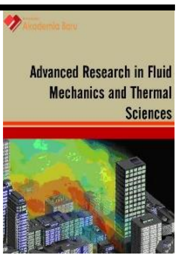
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 56, Issue 2 (2019) 233-247

Penerbit
Akademia Baru

Journal of Advanced Research in Fluid
Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Carbon Nanotube for Solar Energy Applications: A Review

Open Access

Muhammad Mahmud Jamil[1,*], Nor Azwadi Che Sidik[2], Umar Sanusi Umar[1], Muhammad Tukur Hamisu[1], Aisha sa'ad[1]

[1] Department of Mechanical Engineering, Faculty of Engineering, Nigerian Defence Academy, PMB 2109 Kaduna, Nigeria
[2] Malaysia – Japan International Institute of Technology (MJIIT), University Teknologi Malaysia Kuala Lumpur, Jalan Sultan Yahya Petra (Jalan Semarak), 54100 KualaLumpur, Malaysia

ARTICLE INFO

Article history:
Received 11 November 2018
Received in revised form 21 February 2019
Accepted 13 March 2019
Available online 13 April 2019

Keywords:
Solar collector, Carbon nanotube, Thermal conductivity, Nanofluid

ABSTRACT

This paper reports the recent researches of carbon nanotube application in solar collectors. The efficiency of different stationary solar collectors (Flat plate collector FPC, Evacuated tube solar collector ETSC and Direct absorber solar collector DASC) was found to improve with the use of single wall carbon nanotube (SWCNT) and multiwall carbon nanotube (MWCNT) respectively. From literatures many comparisons were reported with other nanoparticles, it has shown that carbon nanotube display higher thermal conductivity compared to other solid nanoparticles. Effect of thermal conductivity, stability and production cost of SWCNT and MWCNT was thoroughly reviewed and investigated for application in stationary solar collectors.

1. Introduction

The primary goal of nanofluid study during the past years was to develop systems with enhance heat transfer. The enhancement may be in cooling or heating applications that depends on type of nanoparticles and concentration used. One of the areas of research that needs nanofluid is solar energy studies. It can be categories into thermal energy conversion using solar collectors and solar electric conversion that used solar photovoltaic panels to generate electric current. Nanofluid as a new type of heat transfer fluid was discovered by Choi *et al.,* [1] two decades ago. During the previous study, it was experimentally observed that solid nanoparticles (metallic, non-metallic and oxides) dispersed in conventional heat transfer fluid like water and ethylene glycol improved the heat transfer characteristics. As aforementioned, these fluids were used in both solar cells [2-4] and solar collectors [5] and significant enhancement was recorded compared to conventional fluids. Many researchers have argued on the importance of solar tracking system due to its effect on the output performance of both solar thermal systems and photovoltaic systems [6-11]. However, the type of solar collectors considered in this study is based on non-tracking solar collectors. The likes of Flat

---

[*] *Corresponding author.*
E-mail address: mjameel87@yahoo.com (Muhammad Mahmud Jamil)

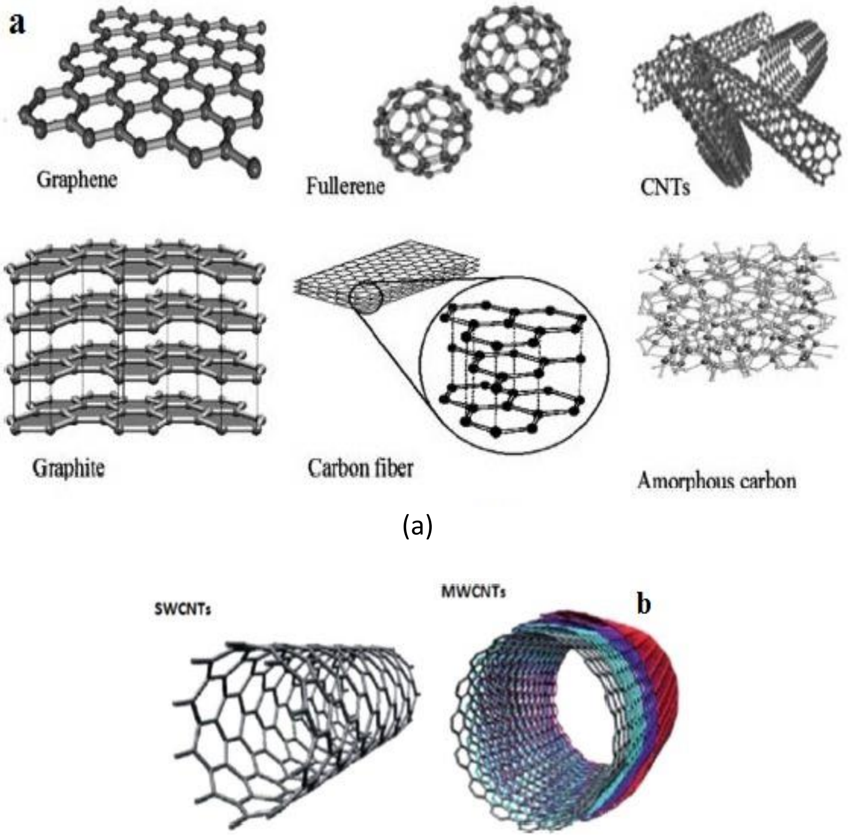
plate collector, Evacuated tube solar collector and direct absorber solar collector are stationary collectors. Tracking of solar energy is more relevant to the photovoltaic and concentrated collectors like parabolic dish reflector that are used to generate electricity [12, 13]. The major components of active solar heating are solar collectors. Solar energy employed through radiation is transform into heat and other useful forms of energy, then the heat is transfer to a fluid usually water is used as conventional fluid. The solar energy collectors are used in heating building, solar pool heaters, solar water heating and dry Agricultural products and solar space water systems [14-16]. Effect of glazing, absorber plate, top covers and heating pipes of flat plate collector's performance was studied largely for domestic hot water. Sheeba *et al.,* [17] reported experimentally the efficiency comparison between combine solar still and solar still flat-collector system. In actual environment, it was found that the efficiency of combine solar still flat collectors is 20.4 and 23.6% more than solar still alone fresh water collector. Zigian *et al.,* [18] studied the efficiency of two flat plate at different flow rates, collector without ETFE foil is 2-3% higher than the collector with ETFE collector. Sebastian *et al.,* [19] studied the performance and reliability of a double glazing in flat plate with an increase of 70% efficiency at a temperature difference of 60K(G=500 W/m2). Faizal *et al.,* [20] mentioned the economy of reducing the size of collector using uses water with Nanofluids and obtained the same desired output due to higher thermal conductivity of Nanofluids. Yousefi *et al.,* [21] experimentally studied the effect of Al2O3-water nanofluid on flat plate collectors with an increase of 28.3% efficiency for mass fraction of 0.2wt%. Morghadam *et al.,* [22] uses CuO-water nanofluid with mass flow rate of 1 kg/min and the collector efficiency was found to increase by 21.8%. He *et al.,* [23] investigated the thermal conductivity enhancement using Cu-water nanofluid with different mass fraction and nanoparticles size, efficiency increases by 23.8% using 25nm and 0.1wt% while it decreases using 25nm and 0.2wt%. Zhu *et al.,* [24] combined flat micro arrays and evacuated tube solar collectors with thermal efficiency improvement of 70% during operation. The improvement in efficiency of FMHPA was due to pressure drop in solar air collector. Said *et al.,* [25] studied performance enhancement of a flat plate using TiO2 nanofluid. Two volume fractions (0.1% and 0.3%) and mass flow rates (0.5.1.5kg/min) were employed, energy efficiency increase by 76.6% for 0.1% volume fraction and 0.5kg/min mass flow rate. Goudarzi *et al.,* [25] performed an experiment of cylindrical solar collector with receiver helical pipe with mass flow rate of 0.0088 to 0.033 kg/s and weight fraction of nanoparticles are 0.1%,0.2% and 0.4% respectively. Result indicated that CuO can significantly enhance thermal efficiency compare to water by 25.6%. Liu *et al.,* [26] observed experimentally graphene [HMM] BF4 based on direct solar thermal collector and result obtained shows good agreement between experiment and numerical result using temperature profiles of 0.0005wt% and 0.001wt% for corresponding fluid height of 7.5cm and 3.8cm respectively. Nasrin *et al.,* [27] numerically analyse thermal performance using finite element method for four different nanoparticles such as Ag, Cu, Al2O3 and CuO. CuO-water nanofluid has the highest performance with efficiency of 65-85%. Jamil *et al.,* [28] numerically studied the effect of inclination angle of ETSC, the maximum nanofluid enhancement was found at inclination angle of 30˚ and volume concentration of 0.5vol%. Recently, Leimang *et al.,* [29] highlighted the extended application of carbon nanotube in Energy storage devices. Also, in a new development, titanium dioxide nanotube (TNT) was considered for energy storage devices, fuel cells and environmental study [30, 31]. Solar cells appeared to give better efficiency when coupled with CNT [32, 33] as shown in Figure 1. Abandroth *et al.,* [34] indicated the viability of CNT as selective coating for solar thermal application. The result gives confidence on low cost and high performance of concentrated solar collector with CNT deposited coatings. Mu *et al.,* [35] compared the performance and effect of graphene and graphene-carbon nanotube as investigated for solar thermal conversion. The result shows that graphene carbon nanotube converts more heat and solar thermal energy when compared to graphene nonmaterial.

