An experimental study on Evacuated tube solar collector using nanofluids

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Abstract

The present study aims to investigate the energy efficiency of an evacuated tube solar collector containing water based single walled carbon nanotube nanofluids. The effect of various parameters such as volume concentration of nanofluid, inlet and outlet fluid temperature, solar radiation and ambient temperature on the collector efficiency is investigated. According to the results, higher efficiency is achieved for higher volume concentration of single walled carbon nanotube nanofluids. The energy efficiency also increased with increasing solar radiation value. The highest collector efficiencies are observed for 84.24% and 94.73% using 0.05 and 0.25 vol% single walled carbon nanotube nanofluids respectively at a mass flow rate of 1.5kg/min.

Abbreviations and nomenclature

ETSC	Evacuated Tube Solar Collector	$\dot{m}$	Mass flow rate of working fluid, Kg/s
SWCNT	Single Walled Carbon Nanotube	G	Solar irradiance, W/m^2
MWCNT	Multi Walled carbon nanotube	η	Efficiency of the collector
Q_u	Useful energy, W	T_i	Inlet temperature of the working fluid; °C
A_c	Collector absorbance area	T_o	Outlet temperature of the working fluid, °C
C_p	Specific heat, j/kg.°C	T_a	Ambient temperature, °C
τ	transmittance	φ	nanoparticles volume fraction, %
α	absorptance		

Introduction

Solar energy is one of the cleanest forms of renewable energy which is sustainable, inexhaustible, and inexpensive. Solar energy is becoming more appealing as it is secure and can be gained without any restrictions. To collect heat from solar energy, solar collectors are the existing technologies which can be used in many energy requirements of buildings; like air-conditioning, cooling demand, heating of domestic hot water, swimming pool heating and so on. Flat-plate solar collectors (FPC) are simple in construction, utilize the beam as well as diffuse radiation and popular for low temperature applications. In comparison with evacuated tube solar collector, FPCs have comparatively low efficiency and outlet temperatures. Evacuated tube solar collectors (ETSC) have outstanding thermal performance due to lower heat loss, easy transportability, and expedient installation and in addition ETSCs are suitable for unfavorable climates (Kalogirou, 2003; Morrison *et al.*, 1984; Tang *et al.*, 2006; Xiao *et al.*, 2004). The vacuum between the glass tubes in ETSC reduces conduction and convection losses and allow the collector to operate at high temperature (Ayompe & Duffy, 2013; Selvakumar *et al.*, 2014; Zhang *et al.*, 2014). The conventional fluids which are used as the heat transfer medium in solar collectors suffer from poor thermal and heat absorption properties. It has been found that these conventional fluids have a limited capacity to carry heat up, which in turn limits the collector performance. From literature, it has been observed that nanoparticles dispersed in conventional fluids (Nanofluids), have improved thermal properties (Javadi *et al.*, 2013; Yu & Xie, 2012). Thus, nanofluids can be a good substitute of the conventional fluids in solar collectors (Hordy *et al.*, 2014; Sahu *et al.*, 2013; Verma & Tiwari, 2015). Several researchers have already used different types of nanofluids to investigate the performance of ETSC.

Experimental and theoretical studies have demonstrated high thermal conductivity of cylindrical structured nanoparticles compared spherical nanoparticles (Harish *et al.*, 2012). Spherical nanoparticles are the metallic and oxide nanomaterials such as aluminium and aluminium oxide have thermal conductivity of 237 W/mK and 40 W/mK respectively (Murshed & Nieto de Castro, 2014). In contrast, CNTs have thermal conductivity in a range of 2000–6000 W/mK. Specifically, the values for thermal conductivity of single walled carbon nanotube (SWCNT), double walled carbon nanotube (DWCNT) and multi walled carbon nanotube (MWCNT) are 6000 W/mK, 3986 W/mK and 3000 W/mK, respectively (Nasiri *et al.*, 2012; Sadri *et al.*, 2014). The thermal conductivity of DWCNT and MWCNT decreases respectively due to the increase of nanotube wall layers (Xie & Chen, 2011).

In this paper single walled carbon nanotube (SWCNT) nanofluid is considered as the working fluid which has been used by some researchers for other types of solar collector.

Background

Karami *et al.* (2014) investigated the performance of direct absorption solar collector (DASC) using CNT nanofluids of six volume concentrations (5, 10, 25, 50, 100, 150 ppm). The nanofluids were prepared by dispersing functionalized CNT nanoparticles into water. From experimental results, it was observed that the thermal conductivity of CNT nanofluid (150 ppm) is 32.2% higher compared to water. Therefore, they reported CNT nanofluid as a very suitable working fluid for increasing overall efficiency of DASC.

