Energy 164 (2018) 275–287

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Energy and exergy investigation of alumina/oil and silica/oil nanofluids in hemispherical cavity receiver: Experimental Study

Reyhaneh Loni [a], E. Askari Asli-Ardeh [a, *], B. Ghobadian [b], A.B. Kasaeian [c], Evangelos Bellos [d]

[a] Department of Biosystems Engineering, University of Mohaghegh Ardabili, Ardabil, Iran
[b] Department of Biosystems Engineering, Tarbiat Modares University, Tehran, Iran
[c] Department of Renewable Energies, Faculty of New Sciences & Technologies, University of Tehran, Tehran, Iran
[d] Thermal Department, School of Mechanical Engineering, National Technical University of Athens, Greece

A R T I C L E I N F O

Article history:
Received 29 January 2018
Received in revised form
29 July 2018
Accepted 23 August 2018
Available online 29 August 2018

Keywords:
Energy and exergy studies
Hemispherical cavity receiver
Nanofluids
Alumina
Silica
Thermal oil

A B S T R A C T

The objective of this work is the investigation of two oil-based nanofluids in a hemispherical cavity receiver of a solar dish concentrator. The investigated nanofluids are Alumina/oil and Silica/oil, while the used oil is the Behran thermal oil. The two nanofluids are examined experimentally and they are energetically and exergetically compared in order to determine their performance in the solar system. Thermal performance of the hemispherical cavity receiver was studied in the steady-state condition. The results elucidated that the average cavity thermal performance has improved with the application of Alumina/oil nanofluid compared to the application of Silica/oil nanofluid, and pure oil as the solar heat transfer fluid. It was found the lower heat loss coefficient of the hemispherical cavity receiver could be achieved using the Alumina/oil nanofluid than the Silica/oil nanofluid and pure oil as the solar working fluids. Three models were presented for cavity thermal performance versus the parameter $\frac{T_{in}-T_{amb}}{I_{beam}}$ using investigated nanofluids, and base fluid. Exergy efficiency and overall thermal efficiency of the hemispherical cavity receiver was highest using Alumina/oil nanofluid than two other investigated heat transfer fluids. Finally, it was concluded that hemispherical cavity receiver with Alumina/oil nanofluid is the best selection from the energy and exergy viewpoint.

1. Introduction

Recently, renewable energy is accounted as an important subject for researchers due to increasing the world energy demand, reducing the fossil fuel resources, and increasing the environmental pollution. Solar energy is investigated as favorable renewable energy [1]. For this affair, solar collectors can be proposed as an efficient system to absorb the solar energy. The solar concentrator collectors such as dish collectors are similar to a heat exchanger for converting the solar radiation to the thermal power. A huge amount of the concentrating sunlight can be absorbed using the solar concentrator collectors [2]. Absorbed heat from the solar concentrator collectors can be used in the power generation or industrial systems [3,4]. Different kinds of the absorber are used in the dish collectors [5,6]. The cavity receivers due to their special structure for reducing the thermal heat losses have higher thermal performance compared to other dish receivers [7]. Some researchers numerically optimized different dimension of cavity receivers [8,9].

Thermal performance for different shapes of the cavity receivers was experimentally considered in some researches as follows [10–15]. Azzouzi et al. [10] evaluated a cylindrical cavity receiver using water as the solar working fluid as experimental and numerical methods. Good agreement was found between experimental data and the numerical results. Some other researchers designed a new two-step dish concentrator with a cavity receiver for heating air as the working fluid of a turbine [11]. Energy and exergy analysis of a cylindrical cavity receiver was studied during the experimental tests [12]. Heat loss factor and optical efficiency of the investigated solar system were presented. Also, another research was conducted for energy and exergy investigation of a dish concentrator using different shapes of cavity receiver with water as the solar working fluid [13]. The results show that the cylindrical cavity receiver has higher performance compared to the

* Corresponding author.
E-mail address: ezzataskari@uma.ac.ir (E.A. Asli-Ardeh).

https://doi.org/10.1016/j.energy.2018.08.174
0360-5442/

Nomenclature

c_p	Specific heat capacity (J/kg.K)
C	Concentrating ratio
D_{conc}	Dish aperture diameter, m
E	Exergy flow, W
F_R	Heat removal factor
I_{beam}	Solar beam irradiance, W/m^2
K	Thermal conductivity (W/m.K)
M	Mass flow rate (kg/s)
Q_{net}	Net heat transfer rate, W
Q_{solar}	Solar irradiation on the collector, W
U_L	Heat loss coefficient, $\frac{W}{m^{2\circ}C}$
V_{wind}	Wind speed, m/s
T	Temperature, $^\circ C$