Figure 2 shows cross-sectional FESEM images of MWCNT and Schematic of device illustrating photo generated effect through temperature difference. Apart from conversion issues, it was tested for storage application. MWCNT was found suitable for study of mechanical deformation of electronic devices. The influence of carbon nanotubes on refrigerants was evaluated by Jiang *et al.,* [36], R113 was used as the host refrigerant. The experimental results show that the thermal conductivity of CNT Nano-refrigerants is much higher than that of CNT–water nanofluids and the thermal conductivity enhancement increases with decrease in diameter of CNT. Tang *et al.,* [37] reported a robust application of CNT for mechanical storage compared to electrochemical storage devices like super capacitor. An efficiency of about 83% was obtained for mechanical energy storage compared to electrochemical batteries. Good thermal conductivity of CNT and its prevailing high absorptive properties makes it useful in steam generation for solar heating applications [38]. Sankapal and Shukrullah reported the effect of MWCNT for energy storage and low activation energy [39, 40]. Only Wang *et al.,* [41] reported the influence of carbon nanotube foam CNTF for energy storage application. Zhai *et al.,* [42] extensively study CNT in three different areas: MWCNT for highway application, SWCNT for memory switches as applied to cell phones and lithium batteries as applied in electric vehicles. Thermal performance of CNT applied to automobile radiator was found to increase the Nusselt number with increase in both particle concentration and velocity of the fluid [43].

In the literatures, there are few researches that reported the thermal characteristic and of Carbon Nanotube CNT applied on solar collector system. The study of solar energy using nanofluid is at its early stage of research. It is authors' hope that this work will be useful in identifying the factors affecting thermal performance of solar collector system and the potential applications of hybrid CNT as a solution to improve heat transfer in solar thermal collectors. The proposed work is limited to application of carbon nanotube in solar collectors. An overview of photovoltaic solar energy is introduced at the beginning. Detail review of SWCNT and MWCNT will be taking into account as applied to Flat plate collector, Evacuated tube solar collector and Direct absorber solar collector

2. Flat Plate Solar Collector

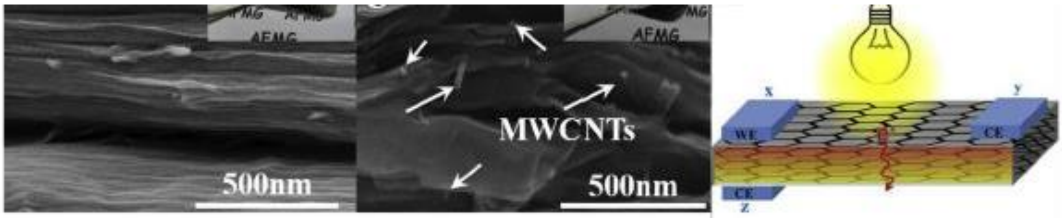
Flat plate solar collectors have been in existence for more than six decades ago. It is common among other groups of solar collectors. Due to its simplicity and easy maintenance, it is popularly used in domestic and industrial water heating. Moreover, the thermal efficiency of FPC is very low because of low thermal conductivity of water been used as working fluid (Heat transfer fluid). Faizal *et al.,* [44] reported the effect in heat transfer enhancement of CNT applied to FPC. In their research, it was found that with application of CNT the overall size of the FPC can be reduce. SWCNT showed better heat transfer performance compared to oxides nanoparticles. It was concluded that SWCNT reduced entropy generation in FPC by 4.34% compared to conventional heat transfer fluid (Water) [45]. Meanwhile, the heat transfer coefficient of the collector increased to 15.33% compared to water. In a different study, the author focused on the effect of energy and exergy efficiency performance of SWCNT applied to FPC. The result indicated that more experimental analysis is required in terms of exergy efficiency because the energy and exergy efficiencies increased to 95.12% and 26.25% compare to water [46]. Thus, it is evident that the exergy efficiency value is lower and closer in value compared to water. Also, CNT increased the pressure drop, pumping power and heat transfer parameter of FPC compared to base fluid [47]. However, apart from CNT, many researchers have used different nanoparticles in FPC. Some of the published articles reviewed showed that different nanoparticles have been used in FPC such as: Al2O3, Ag, SiO2, TiO2, ZnO and Fe2O3 nanoparticles. It can be said that of all the nanoparticles used in FPC, CNT showed higher thermal collector efficiencies at low concentration of nanoparticles compared to almost all the tested nanoparticles previously applied to FPC [48]. It was also recommended that the used of nanofluid could be an alternative to increase solar collector efficiency without any additional cost of the collector design [49]. Verma *et al.,* [50] Compared three different parameters of exergy efficiency, energy efficiency and entropy generation drop of six different nanofluids applied to FPC. MWCNT has shown better enhancement in terms of exergy efficiency, energy efficiency and entropy generation drop compared to other five nanofluid used. The findings for exergy efficiency are as follows: MWCNT/water 29.32%, graphene/water 21.46%, CuO/water 16.67%, Al2O3/water 10.86%, TiO2/water 6.97% and SiO2 5.74%. While the energy efficiency enhancement is as follows: MWCNT/water 23.47%, graphene/water 16.97%, CuO/water 12.64%, Al2O3/water 8.28%, TiO2/water 5.09% and SiO2 4.08%. Lastly, the entropy generation drop is also given as: MWCNT/water 65.55%, graphene/water 57.89%, CuO/water 48.32%, Al2O3/water 36.84%, TiO2/water 24.49% and SiO2 10.04%. The following results contradicted the previous research, in this numerical result it has shown that thermal efficiency and heat transfer coefficient of MWCNT/water, CuO/water and Al2O3/water nanofluid were compared. However, using the same mass concentrations of 1, 2 and 3wt% it was shown that CuO/water nanofluid indicated higher thermal efficiency and heat transfer coefficient compared to both MWCNT/water and Al2O3 nanofluid [51].



