance the heat transfer rate.

Yousefi et al. [25] reported the experimental results on a tube in plate type conventional solar collector (size 2 m^2) using Al_2O_3–H_2O nanofluid of 0.2 wt% and 0.4 wt% concentrations for three different mass flow rates and found 28.3% improvement in efficiency with 0.2 wt% of nanofluid in comparison to water. Yousefi et al. [26] also examined the effects of multiwall carbon nanotubes–water nanofluid and observed remarkable efficiency increase with 0.4 wt% nanofluid.

Tyagi et al. [27] numerically studied a direct absorption solar collector using aluminum nanoparticles in water for performance evaluation and reported efficiency improvement up to 10% than that of a flat-plate collector. Otanicar et al. [28] experimentally studied the role of different nanofluids as the absorption medium on the efficiency of horizontal micro size (3 cm × 5 cm) direct absorption collector in indoor environment and reported efficiency improvement up to 5%.

Very few studies on the thermal performance evaluation of flat plate solar collector with nanofluids are available. As such no study on full size (1.4 m^2) tilted DASC under actual outdoor condition is available. An attempt has been made in the present paper, to experimentally study the effect of Al_2O_3–H_2O nanofluid flowing as thin film over the glass absorber plate as a direct absorbing medium on the efficiency of a tilted direct absorption solar collector under outdoor condition. Effect of three different nanofluid flow rate i.e. 1.5 lpm, 2 lpm and 2.5 lpm were considered on the DASC efficiency and the collector performance was also compared with base fluid distilled water.

2. DASC experimental setup

Schematic diagram explaining the working of direct absorption collector is shown in Fig. 1.

An experimental setup of direct absorption solar collector of size 1.54 m × 0.9 m (gross area of 1.4 m^2) has been developed as shown in Fig. 2.

2.1. Experimental apparatus and procedure

For experimental study, a setup of DASC was developed and erected at the roof top of Mechanical Engineering Department, Malaviya National Institute of Technology, Jaipur (26.01° latitude and 75.52° longitudes). The collector was oriented due south with a tilt angle of 26°. Photograph of experimental setup (Fig. 2) showing direct absorption collector, two tanks and instruments used along specification of the collector components used in Table 1. It mainly consists of a glass base plate (1.5 m long, 0.9 m wide, 0.006 m thick), mounted on a wooden box with inner glass wall on all four sides and equipped

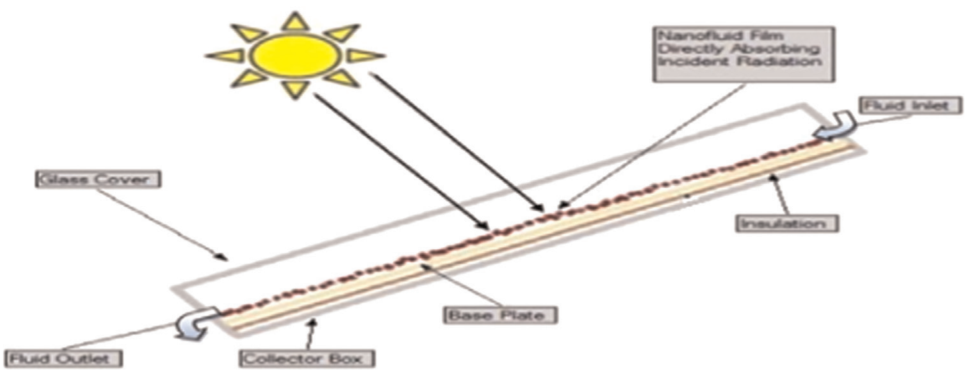

Fig. 1. The schematic of direct absorption solar collector (DASC).