According to Tong *et al.* (2015), the absorbance of MWCNTs is 10%-20% higher than that of water. Moreover, the absorbance of MWCNTs increases with their increasing concentration. Therefore, the MWCNT/water nanofluid was selected as the working fluid to absorb solar radiation directly and the thermal performance of enclosed type evacuated U-tube solar collector. Results of the study demonstrated that nanofluid with a 0.24 vol% concentration showed the highest heat transfer coefficient between the tube and the working fluid and the heat transfer coefficient was about 8% higher than that when only water was used.

Quarter circular solar collector, a novel model for solar thermal collector was proposed by Rahman *et al.* (2014). The enhanced performance was achieved using CNT/water nanofluid by compromising between two parameters which are volume fraction of nanoparticles and tilt angle of the collector.

The performance of FPC consisting heat pipe was compared using CNT nanofluid and water by Chougule (2015). The optimum efficiency was achieved by compromising two parameters which are working fluids (water and CNT nanofluids) and tilt angle (31.5° and 50°). The average collector efficiencies at 31.5° are 25% and 45%, at 50° are 36% and 61% for water and nanofluid respectively. The maximum instantaneous efficiency obtained by using nanofluid is 69% for 50° tilt angle which is 69.44% higher than water.

Methodology

Nanofluid preparation

Two step method was selected in order to prepare nanofluids based on the facility available in the labs of University Malaya. Short SWCNTs (90% CNTs, 60% SWCNTs) nanoparticles were purchased from Nanostructured & Amorphous Materials, Inc., USA. Properties of SWCNT nanoparticles are listed in Table 1. Distilled water used as base fluid to prepare SWCNT nanofluid. Sodium Dodecyl Sulfate (SDS) surfactants were used to prevent nanoparticles agglomerates and makes the fluid stable. The suspension of SWCNTs, SDS and distilled water was then sonicated by a high pressure ultrasonic homogenizer (capacity up to 2000 bar) for 60 min in order to overcome the strong cohesion forces between tubes of SWCNT nanoparticles.

Table 1: Properties of SWCNTs

CNTs (%)	90
SWCNTs (%)	60
Density (g/cm^3)	2.1 at 20°C
Diameter (nm)	1–2
Length (nm)	500
Purity (%)	90
Melting range (°C)	3652–3697
Color	Black
Odor	Odorless
Thermal conductivity (W/mK)	6000 [5]
Specific Surface Area (SSA) (m^2/g)	360–400

Experimental setup and data collection

The evacuated solar collector was experimentally investigated at University Malaya is illustrated at Fig. 1. The specifications of the evacuated tube solar collector that are used for this study is presented in Table 2. According to literature, the heat pipe ETSC must be mounted with a minimum tilt angle of 25º in order to allow the internal fluid of the heat pipe to return to the hot absorber (Vence Linares, 2011). Therefore, the tilt angle of the collector was set at 33°.

Table 2: Specifications of ETSC

Specification	Dimension
Length	1800mm(1.8m)
Outer tube diameter	58mm (0.058m)
Inner tube diameter	47mm (0.047m)
Material	Borosillicate Glass 3.3
Absorbance	0.93
Transmittance	0.89
Collector Area	1.92 m^2
Absorbance Area	1.14 m^2

The ETSC collector was tested at mass flow rates of 1.5 kg/min to investigate the efficiency of the collector. The thermal efficiency of an evacuated tube solar collector can be calculated by (1).

$$\eta = \frac{\dot{m} C_p (T_o - T_i)}{A_c G} \tag{1}$$

The specific heat of nanofluid can be estimated by (2)

$$C_{Pnf} = \frac{(1-\phi)(\rho C_p)_{bf} + \phi(\rho C_p)_{np}}{(1-\phi)\rho_{bf} + \phi\rho_{np}} \tag{2}$$

Figure 1: Experimenatl setup

Table 3: Experiment conditions

Base fluid	Water
Nanoparticle	SWCNT
Nanoparticle type	Cylindrical
Surfactant	SDS
Volume concentration (vol%)	0.05, 0.25
Time (min)	60
Flow rates (kg/min)	1.5

Result and Discussion

The effect of nanofluid on the performance of ETSC was investigated using water and SWCNT nanofluids (0.05 and 0.25 vol %). Before using the nanofluids as working fluid, it was confirmed that the suspension of SWCNT and SDS is stable for more than 1 month, illustrated in Fig. 2.

Figure 2: SWCNT nanofluids after 1 month.

Each test was performed in several days and the similar experimental data of solar radiation and ambient temperature have been chosen in order to calculate and compare the effect of various mass flow rates.