(a)

(b)

Fig. 1. (a) Allotropes of carbon (b) Structural models of SWCNT and MWCNT [33]



(a) (b) (c)

Fig. 2. (a)-(b) shows cross-sectional FESEM images of MWCNT (c) Schematic of device illustrating photo generated effect through temperature difference(35)

3. Evacuated Tube Solar Collector

Generally, solar collectors absorb solar radiation and eventually convert the heat into thermal energy using working fluid. Majority of solar collectors are employed for low temperature applications usually between 0-100°C. Muhammad *et al.,* [52] reviewed the performance of nanofluid application in both evacuated tube solar collector and flat plate solar collector from economic, efficiency enhancement compared to base fluid. Figure 3 below shows a schematic diagram of evacuated tube solar collector with heat pipe arrangement. Functionalised MWCNT was dispersed in Therminol55 resulted in a more stable collector temperature of 250°C. Whereas the functionalised SWCNTs and DWCNTs dispersed in water and propylene glycol produced less thermal stability compared to MWCNT/Therminol55 [53]. Recently, Iranmanesh *et al.,* [54] investigated the effect of GNP/nanofluid with mass concentration of (0.025, 0.05, 0.75 and 0.1wt %). The thermal efficiency of the ETSC enhanced up to 90.7% using GNP nanofluid which is 35.8% higher than Deionised water. Sandesh *et al.,* [55] comprehensively studied a thermosyphon heat pipe collector using carbon nanotube and pure water as working fluids. The thermal performance of the collector was studied based on different collector angles and concentration effect of the CNT particles.

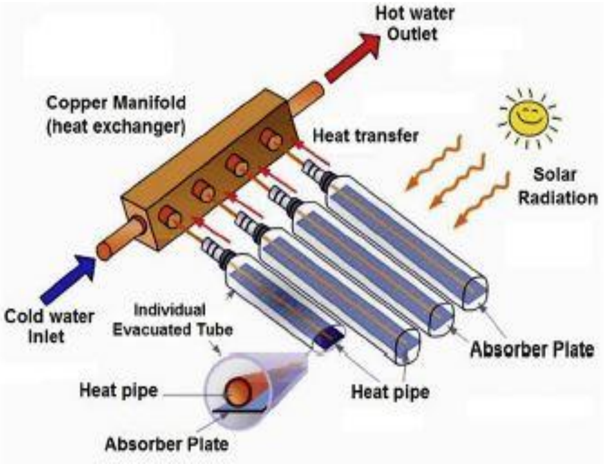


Fig. 3. A schematic diagram of evacuated tube solar collector with heat pipe arrangement [54]

The best thermal efficiency of collector was found with inclination angle of less than 50degree and concentration of less than 0.6%. Nanofluid in ESTC is associated with high sedimentation, high operating temperature and a very high storage capacity. It is therefore, recommended that a new design of the ETSC will remedy the sedimentation phenomena [56]. CNT is suitable for solar thermal application for coating in ETSC due to its stable morphology in the absence of solar radiation [57]. In a similar study, Sobhansarbandi *et al.,* [58] confirmed that CNT sheet coatings improved the solar energy phase change and also increase solar energy absorption. In a different study, CNT can increase the evaporation efficiency of a steam generation [38]. Effect of tilt angle and volume concentration contributed a lot to heat transfer enhancement of ETSC. Rahman *et al.,* [59] numerically investigated the heat transfer enhancement of circular solar collector using varying angle 0-60°C, solid concentration 0-0.12 and Rayleigh Number Ra=10^5-10^8. It was concluded that the effect of inclination angle is more important than the effect of inclination angle is more important than the effect of solid nanoparticles. Although, the two parameters are vital, tilt angle of 30°, Ra=10^7 and concentration 0.08-0.12 produced better heat transfer enhancement. Kim *et al.,* [60] introduced a polymer-CNT is solar collector which achieved high thermal efficiency close to that of glazed flat plate collector. Tong *et al.,* [61] indicated the high thermal conductivity of MWCNT/water applied to an enclosed evacuated U-tube solar collector (EEUSC). The thermal efficiency of EEUSC increased by 4% due to influence of air gap and also thermal conductivity increased with increasing volume concentration as shown in Figure 4. Sabiha *et al.,* [62] experimentally reported the influence of SWCNT/water and water at volume fractions (0.05, 0.1 and 0.2vol %) and flow rate of (0.008, 0.017 and 0.025Kg/s). The efficiency of ETSC with SWCNT/Water is higher than water. The efficiency enhancement of SWCNT/water is 93.43% for 0.2vol% volume fraction and flow rate of 0.025Kg/s.

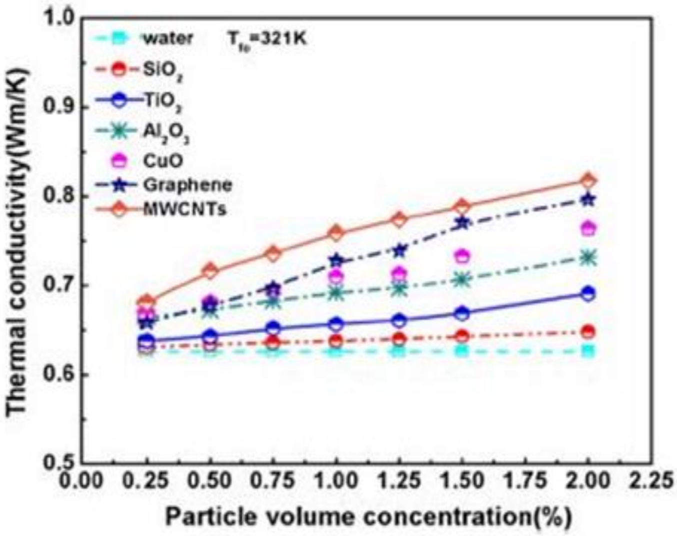
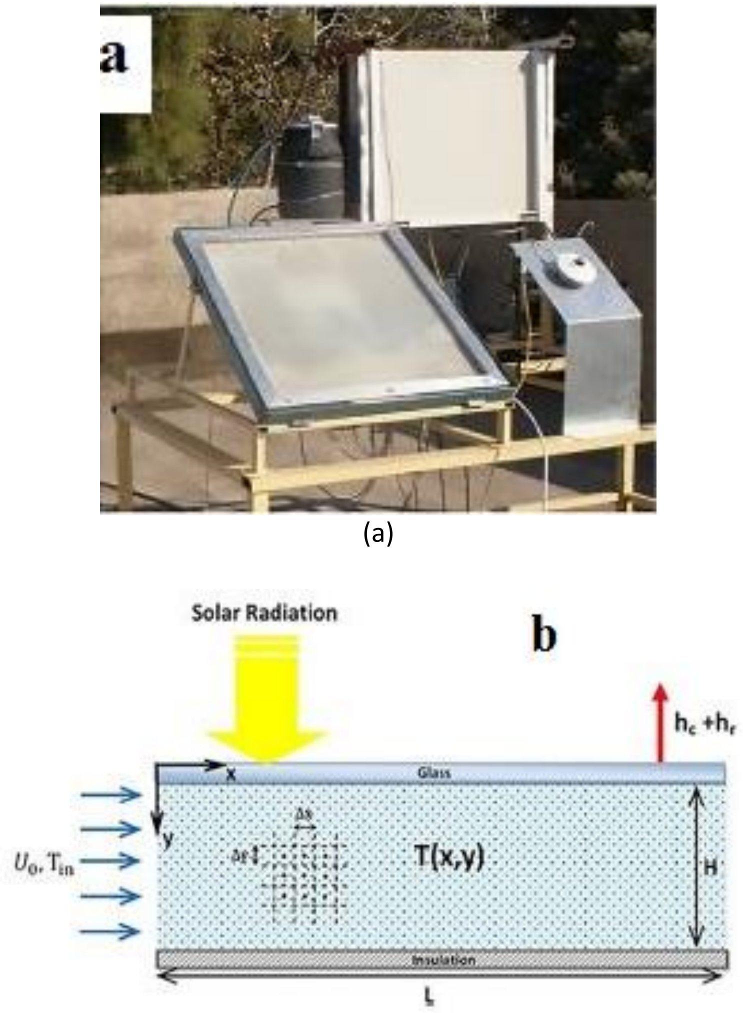


Fig. 4. Thermal conductivity of MWCNT and water [50]

4. Direct Absorber Solar Collector (DASC)

DASC is a new type of collector in which the working fluid is directly exposed to solar irradiance. Ahmad *et al.,* [63] proposed that addition of CNTs to metal oxide and metal nanoparticles will enhance the optical absorption and stability of the collector. Also, functionalised carbon nanotube (f-CNT) increased both absorption properties and stability of the DASC. Sani *et al.,* [64] indicated the significance of carbon nanohorns for application in solar thermal collector. The use of carbon nanohorns showed better absorption compared to pure water. Thus, among other carbon group, carbon nanohorns shows better thermal efficiency enhancement and collector compactness compared to amorphous carbons. Delfani *et al.,* [65] conducted numerical and experimental study of a domestic DASC using MWCNT. The thermal collector efficiency increased with increasing volume concentration. Figure 5 shows DASC outdoor experimental setup and Schematic of a nanofluid-based DASC.



