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Experimental investigation on the thermal behavior of nanofluid direct absorption in a trough collector

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ABSTRACT

In the present work, a solar direct absorption parabolic trough collector is prepared for studying the efficiency enhancement methods. The trough collector was manufactured with a width of 0.7 m and the height of 2 m steel mirror reflector. The main issue in this collector is its absorber tube which is made of borosilicate glass. The glass-glass tube has high transmissivity for longwave radiation and increasing the performance of the collector. The outlet temperature and the thermal efficiency were compared by using of various nanofluids. ASHRAE Standard 93-2010 was used for the operating conditions. The volume fractions of 0.1%, 0.2%, and 0.3% MWCNT/ethylene glycol (EG) and nanosilica/EG were used as various working fluids. The results showed that the temperature difference for 0.1% nanosilica/EG was 2.2 K, for 0.2% nanosilica/EG was 5.3 K, and 7.7 K was obtained for 0.3% nanosilica/EG. while this parameter for 0.1% and 0.2% MWCNT/EG were 5.8 K and 9.3 K. Also, the outlet temperature for 0.3% MWCNT/EG was 15.7 K more than the base fluid. The thermal efficiency of 0.3% carbon nanotube/EG has the highest value, and it is averagely 17% higher than the base fluid. In addition, the optical efficiency of this collector is 71.4%, and the time constant is 8.31 min.

1. Introduction

The primary definition of solar energy conversion is divided to two vital sections including electrical and thermal conversion units. Photovoltaic (PV) panels are used in the electrical part, and the heat behind the panel could be beneficial, but in this case, it would be a PV/thermal equipment. The PVT system is a hybrid system, and its temperature would be low. For higher temperature, the collectors such as parabolic trough collector (PTC), linear Fresnel reflectors (LFR), and dish collector could be used. Among these thermal collectors, parabolic trough collectors have reasonable performance and concentration ratio. Parabolic trough collector is composed of three parts which include: a concave mirror which reflects the solar beams on its focal line, an absorber tube installed in the central of the reflector and working fluid within absorbs the reflection of the reflector. In addition to using these collectors to provide heating in different industries (Bigoni et al., 2014), the structure of these collectors and creating changes in those collectors for improving the efficiency are investigated. Desai and Bandyopadhyay (2015) examined a parabolic trough collector power plant on the prospect of being cost-effective and effect of different factors including the entrance temperature and pressure of turbine on its efficiency. In recent years, many researchers focused on the absorber tube and working fluids. Because of the poor absorption of working fluids, they studied about new fluids for improving the efficiency of the parabolic solar collectors. Nanofluid is a concoction of a liquid stuff (base fluid) and nanoparticles. Sokhansefat et al. (2014) studied the effect of changing the concentration of Al_2O_3 particles (0.5% in volume) in the synthetic oil at the three practical temperatures. With increasing of effective temperature, improvement of heat transfer coefficient due to using more nanoparticles was reduced. Mohammad Zadeh et al. (2015) presented a numerical investigation with the hybrid optimization algorithm for thermal performance of Al_2O_3/synthetic oil as a base fluid. They observed enhancement transfer coefficient with increased nanoparticles concentration while it was decreased by raising of operational temperature. They indicated that the objective function was increased about 10%.

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Nomenclature

A	Area (m^2)
A_f	Geometry factor
C_p	Specific heat capacity (kJ kg^{-1} K)
d	Diameter (m)
f	Focal distance (m)
G	Solar irradiance
$\dot{m}$	Mass flow rate (kg m^{-3})
T	Temperature (K)
W	Aperture width (m)
Subscripts	
a	Aperture
c	Collector
f	Final
i	In
nf	Nanofluid
r	Reflector
ss	Steady state
th	Thermal
v	Envelope
Greek symbols	
α	Absorptance
β	Universal non-random error parameter due to angular errors
γ	Geometry modifier
η	Efficiency (−)
θ	Incidence angle
ρ	Reflectance
τ	Transmittance
φ	Rim angle (degree)