An average daily solar radiation of more than 900 W/m^2 is available in Malaysia. The heat pipe ETSC was exposed to solar radiation half an hour before the readings were taken.

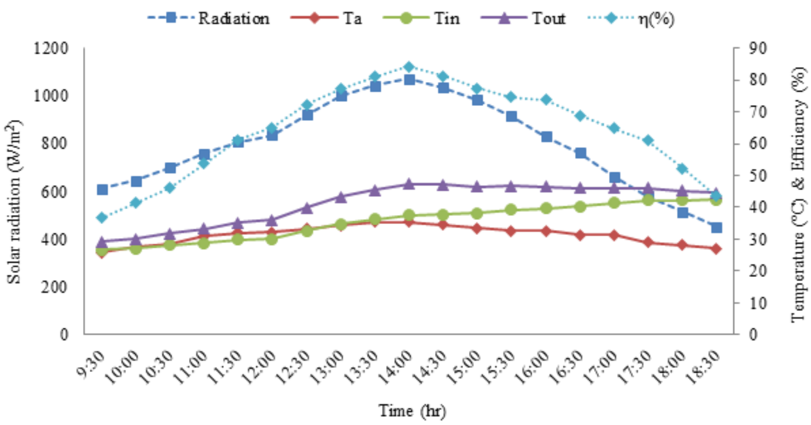

Figure 3: Experimental data of solar radiation, ambient, input and output temperature and the efficiency of ETSC using 0.05 vol% SWCNT nanofluid.

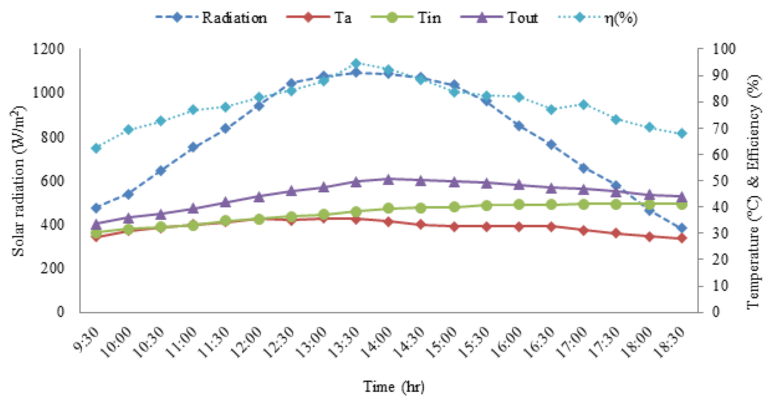

Figure 4: Experimental data of solar radiation, ambient, input and output temperature and the efficiency of ETSC using 0.25 vol% SWCNT nanofluid.

From Fig. 3 and 4, it can be seen that the solar radiation increases from 9:30 hr and reaches around 1000 W/m^2 between 13:00 hr 14:30 hr and then start decreasing. The maximum difference between outlet and inlet temperature obtained for mass flow rate of 1.5 kg/min by 0.05 and 0.25 vol% SWCNT nanofluids are 9.85 and 11.43°C respectively.

Initially obtained efficiencies at 1.5 kg/min are 36.57% and 62.51% for 0.05 and 0.25vol% SWCNT nanofluids respectively. The efficiencies of the evacuated collector using 0.05 and 0.25 vol% SWCNT nanofluids increased up to 84.24% and 97.43% respectively due to higher temperature difference resulted by increased global solar radiation. It is observed from the experimental results that the collector efficiency is 15.66% higher for 0.25vol% compared to 0.05vol% SWCNT nanofluid. The SWCNT nanofluids with higher concentration have higher thermal conductivity which allows the fluid to absorb better heat. The effect of Brownian motion in evacuated collector system is also impressive as nanofluid flows in tube at certain flow rates rather than being in static situation. Therefore, SWCNT nanofluid with higher volume concentrations provides better efficiency.

Conclusion

In this study, the energy efficiency of an evacuated tube solar collector is investigated using SWCNT nanofluids (0.05 and 0.25 vol%) at a mass flow rate of 1.5 kg/min. The efficiency using 0.25 vol% is found to be 15.66% higher compared to 0.05 vol% SWCNT nanofluids. The effect of mass flow rate on the efficiency also can be observed for further research.

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References

Ayompe, L. & Duffy, A. 2013. Thermal performance analysis of a solar water heating system with heat pipe evacuated tube collector using data from a field trial. *Solar Energy*. **90**: 17-28.

Chougule, S. S., & Sahu, S. 2015. Performance of Carbon Nanotubes–Water Nanofluid Charged Wickless Heat Pipe Flat Plate Solar Collectors Having Different Filling Ratio. *Journal of Solar Energy Engineering*. **137**(2): 024501.