(a)

(b)

Fig. 5. (a) DASC outdoor experimental setup (b) Schematic of a nanofluid-based DASC [65]

In a different study, Qin *et al.,* [66] study the absorption properties using mixture of different nanoparticles. Bera *et al.,* [67] investigated the thermal coating based on carbon nanotube and boehmite. The effect of coating approach provided a new design that is efficient, low cost and thermally stable. Kasaeian *et al.,* [68] experimentally conducted the effect of carbon nanotube/EG on direct absorber solar collector attached to parabolic trough. The optical efficiency is 71.4% and the thermal efficiency of the collector is 17% higher than that of the base fluid. MWCNT was found to absorb almost 100% of solar energy as compared to other nanoparticles. That makes it ideal for application in DASC due to its less agglomeration and high stability [69]. Qadir *et al.,* [70] proposed the use of MWCNT in solar adsorption chillers as substitute to silica gel and zeolite adsorbents. Dugaria *et al.,* [71] design DASC attached to parabolic trough using SWCNT as working fluid. The optical efficiency is around 90.6%. Table 1. Below shows a summary of thermal collector efficiency using carbon nanotube (CNT). Karami *et al.,* [72] studied the optical properties of f-CNT for low temperature application in DASC. The thermal efficiency of DASC increases with increase in temperature and volume fraction. Due to the enhancement optical properties of the fluid, the thermal efficiency improvement is common in terms temperature. Mahesh *et al.,* [73] focused on the adsorption material for solar collectors. More findings related to better materials for all solar collectors were thoroughly investigated. Ramaprabhu *et al.,* [74] investigated the DASC using MWCT as working fluid. The thermal conductivity of MWCT/water and MWCNT/EG is given as 27% and 20.7% respectively. However, MWCNT/water probably produced better efficiency of DASC.

Table 1
Summary of thermal collector efficiency using carbon nanotube (CNT)

Ref.	Nanofluid	Collector	Findings
[55]	CNT	FPC	High volume concentration of CNT decreased collector performance. Maximum efficiency of 73% was obtained at 0.6% volume concentration.
[51]	MWCNT	FPC	Thermal efficiency of 13.2% was obtained for volume concentration of 1wt%.
[45]	SWCNT	FPC	Concluded that the entropy generation drop is 4.34% and heat transfer coefficient enhancement of 15.33% to base fluid.
[46]	SWCNT	FPC	The energy and exergy efficiency of nanofluid is 95.12% and 26.25% compared to 42.07% and 8.77% of water
[72]	f-CNT	DASC	Thermal conductivity enhancement (52.2%) is dependent on temperature and volume fraction of the f-CNT.
[62]	SWCNT	ETSC	Maximum collector efficiency of 93.43% was found for mass flow rate of 0.025kg/s and volume concentration of 0.2vol%.
[68]	MWCNT	DASC	Compared thermal efficiency of MWCNT/EG and nanosilica/EG. MWCNT/EG efficiency is 72.8% for 0.3% volume fraction.
[69]	MWCNT	DASC	MWCNT/EG was found to absorb almost 100% of the solar energy. Therefore, it was found to be ideal fluid for DASC application.
[65]	MWCNT	DASC	The collector efficiency (29%) is dependent on increase in mass flow rate and volume concentration of the nanoparticles.
[64]	SWCNT	DASC	It was found that the carbon nanohorns is promising for increasing collector efficiency and environmentally friendly.
[74]	PUMWNT	DASC	The thermal efficiency of PUMWNTs is higher using DI water (27%) compared to 20.97% for EG base fluid.

5. Thermal Conductivity Enhancement of Hybrid Carbon Nanotube

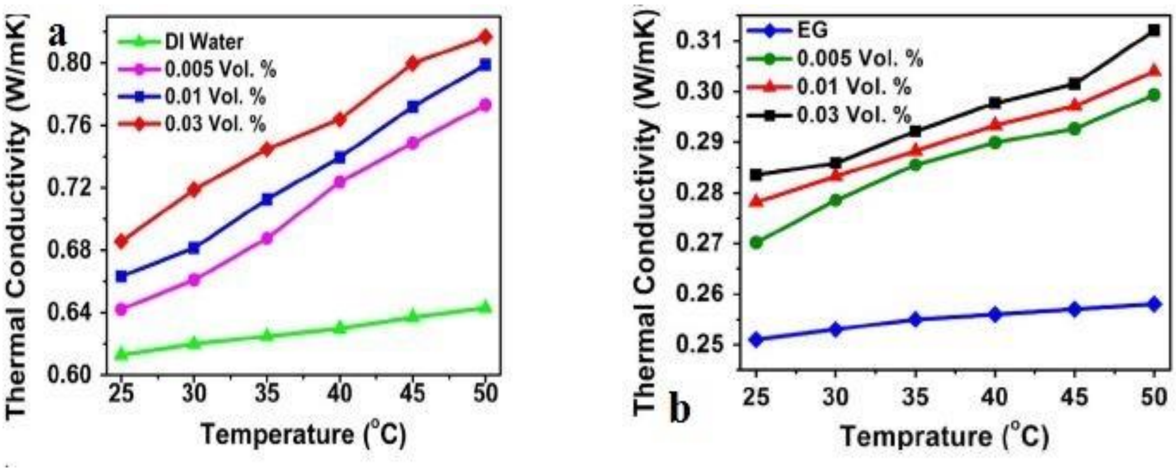
Recent development confirmed the use of hybrid nanofluid for energy applications[75, 76]. The thermal conductivity of hybrid multi-walled carbon nanotube (MWCNT) and Fe_2O_3 nanoparticles was thoroughly investigated[77]. However, volume concentration of MWCNT was fixed to 0.05% while volume concentration of Fe_2O_3 was varied from 0.01% to 0.16%. An enhancement of thermal conductivity of 27.7% was found for 0.02% volume concentration of Fe_2O_3 nanoparticles and 0.05% volume concentration of MWCNT. The enhancement is due to the Fe_2O_3 aggregate on MWCNTs surface, thereby, forming chains along the carbon nanotubes. The surfactant use in this experiment was sodium dodecylbenze sulfonate (NaDDBS) which shows good stability and homogeneity of the Nanofluid. The surfactant was added to water in order to obtain more disperse MWCNTs. The carbon nanotube surface absorbed the applied surfactant, thus, making the surface negatively charged. But Fe_2O_3 are positive in water with PH value of 7.The positively charged metal oxide and negatively charged nanotubes aggregate due to the electrostatic attraction their by forming more effective heat transfer network. It was observed based on their experiment that increase in concentration of Fe_2O_3 nanoparticles decreases the thermal conductivity due to excess aggregation of the nanoparticles which result in the formation of effective heat transfer networks. It was also observed that the alteration of MWCNTs affect the thermal conductivity, an enhancement was obtained when the concentration was increase to 0.2%.