Greek symbols

η	Efficiency
μ	Dynamic viscosity, Pa.s
ρ	Density, kg/m^3
φ_P	Nanoparticle volume fraction

Subscripts

amb	ambient
diff	temperature difference between inlet and outlet temperature of fluid
ex	exergy
in	inlet
nf	nanofluid
np	nanoparticle
opt	optical
out	at the outlet
s	solar
th	thermal
0	reference

conical cavity receiver. Thermal performance of a cubical and cylindrical cavity receiver was considered by experimental and numerical methods [14]. Thermal oil was used as the solar working fluid. A spiral receiver on a dish collector was considered by experimental and numerical studies [6]. It was concluded the most suitable fluids for the low-temperature application and higher application temperature are water and Therminol VP-1 respectively. Reddy et al. [15] numerically and experimentally studied the thermal performance of a prototype solar dish concentrator which used a modified cavity receiver as the dish absorber with water as the solar heat transfer fluid. The results show that the increasing the volume flow rate, the thermal efficiency can be improved. As seen from this part of the literature review, the experimental investigation of a hemispherical cavity receiver using oil is accounted as a novelty subject for research.

Thermal properties of the common working fluid can be enhanced by adding ultra-fine solid particles suspended. The suspension of nano-sized particles (1–100 nm) in a conventional base fluid is called a nanofluid. The application of nanofluids in the solar power systems has important advantages which are given below:

- There is no problem in passing nanoparticle through the hydraulic cycle.
- The receiver shows more uniform temperature contribution.
- The thermal performance will be increased due to better thermal properties of nanofluids compared to base fluids.
- Dependent on the nanoparticle size and shape, the enhancement of the thermal performance can be changed.

There are some researchers that numerically and experimentally studied the application of the nanofluids as the solar working fluids [16–27]. Sarafraz and Arjomandi [16] experimentally considered the application of aluminum oxide/gallium nanofluid in a rectangular microchannel. They resulted that the gallium nanosuspension offers a plausible potential to be used in high heat flux systems. Mahian et al. [17] analytically investigated the Silica/water nanofluid in a flat plate solar collector. The results show that the outlet temperature increased and entropy generation decreased by the application of the nanofluid as the solar working fluid. Mohammad Zadeh et al. [18] numerically investigated the influence of the Alumina/synthetic oil nanofluid as the solar working fluid of a parabolic trough collector. Yousefi et al. [19] experimentally considered the thermal efficiency of the flat plate collector utilizing the MWCNT–water nanofluid as the working fluid of the solar collector. The results show a more significant difference between the nanofluid pH and isoelectric point pH caused the higher efficiency. Yousefi et al. [20] experimentally evaluated the application of Alumina/water nanofluid as the solar working fluid in a flat-plate solar collector. Yousefi et al. [21] examined the thermal performance of a flat plate collector using the multi-wall carbon nanotubes (MWCNT)/Water nanofluid as the solar working fluid. They resulted from the collector efficiency enhanced by 2% using nanofluid as the solar heat transfer fluid compares to the base fluid.

Tong et al. [22] research on an enclosed-type evacuated U-tube solar collector (EEUSC) using Multi-walled carbon nanotube (MWCNT)/water nanofluid as the solar heat transfer fluid. Mwesigye et al. [23] thermodynamically investigated the application of Alumina/Syltherm 800 nanofluid in a parabolic trough solar collector. They reported that the receiver thermodynamic performance improved below some Reynolds number. Madadi et al. [24] studied the energy and exergy analysis of the parabolic dish collector using a cavity receiver and Alumina/water nanofluid as the solar working fluid. The results indicate the thermal efficiency and exergy efficiency of the investigated collector enhanced by increasing the nanofluid concentration. Some researchers [25,26] numerically modeled a cavity receiver using different types of nanofluids. They resulted that the application of nanofluid could improve the thermal performance of the investigated solar system. Some researchers [27] experimentally considered the application of MWCNT/thermal oil nanofluid in a parabolic dish concentrator with a cylindrical cavity receiver. They reported that the nanofluid as working fluid is an effective way of improving the thermal performance of the investigated solar system. It can be seen from the mentioned literature review, the application of nanofluid is an interesting subject for research in the solar systems. The use of nanofluid in the solar dish system using cavity receiver is accounted as a novelty topic for investigation.

As concluded from the aforementioned literature review, application of nanofluids as the solar working fluid is expressed as a novel subject for improving the thermal performance of the dish concentrator system with hemispherical cavity receiver. The use of nanofluid in solar concentrating systems is something very important because there are great heat fluxes on the receiver and there is a need for high heat transfer rates. In order to cover this scientific gap, this work presents experimental results for a