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The use of nanofluids for enhancing the thermal performance of stationary solar collectors: A review

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ABSTRACT

Nanofluid, an advanced type of fluid containing small quantity of nanoparticles (usually less than 100 nm), has been proven to provide more efficient heat transfer compared to conventional fluids. The dispersion of a small amount of solid nanoparticles in conventional fluids such as water or ethylene glycol changes their thermal conductivity remarkably. Recently, nanofluid has been used as a heat transfer fluid to enhance the performance of solar collector devices. This paper reviews recent progress and applications of nanofluids in stationary solar collectors. In addition to reviewing the efficiency of solar collectors which use nanofluids, the paper also discusses the impact of nanofluid usage in solar collector based on economic and environmental viewpoints. Finally, the challenges and future trends related to the application of nanofluids in thermal solar collector is discussed.

Contents

1. Introduction

The current power generation method from fossil fuels such as oil or coal is damaging our environment. For example, nuclear power stations to generate electricity are an unacceptable risk in most locations [1]. Therefore, we need to diversify from this non-renewable energy sources and look for alternatives. Many developing countries cannot fully rely on these conventional methods as they are aware of the damaging effect of CO_2 emission and try to search for other types of green and renewable energy sources. The need for a green and environmentally friendly power generation method is thus obvious and will be further expanded in near future.

One of the most promising renewable energy sources available is solar energy since it is freely available, abundant and has minimum ecological impact. It is estimated that one hour of solar energy received by the earth is equal to the total amount of energy consumed by human in one year [2]. Similar to plants, they use chlorophyll to photosynthesize the sun's irradiation in order to provide energy for their growth. Only 14.4 percent of sunshine survives filtering from the earth's atmosphere and falls on the land where it can be harvested. This is, however, 2800 times more than our energy needs [2].

A lot of research work have been reported in the literature on harvesting energy from solar. In addition, many countries have

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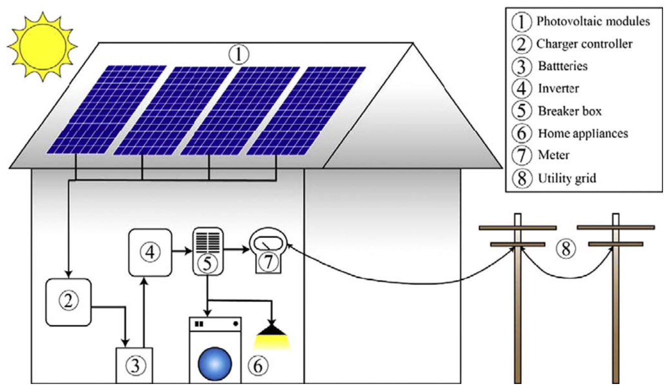

Fig. 1. Schematic of photovoltaic (PV) power system.

made extensive research on solar energy utilization [3–15]. Generally, there are two ways of harvesting solar energy depending on needs; (i) solar–electric conversion (converting solar energy into electrical energy using a photovoltaic solar cell or concentrated solar power) and (ii) solar–thermal conversion (converting solar energy into thermal energy using a solar collector) [16]. Since the first work on solar cell by Charles Fritts in the 1880 s [17] with an efficiency of only 4.5–6%, many efforts have been done to tap this priceless resource of energy [18–20].

Fig. 1 shows the schematic of a photovoltaic (PV) power system. A photovoltaic system produces direct current (DC) power which fluctuates with sunlight's intensity. For practical use, this usually requires conversion to certain desired voltages or alternating current (AC) through the use of inverters [21].

Extensive research on PV system has been done by many researchers [22–25]. Blankenship et al. [26] gave an excellent review on the current challenge and future trends on the subject. Michael [27] made a breakthrough research by introducing dye-sensitized nanocrystalline electrochemical photovoltaic system to replace solid-state junction devices to convert solar energy into electricity. Bernard and Jean-Luc [28] reviewed the application of low cost, highly flexible form factors, and light weight organic photovoltaic to convert sun light into electricity by employing thin organic semiconductor films. Garg and Adhikari [29–31] dedicated their research on the performance analysis of hybrid photovoltaic/thermal air heating collector. Sopian et al. [32] developed a double pass photovoltaic thermal solar collector for solar drying applications.