MWCNT was purified by performing ultra-sonication in Branson ultrasonic cleaner for 5hr using nitric acid (HNO_3) and sulphuric acid (H_2SO_4) the main purpose of the purification was to remove impurities and amorphous carbon and improve the exterior activity of MWCNTs, planetary ball mill (HPM 200) was use to grind the MWCNTs in order to enhance the dispersibility by shortening the length of the nanotubes. For better dispersibility the purified and ground MWCNTs were ultrasonically dispersed in aqueous solution for 40min. The thermal conductivity of the purified and raw MWCNTs were measured at a temperature ranging from 15^0C to 40^0C, it was observed that the purified MWCNTs have higher thermal conductivity and dispersibility in the base fluid. Many factors increased thermal conductivity enhancement such as increase in grinding surface area, reduction in aggregation of MWCNTs and increment in straightness ratio. Composite nanofluid was prepared in this experiment by adding small amount of MWCNT in to Ag- nanoparticles based aqueous nanofluid via PWE method. The composite nanofluid shows high absorbance which indicate good dispersibility and stability according to Beer- Lambert law, the level of absorbance was higher for the composite nanofluid than the one containing MWCNTs only, this indicate the degree of the dispersion of composite nanofluid. The thermal conductivity of the composite nanofluid was higher than that of MWCNT; the improvement is due to improved dispersion of CNT in the matrix. In this experiment a maximum thermal conductivity enhancement of 14.5% was obtain at temperature of 40^oC and hybrid mixture of 0.05wt% MWCNT – 3wt% Ag [78].

Baby and Sundara decorated Silver nanoparticles with fictionalized graphene (f- HEG) [79]. The functionalized graphene was obtained from graphite oxide. The composite nanofluid was prepared by dispersing Ag/HEG in deionize water and ethylene glycol with the aid of ultrasonicator. The composite nanofluid was prepared without surfactant with two volume fractions. The thermal conductivity enhancement is higher using deionise water as base fluid which 7% at temperature of 25^0c and 13% at 70^0c for 0.005% volume fraction of (Ag/HEG) deionize water nanofluid. As the volume fraction increase to 0.05% the enhancement were 25% and 86% at temperature of 25^0c and 70^0c respectively. Conversely, the ethylene glycol base nanofluid shows an enhancement but not as good as deionise water. The low thermal conductivity enhancement was due to high viscosity of the base fluid (ethylene glycol). It was noted that the thermal conductivity increases with increasing particles concentration thus, it agrees with Maxwell hypothesis (J.C. Maxwell – Garnett 1904). The enhancement obtain in this experiment is due to high thermal conductivity of Ag and graphene, the high surface area of these nanoparticles give more contact between the particles which helps electrons and phonons to conduct heat. With increase in temperature the Brownian motion of particles increases and also the thermal conductivity increases too.

In another study, Aravind *et al.,* [80] Used graphene and graphene multi – walled carbon nanotube composite were synthesized using solar electromagnetic radiation. Graphene oxide(GO) was prepared from Bay carbon graphite via Hummer's method, the prepared GO was exposed to intense solar radiation inside a convex lens of 90nm and it was later functionalized by refluxing it in concentrated HNO_3 for 1hr. MWCNT was prepared via catalytic chemical vapour deposition technique , the MWCNT were then synthesize by refluxing it in concentrated HNO_3 and air oxidation at 35^0C for 2hr the main purpose of the purification is to remove impurities from the MWCNT and amorphous carbon. GO and f-MWCNT in a ratio of 1:1 was then reflux in concentrated HNO_3 for 2hr followed by washing to obtain neutral PH and then dried to obtain fine powder of GO-f-MWCNT composite. The solar exfoliation was performed upon this GO-f-MWCNT. The nanofluid was prepared using two step method in which functionalize graphene and functionalized graphene multi-walled carbon nanotube were dispersed in to deionise water and ethylene glycol via ultra-sonication and the thermal conductivity of the nanofluid was measured using KD2 pro thermal property analyser. It was observed base on experiment that the thermal conductivity increase with increase in volume fraction. For the composite nanofluid that is graphene – multi-walled carbon nanotubes, the thermal conductivity enhancement of 10.5% and 87.9% was obtained for volume fraction of 0.04% at temperature of 25^0C and 50^0C for ethylene glycol base nanofluid. Also, Figure 6 below shows the effect of temperature on thermal conductivity of carbon nanotube dispersed in DI water and EG respectively [74].

The increase in thermal conductivity of nanofluid with temperature may be due to decrease in interfacial thermal resistance between base fluid and solid nanoparticles at high temperature, the increment in thermal conductivity of present graphene nanofluid can be due to high synergistic effect of high thermal conductivity of MWCNT and graphene. It was also observed that CNT forms long chain of interconnected network which act as conducting paths, therefore, carbon nanotubes with high aspect ratio percolation path increases which leads to increase in thermal conductivity. Furthermore, a mixture with high aspect ratio of MWCNT and graphene created a high enhancement in thermal conductivity, the electrical conductivity of the nanofluid were measured. More importantly, nanofluid have application in electrical components like transformer oil, it was observed that the electrical conductivity of these nanofluid increase with increase in volume fraction and temperature. The high electrical conductivity is due to good transport of electrons through high aspect ratio and tight binding network of graphene and MWCNT. According to the studies, electrical conductivity depends on factors such as physical properties of the fluid, conductivity of the particles, electrical double layer (EDL) characteristics, volume fractions, ionic concentration and other physiochemical properties.



(a) (b)

Fig. 6. Thermal conductivity of PUMWNTs dispersed (a) DI water (b) EG using three different nanoparticles volume concentration [74]

Jana *et al.,* [81] conducted an experiment for thermal conductivity enhancement of carbon nanotubes (CNTs), copper nanoparticles (CUNPs), gold nanoparticles (AuNPs) and their hybrids. For this experiment AuNPs colloid was added to deionise water in a ratio of 1.4:1 by volume to produce AuNP suspension and the suspension was added to CNT to obtain CNT – AuNP suspension. Laurite salt was added to these suspensions in order to enhance the stability of the suspension. The stability of the suspension was evaluated using Beer lambert law which states that the higher the absorbance of light rays passing through the nanofluid the higher the stability. Base on this experiment 34% enhancement in thermal conductivity was obtain at 0.8% volume fraction of CNT, the normalize thermal conductivity was nonlinearly dependent on volume fraction of CNT and the nonlinearity may be due to the size, shape and loading of CNT in the nanofluid. For CuNP suspension the normalize thermal conductivity increases with increase in CuNP volume fraction,74% increment in thermal conductivity over water was obtain at room temperature, this high increment in comparison with 40% enhancement obtain for ethylene glycol base fluid is as a result of size of the Cu nanoparticles

(35-50nm) and better dispersion due to instant bath sonication. It was observed that at volume fraction of 1.4% AuNP, 37% increment in thermal conductivity was obtained over water. Addition of CNT to nanoparticles containing 1.4% AuNP colloid does not show any obvious improvement in thermal conductivity in order to obtain high thermal conductivity of nanofluid, we need to have high expose surface area of nanoparticles, good network between the individual nanoparticles and good stability, for the above combination the only missing criteria was lack of good network between the nanoparticles, hence this is the reason behind the lower thermal conductivity. For the hybrid combination of CNT – AuNP and CNT – CuNP the thermal conductivity did not increases rather the values obtain were lower than the individual nanofluid acting independently therefore the synergistic effect that is expected did not occur.

6. Conclusion and Remarks

According to the recent researches, carbon nanotube exhibited high thermal conductivity compared to other nanoparticles like Al_2O_3, TiO2, Cu, Ag and Fe_2O_3. The application of CNT in solar energy was extensively studied for different parts of the energy application. In the realm of solar energy, CNT have been employed for solar thermal energy and photovoltaic devices used for electricity generation. The viability of CNT indicated low cost and high performance of concentrated solar collector with CNT deposited coatings. It was also found that CNT are used for storage devices, conversion and absorption for solar collector applications.

