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Performance evaluation and nanofluid using capability study of a solar parabolic trough collector

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ABSTRACT

The aim of present work is to prepare a standard pilot of trough collector to investigate the ways of its performance enhancement. In this paper, a pilot of trough collector was designed and manufactured in a simple way with a 0.7 m width and 2 m in height reflector, which was made of steel mirror. The design, construction procedure and the new shape of receiver coupling are defined by details in the manuscript. The transient response and the optical and thermal performances of the collector were compared using four kinds of receivers: a black painted vacuumed steel tube, a copper bare tube with black chrome coating, a glass enveloped non-evacuated copper tube with black chrome coating, and a vacuumed copper tube with black chrome coating. Then 0.2% and 0.3% carbon nanotube/oil based nanofluids were prepared as working fluid and tested in the pilot with the black chrome coated vacuumed copper absorber tube. All the operating conditions were considered according to ASHRAE Standard 93 (2010) in all steps of test procedure. The results show that the global efficiency of vacuumed tube is averagely 11% higher than the bare tube efficiency, which is in good agreement with the previous works. Also, the nanofluid shows high thermal potential for further and more complete examinations. At last, a model of global efficiency is curve fitted for present prototype and compared with the previous models.

1. Introduction

Parabolic trough collector (PTC) is one of the linear concentrating solar collectors which are appropriate for working in the range of 150–400 °C [1]. Mainly, a parabolic trough collector is made of a parabolic trough mirror which acts as a reflector and a receiver in the focal line of the reflector to absorb the reflected radiation from sun. The concentrated radiation heats up the fluid that circulates through the absorber tube; as a consequence, the solar radiation is transformed to thermal energy [2]. In the mid-1970s, the U.S. Government's Sandia National Laboratories, Honeywell International Inc., and Westinghouse made three PTC prototypes whose receivers were coated by black chrome on carbon steel tubes [3]. Along the continuing of PTC manufacturing in 1980s and 1990s, four major companies – Acurex Corp., Sola Kinetics Inc., Suntec Systems Inc., and Solel Solar Systems made several prototypes with focal lines of 0.272 m up to 0.838 m. The Solar Kinetics's T-800 [4] model was made of black-chrome-coated steel surrounded by a non-evacuated glass. The Suntec Systems' IV model was made of black-chrome-coated steel tube in a sealed glass which was filled with a partially vacuumed argon gas [5]. Sanle03 HCE was the first PTC which had an absorber tube with a graded cermet solar selective coating surrounded by a vacuumed glass; this prototype was manufactured in 2010 by Southeast University and Sanle Electronic Group of China [6]. In 2011, Quoilin et al. designed an organic Rankine cycle for remote power generation by using a PTC. The prototype possessed a 75 m^2 parabolic trough with a Miro aluminum reflector, a heat collection element with a selective coating and air-filled annulus between the absorber tube and glass envelope [7]. Thermal performance of trough collector was first evaluated by Arinze et al. [8] using water as the working fluid. A dynamic computer program was evolved by them for predicting the thermal performance of a water storage system under different charging and discharging conditions. Arasu et al. [9] designed and manufactured a smooth 90° rim angel reinforced parabolic trough collector. The thermal performance of this collector was determined as specified in ASHRAE Standard 93 [10]. Marco Sotto designed two prototypes of parabolic trough collector, the first one (Univpm.01) had a focal line of 0.25 m and the second one (Univpm.02) had a focal line of 0.55 m. Both prototypes receivers were adopted in aluminum tubes which were painted with a high temperature resistant black paint [11]. Kalogiru and Lloyd designed a prototype with focal line of 0.5 m for optimizing the

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Nomenclature

A_f	geometric factor (m^2)
d^*	universal non random error parameter due to angular errors on receiver dislocations
C	concentration ratio
DI	direct solar radiation (W/m^2)
f	focal distance (m)
F_R	heat removal factor
t	time (sec)
T	temperature (°C)
W	aperture width (m)
U_L	overall heat loss coefficient (W/m^2 K)

Subscripts

amb	ambient
c	collector
f	fluid
i	inlet
o	outlet
r	receiver
ss	steady state

Greek symbols

α_r	receiver absorptivity
β^*	universal non random error parameter due to angular errors [$\beta^* = \beta C$]
ϕ	collector rim angle (deg)
η	efficiency (–)
θ	angle of incidence (deg)
ρ_c	collector reflectance
τ_v	transmittance of envelope

performance of the prototype [12]. Kumaresan et al. made a prototype with a reflector including 6 mirrors of 1.25 m^2 aperture area and a absorber tube coated with a high resistant black paint surrounded by a borosilicate glass cover envelope [13].

