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Experimental test of an innovative high concentration nanofluid solar collector

Gianpiero Colangelo *, Ernani Favale, Paola Miglietta, Arturo de Risi, Marco Milanese, Domenico Laforgia

Dipartimento di Ingegneria dell'Innovazione, Università del Salento, Via per Arnesano, 73100 Lecce, Italy

HIGHLIGHTS

- A new type of nanofluid thermal solar collector has been built and tested.
- Al_2O_3–distillated water based nanofluid at high concentration has been used.
- Experimental results showed an increase of thermal efficiency up to 11.7%.

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ABSTRACT

In this study, a modified flat panel solar thermal collector was built and thermal efficiency was measured with two heat transfer fluids: distillated water and Al_2O_3–distillated water based nanofluid at high concentration (3.0%) volume fraction of solid phase. In this work for the first time nanofluid with high nanoparticle concentration has been used thanks to a modified solar thermal collector, based on patent WO2011138752 A1, which consists in bottom and top headers properly shaped in order to reduce sedimentation of clusters of nanoparticles. Thermal efficiency has been measured through an experimental setup, according to EN 12975-2 standard. Experimental results showed that an increase of thermal efficiency up to 11.7% compared to that measured with water has been obtained by using nanofluid. Besides effect of nanofluid on thermal efficiency is greater at high temperatures.

1. Introduction

The interest in improving heat transfer capability of heat transfer fluids have been growing in the last decade and particular attention has been given to nanofluids, a biphasic suspension of metal or metal oxide nanoparticles in a traditional heat transfer fluid such as water, oil, ethylene glycol [1] etc. Therefore nanofluids can also be applied in energy systems in order to increase their efficiency [2] or to enhance heat transfer coefficients in heat exchangers [3], as in cooling system for wind turbines proposed by de Risi et al. [4]. Thermal conductivity of nanofluids and convective heat transfer coefficient have been investigated for different materials and particle sizes by many authors [5]. Syam Sundar et al. [6] analyzed water and ethylene glycol mixture inseminated with Al_2O_3 nanoparticles. They obtained a thermal conductivity enhancement from 9.8% to 17.89% for Al_2O_3 nanofluid with 0.8 vol% of solid phase, in a range of temperature between 15 °C and 50 °C. Yiamsawasd et al. [7] measured thermal conductivity of water based nanofluids with Al_2O_3 nanoparticles, with volume fraction from 0.0% to 8.0%, in a temperature range between 15 °C and 65 °C. They obtained an increase between 2% and 20%. Minsta et al. [8] measured thermal conductivity of water based nanofluids with Al_2O_3 nanoparticles with an average dimension of 47 nm and 37 nm respectively. An enhancement up to 30.0%, in a range of volume fraction from 1.0% to 18.0% was found. Al_2O_3–water based nanofluids at a volume fraction of 1.0%, 2.0% and 3.0% have been prepared and their thermal conductivity has been measured at 20 °C by Colangelo et al. [9]. It was observed an enhancement up to 6.70%.

Although nanoparticles are more stable in base fluid compared with larger particles, which yield problems of clogging, abrasion and sedimentation [10,11], viscosity of nanofluid is higher than that of base fluid.

Convective heat transfer coefficient of nanofluids has been also investigated by many authors. Heyhat et al. [12] measured heat transfer coefficient of water based nanofluids with Al_2O_3 nanoparticles with an average diameter of 40.0 nm and a volume fraction from 0.1% to 2.0% in a circular tube, with constant wall temperature under turbulent flow conditions. Results were compared with

* Corresponding author. Tel.: +39 0832297752; fax: +39 0832297777.
E-mail address: gianpiero.colangelo@unisalento.it (G. Colangelo).

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Nomenclature

v_h	inlet average velocity (m/s)
A_h	inlet cross section area (m^2)
A_i	cross section area at i position (i = 1, 2,...,7) (m^2)
$\dot{m}_i$	mass flowrate at i position (i = 1, 2,...,7) (kg/s)
G	global solar irradiance (W/m^2)
T_a	surrounding air temperature (°C)
G_d/G	diffuse fraction (%)
u	surrounding air speed (m/s)
T_{in}	collector inlet temperature (°C)
T_{out}	collector outlet temperature (°C)
$\dot{Q}$	power extracted by solar collector (W)
c_p	specific heat (J/kg K)
T_m	mean temperature (°C)
$\dot{m}_h$	mass flowrate (kg/s)
A_A	absorber area of the collector (m^2)
A_a	aperture area of the collector (m^2)
T_m^*	reduced temperature difference (°Cm^2/W)
U_{Tout}	uncertainty for outlet temperature (%)
U_{Tin}	uncertainty for inlet temperature (%)
U_G	uncertainty for solar radiation (%)
U_η	uncertainty for efficiency (%)
a_1	heat transfer coefficient (W/m °C)
R^2	uncertainty coefficient

Greek symbols

Θ	incidence angle of beam irradiance (°)
η	efficiency
η_0	zero loss efficiency
ρ	density of the fluid (kg/m^3)

convective heat transfer coefficient obtained with base fluid. An enhancement up to 23.0% was obtained. Hwang et al. [13] studied the convective heat transfer coefficient of water–Al_2O_3 nanofluids flowing in a stainless steel tube. The nanoparticles had an average diameter of 30 nm and they obtained an increase up to 8.0% at a concentration of solid phase of 0.3%. An increase of 20.0% and 15.0% of convective heat transfer coefficient, under laminar and turbulent flow conditions respectively, with a volume fraction of 3.0% in a stainless steel tube with an inner diameter of 4.57 mm, was obtained by Kim et al. [14].