This work centres on the application of CNT that include all it forms like SWCNT and MWCNT applied in solar collectors, there is no doubt about the potential of CNT in solar energy applications. But there are little discrepancies in terms of the nanofluid preparation characteristics and stability during preparation [82]. However, even though It was recommended that the used of nanofluid could be an alternative in increasing solar collector efficiency without any additional cost to the collector design. Moreover, the mode of investigations of nanofluid in solar collectors is limited to some degree of agreement. The experimental mode is limited to nanoparticles agglomeration, stability and corrosion on parts of the experimental set-up. Conversely, numerical simulations are not clear in terms of phase change (two-phase) mixture of the nanofluid in the collector models [83]. further studies that are experimentally validated and amended based on standard are required for the best method that will integrate the CNT applied in solar collectors. Lastly, hybrid nanofluid is new compositions of two or more nanoparticles that have shown confidence in heat transfer study. CNT are one of the hybridized nanofluids that have shown good optical and convective heat transfer enhancement due their high thermal conductivity. Most of the chemistry and compatibility of the hybrid nanofluid is one of the shortcomings of the hybrid nanofluid. More broadly, research is recommended in order to overcome the compatibility and stability of hybrid CNT nanofluid because the hybrid results have shown many positive results in terms of heat transfer applications.

Acknowledgement

The authors wish to thank Nigerian Defence Academy, Kaduna and the Nigerian Government for supporting this research activity.

References

[1] Choi, Stephen US, and Jeffrey A. Eastman. *Enhancing thermal conductivity of fluids with nanoparticles*. No. ANL/MSD/CP-84938; CONF-951135-29. Argonne National Lab., IL (United States), 1995.

[2] Habisreutinger, Severin N., Robin J. Nicholas, and Henry J. Snaith. "Carbon nanotubes in perovskite solar cells." *Advanced Energy Materials* 7, no. 10 (2017): 1601839.

[3] Maruyama, Shigeo, Il Jeon, Takahiro Sakaguchi, Clement Delacou, Shohei Chiashi, Esko Kauppinen, and Yutaka Matsuo. "Carbon Nanotube Films for Organic-Inorganic Hybrid Perovskite Solar Cells." In *Meeting Abstracts*, no. 7, pp. 585-585. The Electrochemical Society, 2017.

[4] Aitola, Kerttu, Konrad Domanski, Juan-Pablo Correa-Baena, Kári Sveinbjörnsson, Michael Saliba, Antonio Abate, Michael Grätzel et al. "High temperature-stable perovskite solar cell based on low-cost carbon nanotube hole contact." *Advanced Materials* 29, no. 17 (2017): 1606398.

[5] Muhammad, Mahmud Jamil, Isa Adamu Muhammad, Nor Azwadi Che Sidik, Muhammad Noor Afiq Witri Muhammad Yazid, Rizalman Mamat, and G. Najafi. "The use of nanofluids for enhancing the thermal performance of stationary solar collectors: a review." *Renewable and Sustainable Energy Reviews* 63 (2016): 226-236.

[6] Yang, Chao-Kai, Tsung-Chieh Cheng, Chin-Hsiang Cheng, Chi-Chia Wang, and Chang-Chun Lee. "Open-loop altitude-azimuth concentrated solar tracking system for solar-thermal applications." *Solar Energy*147 (2017): 52-60.

[7] Ratismith, Wattana, Yann Favre, Maxime Canaff, and John Briggs. "A non-tracking concentrating collector for solar thermal applications." *Applied energy* 200 (2017): 39-46.

[8] Sallaberry, Fabienne, Loreto Valenzuela, and Luis G. Palacin. "On-site parabolic-trough collector testing in solar thermal power plants: Experimental validation of a new approach developed for the IEC 62862-3-2 standard." *Solar Energy* 155 (2017): 398-409.

[9] Sukarno, Kartini, Ag Sufiyan Abd Hamid, Chang HW Jackson, Chee Fuei Pien, and Jedol Dayou. "Comparison of Power Output Between Fixed and Perpendicular Solar Photovoltaic PV Panel in Tropical Climate Region." *Advanced Science Letters* 23, no. 2 (2017): 1259-1263.

[10] Li, Chong, Dequn Zhou, Weiyan Yu, Hui Wang, Dasheng Zhu, Menghui Sun, and Guo Li. "Performance of off-grid residential solar photovoltaic power systems using five solar tracking modes in Kunming, China." *International Journal of Hydrogen Energy* 42, no. 10 (2017): 6502-6510.

[11] Ebrahimnia-Bajestan, Ehsan, Mohammad Charjouei Moghadam, Hamid Niazmand, Weerapun Daungthongsuk, and Somchai Wongwises. "Experimental and numerical investigation of nanofluids heat transfer characteristics for application in solar heat exchangers." *International Journal of Heat and Mass Transfer* 92 (2016): 1041-1052.

[12] Saravanan, K., and C. Sharmeela. "Single axis tracking to enhance power from solar photovoltaic panel." In *Proceedings of 2nd International Conference on Intelligent Computing and Applications*, pp. 671-681. Springer, Singapore, 2017.

[13] Qu, Wanjun, Ruilin Wang, Hui Hong, Jie Sun, and Hongguang Jin. "Test of a solar parabolic trough collector with rotatable axis tracking." *Applied energy* 207 (2017): 7-17.

[14] Amrutkar, Sunil K., Satyshree Ghodke, and K. N. Patil. "Solar flat plate collector analysis." *IOSR Journal of Engineering* 2, no. 2 (2012): 207-213.

[15] Struckmann, Fabio. "Analysis of a flat-plate solar collector." *Heat and Mass Transport, Project Report, 2008MVK160* (2008).

[16] Madhukeshwara, N., and E. S. Prakash. "An investigation on the performance characteristics of solar flat plate collector with different selective surface coatings." *International Journal of Energy & Environment* 3, no. 1 (2012).

[17] Sheeba, K. N., P. Prakash, and S. Jaisankar. "Performance evaluation of a flat plate collector coupled solar still system." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 37, no. 3 (2015): 291-298.

[18] Chen, Ziqian, Simon Furbo, Bengt Perers, Jianhua Fan, and Elsa Andersen. "Efficiencies of flat plate solar collectors at different flow rates." *Energy Procedia* 30 (2012): 65-72.

[19] Föste, Sebastian, Federico Giovannetti, Nicole Ehrmann, and Gunter Rockendorf. "Performance and reliability of a high efficiency flat plate collector–final results on prototypes." *Energy Procedia* 48 (2014): 48-57.

[20] Faizal, M., R. Saidur, S. Mekhilef, and M. A. Alim. "Energy, economic and environmental analysis of metal oxides nanofluid for flat-plate solar collector." *Energy Conversion and Management* 76 (2013): 162-168.

[21] Yousefi, Tooraj, Farzad Veysi, Ehsan Shojaeizadeh, and Sirus Zinadini. "An experimental investigation on the effect of Al2O3–H2O nanofluid on the efficiency of flat-plate solar collectors." *Renewable Energy* 39, no. 1 (2012): 293-298.

[22] Moghadam, Ali Jabari, Mahmood Farzane-Gord, Mahmood Sajadi, and Monireh Hoseyn-Zadeh. "Effects of CuO/water nanofluid on the efficiency of a flat-plate solar collector." *Experimental Thermal and Fluid Science* 58 (2014): 9-14.

[23] He, Qinbo, Shequan Zeng, and Shuangfeng Wang. "Experimental investigation on the efficiency of flat-plate solar collectors with nanofluids." *Applied Thermal Engineering* 88 (2015): 165-171.