Harish, S., Ishikawa, K., Einarsson, E., Aikawa, S., Inoue, T., Zhao, P. & Maruyama, S. 2012. Temperature dependent thermal conductivity increase of aqueous nanofluid with single walled carbon nanotube inclusion. *Materials Express*. **2**(3): 213-223.

Hordy, N., Rabilloud, D., Meunier, J.-L. & Coulombe, S. 2014. High temperature and long-term stability of carbon nanotube nanofluids for direct absorption solar thermal collectors. *Solar Energy*. **105**: 82-90.

Javadi, F., Saidur, R. & Kamalisarvestani, M. 2013. Investigating performance improvement of solar collectors by using nanofluids. *Renewable and Sustainable Energy Reviews*. **28**: 232-245.

Kalogirou, S. 2003. The potential of solar industrial process heat applications. *Applied Energy*. **76**(4): 337-361.

Karami, M., Bahabadi, A., Delfani, S., & Ghozatloo, A. 2014. A new application of carbon nanotubes nanofluid as working fluid of low-temperature direct absorption solar collector. *Solar Energy Materials and Solar Cells*. **121**: 114-118.

Morrison, G., Tran, N., McKenzie, D., Onley, I., Harding, G. & Collins, R. 1984. Long term performance of evacuated tubular solar water heaters in Sydney, Australia. *Solar Energy*. **32**(6): 785-791.

Murshed, S. & Nieto de Castro, C. 2014. Superior thermal features of carbon nanotubes-based nanofluids–A review. *Renewable and Sustainable Energy Reviews*. **37**: 155-167.

Nasiri, A., Shariaty-Niasar, M., Rashidi, A. & Khodafarin, R. 2012. Effect of CNT structures on thermal conductivity and stability of nanofluid. *International Journal of Heat and Mass Transfer*. **55**(5): 1529-1535.

Rahman, M., Mojumder, S., Saha, S., Mekhilef, S. & Saidur, R. 2014. Effect of solid volume fraction and tilt angle in a quarter circular solar thermal collectors filled with CNT–water nanofluid. *International Communications in Heat and Mass Transfer*. **57**: 79-90.

Sadri, R., Ahmadi, G., Togun, H., Dahari, M., Kazi, S. N., Sadeghinezhad, E. & Zubir, N. 2014. An experimental study on thermal conductivity and viscosity of nanofluids containing carbon nanotubes. *Nanoscale Research Letters*. **9**: 151.

Sahu, S., Pise, A. & Chougule, S. 2013. Performance enhancement of two phase thermosyphon flat-plate solar collectors by using surfactant and nanofluid. *Frontiers in Heat Pipes (FHP)*. **4**: 013002.

Selvakumar, P., Somasundaram, P. & Thangavel, P. 2014. Performance study on evacuated tube solar collector using therminol D-12 as heat transfer fluid coupled with parabolic trough. *Energy Conversion and Management*. **85**: 505-510.

Tang, R., Li, Z., Zhong, H. & Lan, Q. 2006. Assessment of uncertainty in mean heat loss coefficient of all glass evacuated solar collector tube testing. *Energy Conversion and Management*. **47**(1): 60-67.

Tong, Y., Kim, J. & Cho, H. 2015. Effects of thermal performance of enclosed-type evacuated U-tube solar collector with multi-walled carbon nanotube/water nanofluid. *Renewable Energy*. 83: 463-473.

Linares, N. V. 2011. *Analysis of Solar Water Heating Systems in Single Family Houses-Comparison between Finnish and Spanish Situation*. MSc Thesis. Tampere University of Technology.

Verma, S. K. & Tiwari, A. K. 2015. Progress of nanofluid application in solar collectors: A review. *Energy Conversion and Management*. **100**: 324-346.

Xiao, C., Luo, H., Tang, R. & Zhong, H. 2004. Solar thermal utilization in China. *Renewable Energy*. **29**(9): 1549-1556.

Xie, H. & Chen, L. 2011. Review on the preparation and thermal performances of carbon nanotube contained nanofluids. *Journal of Chemical & Engineering Data*. **56**(4): 1030-1041.

Yu, W. & Xie, H. 2012. A review on nanofluids: preparation, stability mechanisms, and applications. *Journal of Nanomaterials*. **2012**: Article ID 435873.

Zhang, X., You, S., Ge, H., Gao, Y., Xu, W., Wang, M. & Zheng, X. 2014. Thermal performance of direct-flow coaxial evacuated-tube solar collectors with and without a heat shield. *Energy Conversion and Management*. **84**: 80-87.