Solar flat plate collector by incorporating the effect of nanofluid

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Abstract

The design, analysis and installation of solar collectors are the need of time as its application in the existing systems will reduce the use of conventional source of energy which is limited. On other hand, renewable energy source is unlimited, and it will continue to exist till the existence of life on the planet earth. The main objective of solar collectors is to absorb heat from solar energy for increasing the temperature of fluid flowing through the solar collector and this heated fluid can be used for different applications namely heating to room in colder region, the heat of fluid can be utilized in cement industry and many other similar applications. This article attempts to provide an overview of the various techniques and improvements which allows the flat plate collectors to absorb as much solar radiation as possible while minimizing losses to the surroundings. It has been observed that the use of nanofluid enhances the performance of solar collectors. At last, recommendations have been provided.

Introduction

Solar thermal collectors are a special type of heat exchangers that convert solar radiation energy to thermal energy. Numerous types of solar thermal collectors have been used to collect solar energy (Ahmadi et al., 2020). The flat-plate solar collectors (FPSCs) are the most common type, and it converts solar energy to thermal energy using a solid surface called an “absorber plate” (Gordian et al., 2020). The surface of the absorber plate is usually black matter painted or selectively coated spectrally to achieve high absorptivity of the solar spectrum with low emissivity (Duffy and Beckman, 2013). The received solar radiation is absorbed by the collector’s absorber plate as heat energy and transferred to the heat transfer medium that is flowing through the collector’s tubes.

The reasons for the preference of FPSCs in comparison with other solar thermal collectors are relatively low manufacturing cost, the ability to collect both beam and diffuse radiation, and needless for any sun’s tracking system (Garcia et al., 2019). The major fraction of the incident solar radiation passing through the FPSC’s transparent cover is absorbed by the absorber plate. The bottom and sides of the collector’s absorber plate are fully insulated to minimize the heat losses by conduction and natural convection. The collector’s glass cover diminishes the heat losses by convection via containment of an air layer and by radiation in that it is transparent to the sun’s shortwave solar radiation but practically non-transparent to the long-wave thermal radiation emitted by the absorber plate (Sarsam et al., 2015). The tubes through which the working fluid is flowing along the collector, i.e., riser tubes, can either be an implicit part of the absorber plate or welded to it. At both ends of the collector, the riser tubes are connected to the larger-diameter header tubes (Pang et al., 2020).

The drawback of FPSCs is not only its low thermal efficiency but also the low convective heat transfer coefficient between the absorber and circulating fluid (Zayed et al., 2019). The collector efficiency was increased by improving the optical property of absorber materials to increase the absorption of solar radiation and increasing the number of glass cover to decrease the heat loss. The efficiency of the collector has been improved by using polymer absorber, mini and microchannels for fluid flow, various nanofluids as heat transfer fluids (HTFs), the use of phase-changing materials (PCMs), different absorber plate designs, integrating the energy storage system and using different enhancing devices (Farhana et al., 2019), (Akram et al., 2019b), (Venkatesan and Senthil, 2020). Due to low heat transfer rate between the absorber and HTF, the FPSCs have lower thermal efficiency. To improve the thermal performance, active and passive methods are employed, the passive methods are mainly focused to improve the heat transfer ability of absorber tubes (Muhammad et al., 2016), (Pandey and Chourasia, 2017), (Raj and Subuddhi, 2018), (Sakhalin and Vali pour, 2019). The heat transfer enhancer devices such as twisted tape (Sandhu et al., 2014), wire coil inserts (García et al., 2018), Vortex generator (Wang et al., 2019) (da Silva et al., 2019) and different type of flow inserts were used to increase the heat transfer behaviour of absorber tubes by creating turbulence in the fluid flow with better fluid mixing. Different nanofluids such as metal oxides (Choudhary et al., 2020a), (Saffarian et al., 2020), non-metal oxides (Jaabari et al., 2019), solid metals (Shamshir Aran et al., 2018), semiconductor oxides (Ahmadlouydarab et al., 2019), carbon nanostructured (Alawi et al., 2019), (Eltaweel and Abdel-Rahim, 2019) and nanocomposites (Verma et al., 2018), (Hussein et al., 2020).