Nanofluids have been exhibited novel and improved thermo physical properties due to their nanoscale size. Many experimental works have been done in the nanofluids area. Some of these works are focused on the usage of nanofluids in the horizontal tube and heat exchangers. Among the nanoparticles, carbon nanotubes (CNT) have great properties. Ding et al. in 2005 [14] made a study of the heat transfer performance of nanofluid in a carbon nanotube with inner diameter of 4.5 mm. The research result showed that the enhancement of heat convection coefficient was greater than the enhancement of thermal conductivity. It was also thought that the enhancement of heat convection coefficient was mainly caused by the aspect ratio of the added CNTs. Heat transfer enhancement of multi-walled carbon nanotube (MWNT)/water nanofluid in a horizontal shell and tube heat exchanger has been studied experimentally by Rashidi et al. in 2012 [15]. The results indicate that heat transfer enhances in the presence of multi-walled nanotubes in comparison with the base fluid.

The concept of using nanofluid in solar collectors doesn‘t have a long history. Yousefi et al. [16] evaluated the effect of Al_2O_3 –H_2O nanofluid on the efficiency of a flat plate solar collector. In comparison with pure water, they observed 28.3% enhancement of efficiency with 0.2 wt% nanoparticle concentration. The results of this research also showed that utilizing MWCNT–H_2O nanofluid would enhance the efficiency of the flat plate solar collector [17]. In the research by Filho et al. [18] excellent enhancement in the stored thermal energy of nanofluid based direct absorption system obtained at the peak temperature for a particle concentration of 6.5 ppm silver nanoparticles. Liu et al. [19] evaluated the influence of water-based CuO nanofluids upon an evacuated tubular solar air collector integrated with simplified CPC (compound parabolic concentrator) and special open thermosyphon. Experimental results show that the solar collector integrated with open thermosyphon has a much better collecting performance. The effects of using the cuprous and aluminum oxides on the performance of solar still were studied by Kabeela et al. [20]. The performance was investigated at different weight fraction concentrations of nanoparticles in the basin water with and without providing vacuum. These nanoparticles greatly improve the evaporation and condensation rates and hence the distillate yield was augmented. In 2013, Abu-Hamdeh et al. developed a prototype for refrigeration. The receiver was stainless steel tube covered by a glass envelope, while the tube was coated in a bed of steel casings [21]. In the last few years, Taylor et al. [22] and kasaeian et al. [23,24] proposed the idea of nanofluid usage in trough collectors for heat transfer enhancement of fluid flow in the absorber tube. The results of the numerical study by Kasaeian et al. [24] show heat transfer enhancement due to nanoparticles addition to the fluid. Khullar et al. [25] studied the nanofluid usage in a concentrating parabolic solar collector theoretically and compared the results with the experimental data of the conventional concentrating parabolic solar collectors. Their results demonstrate 5–10% higher efficiency as compared to the conventional models.

As explained above, many researchers have focused on the design aspects of trough collectors to improve its global efficiency. Furthermore, the advances in working fluid of PTC were quite little attempted. In the present study a pilot of solar trough collector was designed and manufactured for experimental investigation of the collector global efficiency, using multi walled carbon nanotube (MWCNT)/oil based nanofluid as the working fluid. The general aim of this study was having an applicable and standard trough collector to improve its performance, taking into account simplicity of manufacturing and proper usage of nanofluid. Also, the time constant, optical and thermal efficiency of different receiver tubes with different coatings have been applied and compared.

2. Design, manufacturing and test procedure

2.1. Parabolic steel mirror sheet reflector

A parabolic reflector was designed with the length of 2 m and aperture width of 0.7 m. The reflector was made of steel mirror with thickness of 0.8 mm. For the purpose of fabricating the reflector, a polyurethane mold with parabola shape was produced by CNC. Then, a steel mirror sheet was cut by laser and placed on the mold to obtain the shape of the parabola. The rim angle of this prototype was selected as 90° and, as reported by Valan Arasu and Sornakumar [9], this degree represents a suitable rim angle. The two-dimensional equation and focal distance for the parabolic concentrator is as follow [26]:

$$Y = \frac{1}{4f}X^2 \tag{1}$$

$$f = \frac{W}{2}\cot\phi + \frac{W^2}{16f} \tag{2}$$