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Flat Plat Solar Collector Using Nanofluids

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Abstract: ***Solar energy is one of the cleaner forms of renewable energy resources. The conventional solar collector is a well established technology which has various applications such as water heating, space heating and cooling. However, the thermal efficiency of these collectors is limited by the absorption properties of the working fluid, which is very poor for typical conventional solar flat plate collector. Recently usage of nano fluids, which is basically liquid- nano particle colloidal dispersion as a working fluid has been found to enhance solar flat plate collector thermal efficiency maximum by 30 percent. In this paper an effort has been made to present a comprehensive overview on thermal performance of solar flat plate collector for water heating using different nano fluids. Moreover, kgCO2/kWh at the site due to usage of nano fluid as a result of enhancement of thermal performance has also been discussed.***

Keywords: colloidal dispersion, conventional solar collector, Thermal Efficiency

1. Introduction

The fluids with nano sized solid particles suspended in them are called “nanofluids.” The suspended metallic or nonmetallic nanoparticles change the transport properties and heat transfer characteristics of the base fluid. Nanofluids are the new generation heat transfer fluids for various industrial and automotive applications because of their excellent thermal performance and the word was which was coined at Argonne National Laboratory of USA by Choi in 1995 [1], which showed that the conventional liquid thermal performance could be remarkably improved using nanoparticles. Nanofluids can be used for a wide variety of engineering applications like transportation, thermal management of electronics, medical, food, defense, nuclear, space, and manufacturing of many types [2]. Heat transfer enhancement in solar devices is one of the key issues of energy saving and compact designs. Solar energy is widely used in applications such as electricity generation, chemical processing, and thermal heating due to its renewable and nonpolluting nature. Most solar water heating systems have two main parts: a solar collector and a storage tank. The most common collector is called a flat-plate collector but these suffer from relatively low efficiency. There are so many methods introduced to increase the efficiency of the solar water heater [3-6]. But the novel approach is to introduce the nanofluids in solar collector instead of conventional heat transfer fluids (like water).One of the key feature for heat transfer enhancement is the thermal conductivity, the majority of the studies [7-13] have discussed the thermal conductivity of nanofluids.Recently some studies were reported about using the nanofluids in solar collectors. Natarajan [14] has investigated the thermal conductivity enhancement of base fluids using carbon nanotubes and suggested if these fluids are used as a heat transport medium, it increases the efficiency of the conventional solar water heater. Tyagi et al. [15] has studied theoretically the capability of using a non concentrating direct absorption solar collector and compared its performance with that of a conventional flat-plate collector. Otanicar [16] has studied environmental and economic influence of using nanofluids to enhance solar collector efficiency in compare with conventional solar collectors. Otanicar [17] has studied experimentally the effect of different nanofluids on the efficiency of the micro-solar-thermal-collector. He reported an efficiency improvement up to 5% in solar thermal collectors by utilizing the nanofluids as the absorption medium. Yousefi et al. [18] experimentally investigated the effect of Al2O3 nanofluid in a flat-plate solar water heater and reported that using the surfactant the maximum enhanced efficiency is 15.63%. Yousefi et al. [19] experimentally investigated the effect of pH variation of MWCNT–H2O nanofluid on the efficiency of a flat-plate solar collector and showed that by the more differences between the pH of nanofluid and pH of iso electric point causes the more enhancements in the efficiency of collector. Very limited information is available flat-plate solar collectors using nanofluids which motivated this investigation. The major goal of the present study, theoretically investigates the performance of flat-plate solar collectors with Al2O3/water nanofluid. The effect of using Al2O3 nanofluid with different particle volume concentrations (0.5-2%) are investigated in this study.

2. Thermal Performance Analysis

The Al2O3nanofluid based flat-plate solar collectors considered in present study. The physical dimensions and configuration of the flat-plate solar collector are listed in Table 1.

Table 1: Flat-plate solar collector geometry

Property	*Value*
Width x length	1x2 (m)
Glazing transmittance	0.90
Absorber absorptance	0.95
Absorber thickness	0.25 (mm)
Width of absorber fin	115 (mm)
Heat transfer fluid	Al2O3/water nanofluid

ASHRAE Standard suggests performing the tests in various inlet temperatures. The useful energy can be calculated using Eq. (1).

$$Q_u = mc_p\,(T_{fo} - T_{fi}) \ldots (1)$$

Where, is the rate of useful energy gained, is the mass flow rate of fluid flow, Cp is the heat capacity of water or nanofluid and are the inlet and outlet fluid temperature of solar collector. The effective specific heat of the nanofluid can be calculated from Xuan and Roetzel relation [20] as:

$$(\rho cp)nf = (1-\o)(\rho cp)w + \o(\rho cp)p \ldots(2)$$

Where refers to the heat capacity is the effective density of nanofluid, the subscripts p, w and nf refer to the nanoparticle, base fluid and the nanofluid, respectively and is the nanoparticle volume concentration. The density of nanofluid is calculated from Pak and Cho [21] using the following equation:

$$\rho nf = \o\, \rho p + (1-\o)\rho w \ldots(3)$$

Where is the subscripts nf effective density of nanofluid. The useful energy can also be expressed in terms of the energy absorbed by the absorber and the energy lost from the absorber as given by Eq. (4).