[24] Zhu, Ting-ting, Yan-hua Diao, Yao-hua Zhao, and Yue-chao Deng. "Experimental study on the thermal performance and pressure drop of a solar air collector based on flat micro-heat pipe arrays." *Energy conversion and management* 94 (2015): 447-457.

[25] Said, Z., M. A. Sabiha, R. Saidur, A. Hepbasli, N. A. Rahim, S. Mekhilef, and T. A. Ward. "Performance enhancement of a flat plate solar collector using titanium dioxide nanofluid and polyethylene glycol dispersant." *Journal of Cleaner Production* 92 (2015): 343-353.

[26] Liu, Jian, Zhuocheng Ye, Long Zhang, Xiaoming Fang, and Zhengguo Zhang. "A combined numerical and experimental study on graphene/ionic liquid nanofluid based direct absorption solar collector." *Solar Energy Materials and Solar Cells* 136 (2015): 177-186.

[27] Nasrin, Rehena, Salma Parvin, and M. A. Alim. "Heat transfer by nanofluids through a flat plate solar collector." *Procedia Engineering* 90 (2014): 364-370.

[28] Jamil, M., N. C. Sidik, and MNAW Muhammad Yazid. "Thermal performance of thermosyphon evacuated tube solar collector using TiO2/water nanofluid." *J. Adv. Res. Fluid Mech. Therm. Sci* 20, no. 1 (2016): 12-29.

[29] Sun, Leimeng, Xinghui Wang, Yanrong Wang, and Qing Zhang. "Roles of carbon nanotubes in novel energy storage devices." *Carbon* 122 (2017): 462-474.

[30] Abdullah, M., and Siti Kartom Kamarudin. "Titanium dioxide nanotubes (TNT) in energy and environmental applications: An overview." *Renewable and Sustainable Energy Reviews* 76 (2017): 212-225.

[31] Fernández-Werner, Luciana, Fernando Pignanelli, Benjamín Montenegro, Mariano Romero, Helena Pardo, Ricardo Faccio, and Álvaro W. Mombrú. "Characterization of titanate nanotubes for energy applications." *Journal of Energy Storage* 12 (2017): 66-77.

[32] Singh, Khomdram Jolson, Thokchom Jayenta Singh, Dhanu Chettri, and Subir Kumar Sarkar. "A thin layer of Carbon Nano Tube (CNT) as semi-transparent charge collector that improve the performance of the GaAs Solar Cell." *Optik* 135 (2017): 256-270.

[33] Hanaei, Hengameh, M. Khalaji Assadi, and R. Saidur. "Highly efficient antireflective and self-cleaning coatings that incorporate carbon nanotubes (CNTs) into solar cells: A review." *Renewable and Sustainable Energy Reviews*59 (2016): 620-635.

[34] Abendroth, Thomas, Holger Althues, Gerrit Mäder, Paul Härtel, Stefan Kaskel, and Eckhard Beyer. "Selective absorption of Carbon Nanotube thin films for solar energy applications." *Solar Energy Materials and Solar Cells* 143 (2015): 553-556.

[35] Mu, Jiuke, Chengyi Hou, Hongzhi Wang, Yaogang Li, and Qinghong Zhang. "Graphene-carbon nanotube papers for energy conversion and storage under sunlight and heat." *Carbon* 95 (2015): 150-156.

[36] Jiang, Weiting, Guoliang Ding, and Hao Peng. "Measurement and model on thermal conductivities of carbon nanotube nanorefrigerants." *International Journal of Thermal Sciences* 48, no. 6 (2009): 1108-1115.

[37] Tang, Cheng, Qiang Zhang, Meng-Qiang Zhao, Gui-Li Tian, and Fei Wei. "Resilient aligned carbon nanotube/graphene sandwiches for robust mechanical energy storage." *Nano Energy* 7 (2014): 161-169.

[38] Wang, Xinzhi, Yurong He, Xing Liu, and Jiaqi Zhu. "Enhanced direct steam generation via a bio-inspired solar heating method using carbon nanotube films." *Powder technology* 321 (2017): 276-285.

[39] Sankapal, Babasaheb R., Hemant B. Gajare, Swapnil S. Karade, Rahul R. Salunkhe, and Deepak P. Dubal. "Zinc oxide encapsulated carbon nanotube thin films for energy storage applications." *Electrochimica Acta* 192 (2016): 377-384.

[40] Shukrullah, Shazia, Norani Muti Mohamed, and Maizatul Shima Shaharun. "Optimum temperature on structural growth of multiwalled carbon nanotubes with low activation energy." *Diamond and Related Materials* 58 (2015): 129-138.

[41] Wang, Chunlei, Yujie Feng, Xiaochen Sun, Haibin Sun, Tao Peng, Yang Lu, Junqi Xu, Yongsong Luo, and Benhai Yu. "Fabrication and activation of carbon nanotube foam and its application in energy storage." *Electrochimica Acta*236 (2017): 343-350.

[42] Zhai, Pei, Jacqueline A. Isaacs, and Matthew J. Eckelman. "Net energy benefits of carbon nanotube applications." *Applied energy* 173 (2016): 624-634.

[43] Chougule, Sandesh S., and S. K. Sahu. "Thermal performance of automobile radiator using carbon nanotube-water nanofluid—experimental study." *Journal of Thermal Science and Engineering Applications* 6, no. 4 (2014): 041009.

[44] Faizal, M., R. Saidur, and Saad Mekhilef. "Potential of size reduction of flat-plate solar collectors when applying MWCNT nanofluid." In *IOP Conference Series: Earth and Environmental Science*, vol. 16, no. 1, p. 012004. IOP Publishing, 2013.

[45] Said, Z., R. Saidur, N. A. Rahim, and M. A. Alim. "Analyses of exergy efficiency and pumping power for a conventional flat plate solar collector using SWCNTs based nanofluid." *Energy and Buildings* 78 (2014): 1-9.

[46] Said, Z., R. Saidur, M. A. Sabiha, N. A. Rahim, and M. R. Anisur. "Thermophysical properties of Single Wall Carbon Nanotubes and its effect on exergy efficiency of a flat plate solar collector." *Solar Energy* 115 (2015): 757-769.

[47] Ahlatli, Selim, Thierry Maré, Patrice Estellé, and Nimeti Doner. "Thermal performance of carbon nanotube nanofluids in solar microchannel collectors: an experimental study." *International Journal of Technology (IJTech)* 2 (2016): 78-85.

[48] Sarsam, Wail Sami, S. N. Kazi, and A. Badarudin. "A review of studies on using nanofluids in flat-plate solar collectors." *Solar Energy* 122 (2015): 1245-1265.

[49] Colangelo, Gianpiero, Ernani Favale, Paola Miglietta, and Arturo de Risi. "Innovation in flat solar thermal collectors: A review of the last ten years experimental results." *Renewable and Sustainable Energy Reviews* 57 (2016): 1141-1159.

[50] Verma, Sujit Kumar, Arun Kumar Tiwari, and Durg Singh Chauhan. "Experimental evaluation of flat plate solar collector using nanofluids." *Energy conversion and Management* 134 (2017): 103-115.

[51] Ekramian, E., S. Gh Etemad, and M. Haghshenasfard. "Numerical investigations of heat transfer performance of nanofluids in a flat plate solar collector." *International Journal of Theoretical and Applied Nanotechnology* 2 (2014): 30-39.

[52] Muhammad, Mahmud Jamil, Isa Adamu Muhammad, Nor Azwadi Che Sidik, and Muhammad Noor Afiq Witri Muhammad Yazid. "Thermal performance enhancement of flat-plate and evacuated tube solar collectors using nanofluid: a review." *International Communications in Heat and Mass Transfer* 76 (2016): 6-15.

[53] Mesgari, Sara, Robert A. Taylor, Natasha E. Hjerrild, Felipe Crisostomo, Qiyuan Li, and Jason Scott. "An investigation of thermal stability of carbon nanofluids for solar thermal applications." *Solar Energy Materials and Solar Cells* 157 (2016): 652-659.