On the other hand, research on solar–thermal systems has attracted many investigators from all around the globe. Soteris [33] provided an extensive review on the historical development and current progress of solar collectors. Mills [34], in his review article, discussed the current technologies that are being applied to develop single and two-axis tracking solar collectors, several types of low temperature technologies such as evacuated tube collector, organic Rankine cycle turbine and solar updraft power plants. Several other important reviews relating to solar–thermal conversion are listed in Table 1 (adapted from Table 1 [35]).

Table 1
Reviews on solar–thermal conversion.

Authors	System
Soteris [33]	Solar thermal collector
Shukla et al. [36]	Solar water heaters
Ogueke et al. [37]	Solar water heating system
Jaisankar et al. [38]	Solar water heaters
Barlev et al. [39]	Concentrated collectors
Kumar and Rosen [40]	Photovoltaic–thermal collectors
Ibrahim et al. [41]	Photovoltaic–thermal collectors
Hossain et al. [42]	Solar water heaters
Chamoli et al. [43]	Double-pass solar water heaters
Tyagi et al. [44]	Solar air heating system
Shukla et al. [45]	Solar water heating system
Ho and Iverson [46]	Solar concentrating system

A major shortcoming of solar collectors, however, is their low thermal conversion efficiency. Traditional working fluids (water or oil based fluids) have low heat absorption and heat transfer capacity. Cheng et al. [47] also urged the need to improve the thermophysical properties of working fluids used in solar energy for medium and high temperatures.

Nanofluid, an advanced type of fluid containing small quantity of nanoparticles (usually less than 100 nm), was introduced by Choi [48] and has been proven to provide efficient heat transfer compared to conventional fluids. The dispersion of a small amount of solid nanoparticles in conventional fluids such as water or ethylene glycol changes their thermal conductivity remarkably [49,50]. Thermal conductivity of nanofluids has been measured by several authors with different nanoparticle volume fractions, materials and dimensions in several base fluids. Most of the findings showed that thermal conductivity of nanofluid is higher than base fluids. Among them, Lee et al. [51] demonstrated that oxide ceramic nanofluids consisting of CuO or Al_2O_3 nanoparticles in water or ethylene–glycol exhibited enhanced thermal conductivity. For example, using Al_2O_3 nanoparticles with a mean diameter of 13 nm at 4.3% volume fraction increased the thermal conductivity of water under stationary condition by 30% [52]. On the other hand, larger particles with an average diameter of 40 nm led to an increase of less than 10% [52]. Vajjha et al. [53] investigated the thermal conductivity enhancement of three different nanofluids, CuO, ZnO_2 and Al_2O_3 nanofluids. Thermal conductivity increased with increasing temperature and volume concentration. A model was proposed by Murshed et al. [54] to predict theoretical thermal conductivity under dynamic and static processes taking into account the effect of Brownian motion, particle size, nanolayer and particle surface. They concluded that thermal conductivity was due to both static and dynamic mechanisms. In a different study, Hong et al. [55] reported a nonlinear model resulted in thermal conductivity enhancement of 18% at volume fraction of 0.05 vol% using Fe–ethylene glycol nanofluid. Eastman et al. [56] compared the thermal conductivity of Cu–ethylene glycol nanofluid and that of pure ethylene glycol. The result indicated 40% increase in thermal conductivity of Cu–ethylene nanofluid at a volume fraction of 0.3 vol%. Liu et al. [57] recorded 23.8% thermal conductivity enhancement of Cu water nanofluid using the chemical reduction method. The enhancement of thermal conductivity as reported by various researchers is presented in Table 2 (adapted from Table 1 [58]).

Based on the brief review above, many researchers admitted the enhancement of thermo properties of nanofluids compared to base fluid. In this paper, further review is conducted to understand the contribution of nanofluids in a solar thermal conversion system.

2. Types of solar collectors

Solar energy collectors are mediums, generally designed to collect and absorb solar radiation. The absorbed solar radiation is converted into heat by these collector devices which is eventually transferred to the working fluid of a system, usually water or air. Basically, there are two types of solar collectors: stationary and sun tracking or concentrating solar collector [33]. In this paper, the discussion will only focus on stationary solar collector.

Stationary solar collectors are characterized by having the same area for intercepting and absorbing solar radiation. However, they are installed at particular tilt and orientation angles to maximize the harnessing of solar radiation, as shown in Fig. 2. Depending on