$$Qu = ACFR\,[I\,(\tau\alpha) - UL\,(Tfi - Ta)] \ldots (4)$$

Where F_R is the 'collector heat removal factor' defined as the ratio of the actual heat transfer to the maximum possible rate, Ac is the surface area of solar collector, I is the global solar radiation, is the absorptance–transmittance product, U_L is the overall loss coefficient of solar collector, and Ta is the ambient temperature. The relation between the collector efficiency factor and the heat removal factor F_R is given as:

$$FR = mcp / AC\,UL\,[1 - \exp(-AC\,UL\,F' / mcp)] \ldots (5)$$

The instantaneous collector efficiency relates the useful energy to the total radiation incident on the collector surface by Eq. (6) or (7).

$$\eta = Qu/AcI = AC\,FR\,[I\,(\tau\alpha) - UL\,(Tfi - Ta] / Ac\,I \ldots (6)$$
$$\eta = FR\,(\tau\alpha) - FR\,UL\,(Tfi - Ta) / I \ldots (7)$$

In a particular case of a solar collector where the temperature of the fluid entering the collector equals the ambient temperature i.e., results collector efficiency is at its maximum that is If the efficiency test is performed at near the normal incidence conditions so that FR is constant and both FR and UL are constant within the range of tested temperatures, a straight line will result when the efficiencies are obtained from averaged data is plotted against according to Eq. (7). The intersection of the line with the vertical efficiency axis equals to FR. The slope of the line is equal to FRUL. At the intersection of the line with the horizontal axis collector efficiency is zero usually occurs when no fluid flows in the collector.

3. Results and Discussions

The solar collector is modeled tested for various mass flow rates of 0.5, 1, 1.5 and 2 Lit/min. The experimental data has been taken from literature. The performance parameters are calculated for various input parameters. Due to lack of available experimental data on solar collector using nanofluid, the results has been tested with the design example and showed well matching. Table 2 show that the, value of the collector for 2 Lit/min is highest, and the FR, UL value in this mass flow rate is lowest. Therefore based on the Eq. (7) the efficiency of solar collector in this mass flow rate is highest. Solar collector efficiency decreases with decreasing the mass flow rate. The efficiency of flat-plate solar collector with Al2O3 nanofluid is higher than the efficiency of flat-plate solar collector with water as working fluid. This can be deduced by comparing the value of for Al2O3 nanofluid and water, which shows that the removed energy parameter, FRUL, values for Al2O3 nanofluid and water are close to each other. However, the absorbed energy parameter,, value for nanofluid is higher than that for water by 31.64%. This causes the efficiency of solar collector with 1.5% particle volume fraction of Al2O3 nanofluid become greater than that with water by 31.64%.

Table 2: Efficiency parameter of the Flat-plate solar collector for water at various flow rates

Mass flow rates (Lit/min)	*FR,UL*	*η*
0.5	48.6	0.482
1.0	44.68	0.493
1.5	39.52	0.516
2.0	35.96	0.524

Table 3: Efficiency parameter of the Flat-plate solar collector for Al2O3nanofluid at various Concentrations

% Concentration	*FRUL*	*η*
0.5	49.23	0.549
1.0	45.19	0.649
1.5	42.36	0.726
2.0	36.29	0.639

By comparing the efficiencies of nanofluid with different concentrations, it can be seen that the efficiency at 1.5% particle volume fraction of Al2O3nanofluid is higher than that the other three particle volume fraction concentration. Based on the Eq. (7), is dominant parameter in small temperature differences, and FRUL is dominant parameter in higher temperature differences. The value of 1.5% particle volume fraction nanofluid is greater than that for other three in lower temperature differences. In higher temperature differences, the value of FRUL for 1.5% particle volume fraction is larger than that for other concentration as that is optimum. So, the efficiency in this range is greater than the others. The mass flow rates of nanofluid were 0.5, 1, 1.5 and 2 Lit/min. and FRUL values of solar collector for each mass flow rate of Al2O3 nanofluid are presented in Table 4. For the wide range of temperature differences, the efficiency of solar collector increase with increasing the mass flow rate at the optimum concentration level for maximum heat transfer.

Table 4: Efficiency parameter of the Flat-plate solar collector for Al2O3nanofluid mass flow rates

Mass flow rates (Lit/min)	*FRUL*	*η*
0.5	42.6	0.643
1.0	34.52	0.702
1.5	24.56	0.712
2.0	26.52	0.616

However, solar flat plate based water heating system uses some kind of electrical, gas fired back up for a continuous supply of hot water. So in a hybrid mode improvement in solar collector thermal efficiency due to usage of nanofluid indicates proportional savings in kgCO2/kWh saving in comparison with the conventional water based flat plate collector. So Al2O3 nanofluid based solar water heating system has a potential of 31% kgCO2/kWh saving in comparison with the conventional SWHS (Solar water heating system).

4. Conclusions

The effect of using the Al2O3 nanofluid as absorbing medium in a flat-plate solar collector is investigated. The effect of mass flow rate and particle volume fraction on the efficiency of the collector is investigated. The results show that using the 1.5% (optimum) particle volume fraction of Al2O3 nanofluid increases the thermal efficiency as well as kgCO2/kWh saving in hybrid mode of solar collector in comparison with water as working fluid by 31.64%.

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