

Improving the performance of heat pipe-evacuated tube solar collector experimentally by using Al_2O_3 and CuO /acetone nanofluids

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ABSTRACT

Research has been undertaken on heat pipe evacuated tube solar collector (HP-ETSC) for hot water applications, which is common in most Middle East regions. The enhancement in thermal performance by using various types of acetone based nanofluids has been explored. This work includes two experimental parts of the gravity-assisted heat pipe (GAHP) installed in evacuated tube solar collector system. The first part is designed to reach the optimal performance conditions for HP-ETSC which is charged with acetone as a working fluid inside the GAHP. Various values of filling ratios (40, 50, 60, 70 and 80%) and tilt angles (30°, 45° and 60°) are considered. The results show that there is an optimal performance at filling ratio equal to 70% and inclination angle equal to 45° when compared with other values during the course of study. This indicates that the importance of fully integrating design process right from the outset of the system design if GAHP is to be installed into an ETSC system to give the maximum possible solar energy benefits of efficient hot water solar collector designs. The main objective of the second experimental investigation is analyzing the impact of the two types of nanofluid (Al_2O_3 and CuO /acetone-based) on the thermal performance of the HP-ETSC. These two nanofluids are used as working fluid inside the GAHP and two concentration values (0.25% and 0.5% vol.) at the optimal conditions from the first experimental part. On the basis of the present study, it is recommended that HP-ETSC systems should be charged with nanofluids for thermal performance enhancement (20–54%) and efficiency (15–38%).

1. Introduction

The world is in fierce competition to secure alternative resources of energy as the conventional fuel resources are under continuous depletion. The most promising source of energy is the sun, where its solar energy can be invested in many different ways. For instance, solar radiation can be captured by means of solar thermal collectors, which produces thermal energy that is subsequently transferred to working fluid. In general, in stationary collectors, evacuated tube solar collectors (ETSCs) are better than flat plate solar collectors (FPCs), since heat loss in ETSCs is much less and, hence, thermal performance eventually is much better. ETSCs also feature quick installation and easy transportability. Moreover, the internal vacuum between glass tubes reduces the heat loss through convection and conduction, and this qualifies the ETSCs to operate at high temperatures (Zhang et al., 2014; Selvakumar et al., 2014; Ayompe and Duffy, 2013), which implies that ETSCs can be implemented in severe climate regions (Sabiha et al., 2015; Ruchi Shukla et al., 2013; Islam et al., 2013; Ghoneim, 2018). The operation

of ETSC relies on heat transfer from the solar radiation to working fluid. However, most of the conventional working fluids are not thermally efficient, since it has limited capacity to carry heat up which significantly affects the overall the performance of the solar collector. Therefore, many researchers worked on enhancing the thermal properties of conventional working fluids by adding nanoparticles to obtain nanofluids (Javadi et al., 2013; Yu and Xie, 2012), which provide a very good alternative to working fluids for solar collectors (Hordy et al., 2014; Sahu et al., 2013; Al-Shamani et al., 2014; Verma and Tiwari, 2015). In the literature, many different studies have focused on the use of various nanofluids to investigate the performance of an ETSC. For instance, Hussain et al. (2015) used zirconium oxide (ZrO_2 – 50 nm) and Silver (Ag – 30 nm) nanoparticles which are dispersed in distilled water. Different vol.% were used, namely at 0, 1, 3, and 5, by implementing two step method to prepare the nanofluids. They observed that with Ag nanofluid the efficiency was higher for 5 vol% in comparison to ZrO_2 nanofluid and the thermal performance was high for both Ag and ZrO_2 nanofluids. Al-Mashat and Hasan (2013) designed

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Nomenclature

A	surface area (m ²)
I	solar energy (w/m ²)
W	weight (kg)
C	specific heat, kJ/kg·K
r	radius (m)
h	heat transfer coefficient (W/m ² K)
k	thermal conductivity (W/m K)
l	length (m)
$\dot{m}$	mass flow rate (kg/s)
Q	heat transfer rate (W)
R	thermal resistance (°C/W)
T	temperature (°C)

Greek symbols

η	efficiency
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ϕ	volume fraction of nanoparticles (%)
ρ	density (kg/m ³)

Subscripts

bf	base-fluid
nf	nanofluid
np	nanoparticle
C	condenser section
E	evaporator section
exp	experimental
wout	water outlet
win	water inlet
v	vapour
u	useful
o	outer