[54] Iranmanesh, Soudeh, Hwai Chyuan Ong, Bee Chin Ang, Emad Sadeghinezhad, Alireza Esmaeilzadeh, and Mohammad Mehrali. "Thermal performance enhancement of an evacuated tube solar collector using graphene nanoplatelets nanofluid." *Journal of cleaner production*162 (2017): 121-129.

[55] Chougule, Sandesh S., S. K. Sahu, and Ashok T. Pise. "Thermal performance of two phase thermosyphon flat-plate solar collectors using nanofluid." *Journal of Solar Energy Engineering* 136, no. 1 (2014): 014503.

[56] Hussein, Ahmed Kadhim. "Applications of nanotechnology to improve the performance of solar collectors–Recent advances and overview." *Renewable and Sustainable Energy Reviews* 62 (2016): 767-792.

[57] Martinez, Patricia M., Vladimir A. Pozdin, Alexios Papadimitratos, William Holmes, Fatemeh Hassanipour, and Anvar A. Zakhidov. "Dual use of carbon nanotube selective coatings in evacuated tube solar collectors." *Carbon* 119 (2017): 133-141.

[58] Sobhansarbandi, Sarvenaz, Patricia M. Martinez, Alexios Papadimitratos, Anvar Zakhidov, and Fatemeh Hassanipour. "Evacuated tube solar collector with multifunctional absorber layers." *Solar Energy* 146 (2017): 342-350.

[59] Rahman, M. M., S. Mojumder, S. Saha, S. Mekhilef, and R. Saidur. "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 (2014): 79-90.

[60] In Kim, Sung, John Kissick, Stephen Spence, and Christine Boyle. "Design, analysis and performance of a polymer–carbon nanotubes based economic solar collector." *Solar Energy* 134 (2016): 251-263.

[61] Tong, Yijie, Jinhyun Kim, and Honghyun Cho. "Effects of thermal performance of enclosed-type evacuated U-tube solar collector with multi-walled carbon nanotube/water nanofluid." *Renewable energy* 83 (2015): 463-473.

[62] Sabiha, M. A., R. Saidur, S. Hassani, Z. Said, and Saad Mekhilef. "Energy performance of an evacuated tube solar collector using single walled carbon nanotubes nanofluids." *Energy Conversion and Management* 105 (2015): 1377-1388.

[63] Ahmad, S. H. A., R. Saidur, I. M. Mahbubul, and F. A. Al-Sulaiman. "Optical properties of various nanofluids used in solar collector: a review." *Renewable and Sustainable Energy Reviews* 73 (2017): 1014-1030.

[64] Sani, E., L. Mercatelli, S. Barison, C. Pagura, F. Agresti, L. Colla, and P. Sansoni. "Potential of carbon nanohorn-based suspensions for solar thermal collectors." *Solar Energy Materials and Solar Cells* 95, no. 11 (2011): 2994-3000.

[65] Delfani, Sh, M. Karami, and M. A. Akhavan-Behabadi. "Performance characteristics of a residential-type direct absorption solar collector using MWCNT nanofluid." *Renewable Energy* 87 (2016): 754-764.

[66] Qin, Caiyan, Kyeonghwan Kang, Ikjin Lee, and Bong Jae Lee. "Optimization of a direct absorption solar collector with blended plasmonic nanofluids." *Solar Energy* 150 (2017): 512-520.

[67] Bera, Raj Kumar, Subodh Gautam Mhaisalkar, Daniel Mandler, and Shlomo Magdassi. "Formation and performance of highly absorbing solar thermal coating based on carbon nanotubes and boehmite." *Energy conversion and management* 120 (2016): 287-293.

[68] Kasaeian, Alibakhsh, Reza Daneshazarian, Roya Rezaei, Fathollah Pourfayaz, and Ghasem Kasaeian. "Experimental investigation on the thermal behavior of nanofluid direct absorption in a trough collector." *Journal of Cleaner Production* 158 (2017): 276-284.

[69] Hordy, Nathan, Delphine Rabilloud, Jean-Luc Meunier, and Sylvain Coulombe. "High temperature and long-term stability of carbon nanotube nanofluids for direct absorption solar thermal collectors." *Solar Energy* 105 (2014): 82-90.

[70] Ul Qadir, Najam, Syed AM Said, and Rached Ben Mansour. "Modeling the performance of a two-bed solar adsorption chiller using a multi-walled carbon nanotube/MIL-100 (Fe) composite adsorbent." *Renewable energy* 109 (2017): 602-612.

[71] Dugaria, Simone, Matteo Bortolato, and Davide Del Col. "Modelling of a direct absorption solar receiver using carbon based nanofluids under concentrated solar radiation." *Renewable Energy* 128 (2018): 495-508.

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

[73] Mahesh, A. "Solar collectors and adsorption materials aspects of cooling system." *Renewable and Sustainable Energy Reviews* 73 (2017): 1300-1312.

[74] Shende, Rashmi Chandrabhan, and S. Ramaprabhu. "Thermo-optical properties of partially unzipped multiwalled carbon nanotubes dispersed nanofluids for direct absorption solar thermal energy systems." *Solar Energy Materials and Solar Cells* 157 (2016): 117-125.

[75] Sidik, Nor Azwadi Che, Isa Muhammad Adamu, Muhammad Mahmud Jamil, G. H. R. Kefayati, Rizalman Mamat, and G. Najafi. "Recent progress on hybrid nanofluids in heat transfer applications: a comprehensive review." *International Communications in Heat and Mass Transfer* 78 (2016): 68-79.

[76] Sidik, Nor Azwadi Che, Muhammad Mahmud Jamil, Wan Mohd Arif Aziz Japar, and Isa Muhammad Adamu. "A review on preparation methods, stability and applications of hybrid nanofluids." *Renewable and Sustainable Energy Reviews* 80 (2017): 1112-1122.

[77] Chen, Li Fei, Min Cheng, De Jun Yang, and Lei Yang. "Enhanced thermal conductivity of nanofluid by synergistic effect of multi-walled carbon nanotubes and Fe2O3 nanoparticles." In *Applied Mechanics and Materials*, vol. 548, pp. 118-123. Trans Tech Publications, 2014.

[78] Munkhbayar, B., Md Riyad Tanshen, Jinseong Jeoun, Hanshik Chung, and Hyomin Jeong. "Surfactant-free dispersion of silver nanoparticles into MWCNT-aqueous nanofluids prepared by one-step technique and their thermal characteristics." *Ceramics International* 39, no. 6 (2013): 6415-6425.

[79] Baby, Tessy Theres, and Sundara Ramaprabhu. "Experimental investigation of the thermal transport properties of a carbon nanohybrid dispersed nanofluid." *Nanoscale* 3, no. 5 (2011): 2208-2214.

[80] Aravind, SS Jyothirmayee, and S. Ramaprabhu. "Graphene–multiwalled carbon nanotube-based nanofluids for improved heat dissipation." *Rsc Advances*3, no. 13 (2013): 4199-4206.

[81] Jana, Soumen, Amin Salehi-Khojin, and Wei-Hong Zhong. "Enhancement of fluid thermal conductivity by the addition of single and hybrid nano-additives." *Thermochimica acta*462, no. 1-2 (2007): 45-55.

[82] Sidik, Nor Azwadi Che, Muhammad Noor Afiq Witri Muhammad Yazid, and Syahrullail Samion. "A review on the use of carbon nanotubes nanofluid for energy harvesting system." *International Journal of Heat and Mass Transfer* 111 (2017): 782-794.

[83] Nagarajan, P. K., J. Subramani, S. Suyambazhahan, and Ravishankar Sathyamurthy. "Nanofluids for solar collector applications: a review." *Energy Procedia* 61 (2014): 2416-2434.