Thermal and optical performances are the main criteria for improvement in the solar collectors. The energy efficiency of six variety nanoparticles at different concentration in comparison with water was investigated by Coccia et al. (2016). Kasaeian et al. (2015) designed and manufactured a solar parabolic collector. The performance of the parabolic trough collector was studied by using of the multiwall carbon nanotubes (MWCNT) in the Therminol oil, as a base-fluid, in the vacuumed absorber tube made of copper with black chrome coating. The result showed the total efficiency of the collector was increased by using 0.2% and 0.3% concentration of nanofluid about 4–5% and 5–7% in comparison of base fluid (oil). The effective factors the performance of the solar collector's receiver, including diameters of the glass cover, wind velocity, solar incident angle were studied by Guo et al. (2016). There were two substantial losses in the collector's receiver, heat losses, and optical heat losses which the elimination of optical, thermal efficiency was imperative because the amount of the losses of this was much greater. Using the longitudinal fins and nanofluid in a trough collector's receiver was studied numerically by Amina et al. (2016) and it was compared with the experimental data. The results indicated in the same condition, heat transfer, and thermo-hydraulic were enhanced when compounding both of them and utilizing metallic nanoparticles increased the heat transfer in comparison with other nanoparticles.

In the conventional solar collector, solar beams were taken by spectral coating on the absorber, then transferred to working fluid. Other modern applications are direct absorption solar collectors (DASC). In these technologies, solar beams absorbed in a straight way without any intermediate surfaces (Minardi and Chuang, 1975); In reality, the working fluid was absorbent fluid. Tyagi et al. (2009) examined a theoretical study of a solar collector's nanofluid (Al/water) based on direct absorption which represented an improvement on the efficiency by 10% more than a conventional flat-plate collector. Otanicar et al. (2010) considered the performance of the collector by using different nanofluids (nanoparticles: carbon nanotubes, graphite, and silver), it enhanced up to 5% experimentally. Lenert and Wang (2012) investigated the effect of carbon-coated absorbing nanoparticles experimentally and numerically. Their results showed that the performance of the receiver was an ascending function of solar concentration and the nanofluid dimensions. Taylor et al. (2011) studied the optical properties of nanoparticles for direct absorption collectors, and showed that graphite nanoparticles would perform better than metallic nanoparticles. He et al. (2013) indicated the maximal temperature of Cu-H_2O nanofluids was 25.3% at 0.1 wt. Their results showed that the performance of direct absorption collector was improved by using this nanofluid in comparison with natural water. Karami et al. (2014) announced functionalized CNT nanofluid as an absorber fluid to enhance the efficiency of low-temperature DASC and investigated effective properties of the fluid in the absorption of sunlight. They showed conductance was increased 32% by shedding 150 ppm of this nanoparticles and the thermal conductivity depended on more on temperature than concentration. Luo et al. (2014) demonstrated that the presence of nanofluids enhances the performance of direct absorption regarding efficiency and output temperature. Bandarra Filho et al. (2014) experimentally revealed that Ag nanoparticles of direct absorption collection increased the performance of the collector even at a low volumetric fraction. After manufacturing the direct absorption solar collector based nanofluids (CuO) for residentiary utilization was indicated that by increasing the flow rate and volume fraction of nanoparticles, efficiency of the collector was enhanced 9–17% (Karami et al., 2015).

Gupta et al. (2015) studied the performance of different concentration of Al_2O_3-H_2O nanofluid thin film on direct absorption solar collector to show that the maximum of collector efficiency occurred at special concentration of nanofluid, so it is needless to say it was decreased at proximity of that concentration. Shende and Sundara (2015) evaluated the thermal conductivity and efficiency were improved by using N-(rGO-MWNTs) in DI water and EG based nanofluids compared with using rGO and MWNTs each alone, and indicated this mixture of nanoparticles was more forcible for DASC. Milanese et al. (2016) investigated the optical absorption of different types of nanoparticles for used on direct absorption low-temperature flat panel solar collector. Their results revealed that transmittance was higher in the infrared region, and the extinction distance becomes greater than the typical solar collector diameter for some cases. Menbari and Alemrajabi (2016) performed both numerical and experimental study to investigate the extinction of binary nanofluids based on different base fluid including water, ethylene glycol and the mixture of ethylene glycol-water. The result explained binary nanoparticles scattered in water have more extinction coefficient than others.

Gorji and Ranjbar (2016) studied numerically and experimentally using of nanoparticles (graphite, magnetite, and silver) on the base fluid and another parameters of DASC. It was found that the