ETSC consisting of 16 evacuating tubes, and the nanofluid is Al₂O₃/water. The efficiency and performance of ETSC are found to be proportional to volume concentration. The results showed a 28.4% enhancement in efficiency with 1 vol% and 6.8% with 0.6 vol% (Al₂O₃). Moreover, with using flat plate reflector, the efficiency is increased by 7.08%, whereas the efficiency is increased by 16.9% when curved plate reflector is used. Lu et al. (2011) used water and Deionized water based CuO nanofluids for an evacuated tube solar air collector. It was shown that the evaporation heat transfer coefficient is increased by 30% due to the presence of the CuO nanoparticles, whereas the wall temperature decreases for the same reason in the open thermosyphon. Park and Kim (2014) proposed a new method to enhance the heat transfer efficiency of a heat pipe in a solar collector, where they combined the hydroxyl radicals with oxidized MWCNTs and used it as working fluid. Sabiha et al. (2015) presented an experimental study of the thermal efficiency of ETSC that is implemented based on single-walled carbon nanotubes (SWCNTs) nanofluids with 0.05, 0.1, and 0.2 vol% concentration volume. The results showed that the collector efficiency increases when nanofluid is used as working fluid instead of water, where the

maximum efficiency is found to be 93.43% for 0.2 vol% SWCNTs nanofluids when the mass flow rate is 0.025 kg/s. Javad Ghaderian et al. (Ghaderian and Sidik, 2017; Ghaderian et al., 2017) built an experimental system to study the details of the effect of using Al₂O₃-CuO/distilled water nanofluid as the working fluid on the thermal performance of ETSC with passive circulation (internal spherical coil inside the horizontal tank). Two values of nanoparticle volume fraction (0.03% and 0.06%) were used for both types (Al₂O₃ and CuO) with a surfactant to minimize the settling effect and different water mass flow rate through the coil (20–60 l/h). From these two studies, it was concluded that the ETSC efficiency shows greater enhancement at the highest volume fraction (0.06%) for Al₂O₃ and CuO/DI water-based nanofluid when compared to pure water.

The operation principle of the gravity-assisted heat pipe (GAHP) transfers heat hundred times more than the best conductors with demonstrated ability to work even with very small temperature difference, hence GAHP is widely used in heat recovery and renewable energy applications (Jafari et al., 2016), where GAHP is successfully used to enhance the efficiency of ETSCs (Nkwetta and Smyth, 2012). A

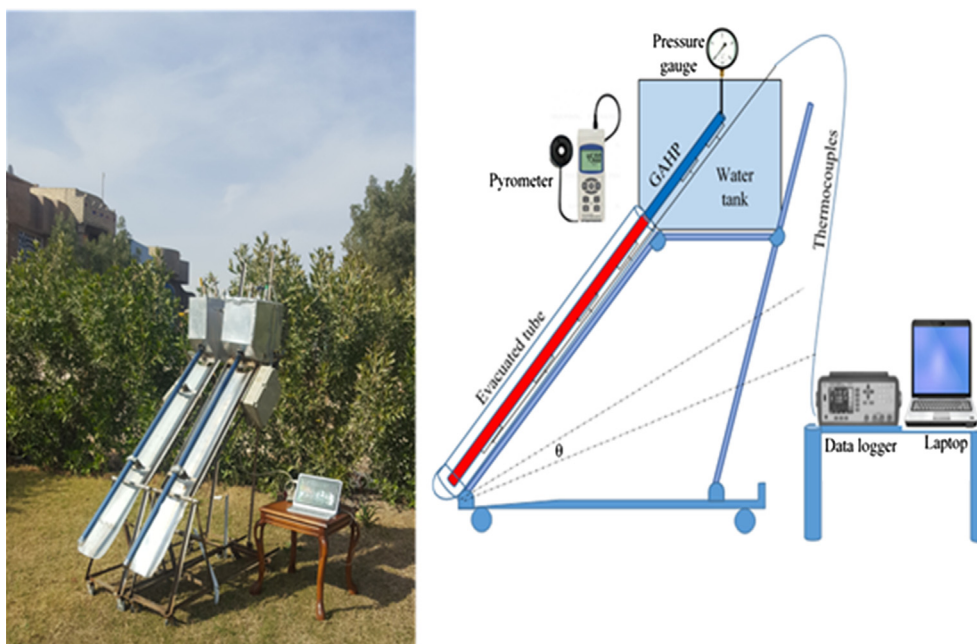


Fig. 1. The experimental setup rig and outlines diagram for two HP-ETSC systems.

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