Fotukian and Esfahany [15] experimentally investigated that the maximum value of heat transfer coefficient enhancement is 48% for alumina nanofluids, with a volume fraction less than 0.2%, compared to water, in turbulent flow condition, inside a copper tube with inner diameter of 5.0 mm. Besides Wen and Ding [16] found that the trend of convective heat coefficient for Al_2O_3 nanofluids (with a volume concentration from 0.6% to 1.6%) is a function of volume fraction and that in the entry region the enhancement is much higher and then it decreases with axial distance. Heris et al. [17] obtained enhancement of heat transfer coefficient up to 20.0% compared to that of the water with alumina nanofluids with a volume fraction from 0.2% to 2.5%. Heris et al. [18] observed that heat transfer coefficient of alumina nanofluids increases of 29.0%, under laminar flow condition, with a volume fraction of 2.5%. Anoop et al. [19] studied the effect of nanoparticles size on heat transfer coefficient of Al_2O_3–water based nanofluids. An enhancement of 25% for 45 nm nanoparticles and 11% for 150 nm ones at 4 wt% has been obtained. Sahin et al. [20] determined heat transfer coefficient of Al_2O_3–water nanofluids (from 0.5 vol% to 4.0 vol%) in an aluminum circular tube, with inner diameter of 11.7 mm, under a constant heat flux. A parabolic trend was obtained and maximum values were measured at 1.0 vol% of solid phase.

Nanofluids can be employed in solar energy systems in order to improve their efficiency. Taylor et al. [21] asserted that nanofluids in a receiver of a concentrating solar thermal system can increase efficiency up to 10%. Otanicar et al. [22] investigated the effect of water based nanofluids on a micro scale direct absorption solar collector (DASC). Using silver nanoparticles, CNTs and graphite nanoparticles respectively an enhancement of the efficiency with a volume fraction of 0.5% was obtained. Besides a remarkable efficiency dependence on particle size was observed for silver nanoparticles with a diameter between 20 nm and 40 nm. Yousefi et al. [23] investigated nanofluids effect in a flat plate solar collector using water–Al_2O_3 dispersion at a weight fraction of 0.2%. An enhancement of 28.3% in comparison with water was obtained and adding a surfactant to the suspension the efficiency enhanced of 15.63%. Chaji et al. [24] studied the effect of TiO_2 water based nanofluid inside a small flat plate solar collector with 0.1, 0.2 and 0.3 wt% of solid phase. An index of collector total efficiency was used to compare the different cases. Efficiency was investigated at 36 l/m^2 h, 72 l/m^2 h, and 108 l/m^2 h respectively. An enhancement between 2.6% and 7.0% was obtained. Moghadam et al. [25] studied the effect of CuO–water base nanofluid at 0.4 vol% and average diameter of 40 nm on the efficiency of a flat plate solar collector. An enhancement of 4.74% and 21.8% compared to that of water has been obtained with a mass flow rate of 2 and 1 kg/min respectively.

Although nanoparticles are more stable in liquid phase than millimeter or micrometer particles, sedimentation phenomenon can be detected in piping of the systems and therefore also in solar collector, as Colangelo et al. [26] demonstrated with a water–Al_2O_3 nanofluid with a volume fraction between 1.0% and 3.0%. They proposed a modified flat plate solar collector to avoid this phenomenon, in order to maintain a constant flow velocity along both bottom and top header. The sedimentation analysis was carried out through an optical investigation. For this purpose, a modified flat plate solar collector was built with transparent tubes.

The aim of this work is to continue the research on a modified flat plate solar collector analyzed by Colangelo et al. [26] and to evaluate the increase of performance of a flat plate solar collector due to the use of water–Al_2O_3 nanofluid as heat transfer fluid. In particular, a modified flat plate solar collector using water–Al_2O_3 nanofluids was built and its efficiency was measured under different working conditions, according to EN 12975-2 standard. In this work for the first time the performance of a nanofluid solar collector is evaluated according to EN 12975-2 standard [27]. In other works the experimental campaign has been carried out using a traditional solar collector with no compliance to any standard. In this work, instead, a new model of solar collector has been designed and built, able to work specifically with nanofluids and all the experimental tests have been carried out following the EN 12975-2 standard. In this way the comparison between the heat transfer fluids has been performed in controlled and standard conditions, reducing the possibility of error. In this work a volume fraction of 3.0% of nanoparticles has been chosen to evaluate the possible problems related to sedimentation and to collect data about the most stressing conditions for the system. Other works used lower nanoparticle concentrations [22–25] to avoid inevitable sedimentation problems and to reduce pumping problems. In this