This article reviews different experimental, numerical and theoretical investigations using the common types of nanofluids as circulating fluids within solar collectors. It is important to note that, this literature focuses on improving the thermal performance of the absorber, as it considers the main factor in determining the utility of nanofluids as circulating fluids in solar collectors. More specifically, the effects on the thermal efficiency of the absorber of various parameters such as the shape and size of nanoparticles, the mass/volume concentration of nanoparticles, the radiation intensity and the nanofluid mass flow rate are extensively studied with detailed discussions. Moreover, this review article highlights further performance evaluation criteria such as the entropy generation/exergy efficiency, size reduction of the collector, and pumping power, as well as the effect of hybrid enhancement methods with economic importance and various industrial applications.

Research methods

The current study deals with reviewing and analysing recent experimental, theoretical and numerical studies that used different types of nanofluids as heat transfer carriers in FPSCs. First, the concepts and mechanisms of the solar thermal collectors were explored in the introduction section. This was then supported by a short overview of the recent development of methodologies for improving thermal efficiency. Thirdly, basic theoretical formulas were included to calculate the thermophysical

Experimental setup and procedure

Fig. 1 shows a photograph of the flat plate solar collector and schematics of a solar collector system used in this study. Table 1 lists the specifications of the flat plate solar collector.

The working fluids used in the flat plate solar collector were water, and Al_2O_3, CuO, Fe_3O_4, and MWCNT nanofluids. The performance experiment was conducted under varied operating parameters. For the experiment, the flat plate solar collector was installed at a 45° angle in Gwangju, South Korea (latitude of

Thermophysical properties of nanofluids

The primary theoretical equations for the thermophysical properties of nanofluids are evaluated in this section as follows (Zayed et al., 2019).

(Xuan and Reitzel, 2000) suggested a formula to calculate the effective specific heat of the nanofluid: $C_{p,nf} = C_{p,bf}\rho_{bf}(1-\phi) + C_{p,np}\rho_{np}\phi\rho_{nf}$ where, (Cp, ρ, ϕ) refer to the specific heat capacity, density, and volume concentration, respectively. The subscripts of (nf, np, and bf) stand for nanofluid, nanoparticle, and base fluid, respectively.

Applications of nanofluids in FPSCs

The experimental, numerical and theoretical applications using nanofluids as circulating fluids in FPSCs are discussed in different six subsections. The 1st and 2nd subsections discuss the utilization of metal oxides and solid metal nanofluids in FPSC systems. While the 3rd and 4th subsections review the non-metal and semiconductor nanomaterials. The 5th and 6th subsections survey the carbon nanostructures and nanocomposites as heat transfer fluids. The main factors that led to the improvement.

Discussion on thermal performance enhancers in FPSCs

The applied techniques of heat transfer augmentation can be classified into two categories: active methods and passive methods. The active techniques require external power such as mechanical aids, surface vibration, fluid vibration, and electrostatic fields. The passive methods, require no direct application of external power such as rough surface, extended surfaces (fins), displaced promoters, vortex flow devices, and fluid additives (nanofluids). This section focuses on the reasons behind

Conclusions

This study introduced a comprehensive review on the use of nanofluids for improving the energy and exergy performance of FPSCs. From the literature study, significant conclusions are summarized below. Furthermore, some future trends for optimizing the use of nanofluids with the FPSCs are also suggested. By reviewing and comparing the results obtained from several investigations, it is concluded that:

1- Most of the available studies in the literature were focused on metallic oxides nanofluids as

Challenges and future recommendations

Application of nanofluids in flat plate solar collectors faces a lot of difficulties and challenges. Many complicated issues are mentioned in different studies of nanofluids such as (1) high cost of nanoparticles, (2) long-term stability, (3) dispersing agents (surfactants), (4) nanoparticles size/shape and mass/volume percentages, (5) high dynamic viscosity of nanofluids, (6) pumping power and pressure loss, and (7) erosion/corrosion of nanofluids. Several types of nanofluids were assessed as

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The support of University Technology Malaysia (UTM), under the Research University Grant vote number (04E76), managed by the Research Management Centre (RMC) is duly acknowledged.