Solar Energy Materials & Solar Cells 140 (2015) 9–16

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

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

# Nitrogen doped hybrid carbon based composite dispersed nanofluids as working fluid for low-temperature direct absorption solar collectors

Rashmi Shende, Ramaprabhu Sundara *

*Alternative Energy and Nanotechnology Laboratory (AENL), Nano-functional Materials Technology Centre (NFMTC), Department of Physics, Indian Institute of Technology Madras (IITM ), Chennai 600036, India*

ARTICLE INFO

*Article history:*
Received 13 November 2014
Received in revised form
5 March 2015
Accepted 11 March 2015

*Keywords:*
Graphene
MWNTs
Nanofluids
Thermal conductivity
Solar collectors

ABSTRACT

Solar energy is the best source of renewable energy among all other natural resources. Due to the abundant availability of solar energy it could effectively be used to fulfil the energy requirement of modern industrial society. Application of nanofluids in Direct Absorption Solar Collectors (DASC) can significantly increase its efficiency. Carbon nanotubes (CNTs) and graphene, that exhibit high thermal conductivity, unique optical properties, good mechanical strength, and large surface area have been of great advantage in the field of nanofluids. In this present work, application of N-(rGO-MWNTs) (nitrogen doped hybrid structure of reduced graphene oxide (rGO) and multiwalled carbon nanotubes (MWNTs)) in DASC has been investigated. The absorption and transmittance studies have been carried out by UV–visible–NIR spectrophotometer. Furthermore, temperature dependant thermal conductivity study with different volume fractions has been carried out. A significant enhancement in thermal conductivity of 17.7% is achieved with 0.02% volume fraction in DI water and 15.1% with 0.03% volume fraction with EG. Furthermore, we have observed that these nanofluids have very good stability without any agglomeration and sedimentation due to percolation network formed through intercalation of MWNTs in-between rGO layers.



## 1. Introduction

In recent years, the energy demand of world has increased due to globalisation and industrialisation. The dependence on non-renewable sources of energy such as fossil fuels, oil, natural gases etc. is resulting in the problems like global warming. Therefore, there is a clear necessity of shifting towards the clean renewable source of energy, particularly solar energy [1]. Researchers are working for effective utilisation and conversion of solar energy into the useful form of energy [2,3]. Solar thermal utilisation is one of the fields where solar energy is captured in DSAC and further used for various applications [4,5,6]. Conventionally used flat solar panel collectors [7] have the disadvantages such as low efficiency, corrosion, and heating losses [8]. It has been shown that replacing the solid coatings with liquids overcome the above mentioned problems [9]. In general, low temperature DASC uses water or EG, propylene glycol (PG) or mixture of EG and water [10]. EG acts as an anti-freezing formulation. However, conventional base fluids such as water, ethylene glycol (EG), have the limitation of low thermal conductivity as well as they are transparent to solar radiation. This is the major constraint in effectively absorbing incident solar radiation, which results in reduction of solar collector efficiency. The decades of research confirm that the dispersion of small fraction of nanomaterials considerably changes the thermal and optical properties of base fluids [11–14]. Subsequently, addition of trace amounts of nanoparticles in base fluids effectively increases the scattering of incident radiation which consequence in the effective absorption of solar energy along with the advantage of increase in thermal conductivity and thus enhancing the efficiency solar collector.

Most commonly studied nanoparticles are $Al_2O_3$, $TiO_2$, CuO, and carbon nanostructures (CNS). CNS because of their unique properties such as high optical absorption, high thermal conductivity [15,16], large surface area, good mechanical strength [17,18] and low density compared to metal and metal oxide nanoparticles, make them promising materials in the research area of nanofluids [19]. Among all carbon nanostructures, CNTs and graphene exhibit extremely high thermal conductivity i.e. for MWNTs ~3000 W/m K [16], for single walled carbon nanotubes (SWNTs) ~6000 W/m K [20], and ~5200 W/m K for graphene [15]. In addition to that, CNTs behave like a black body having absorption from far-ultraviolet (200 nm) to far-infra-red (200 μm) [21,22]. Tyagi et al. studied the effect of particle size on the solar collector efficiency and showed that the efficiency of collectors decreases with the increase in particle size [8]. He et al. carried out the comparative study between $TiO_2$ and

* Corresponding author.
*E-mail address:* ramp@iitm.ac.in (R. Sundara).

http://dx.doi.org/10.1016/j.solmat.2015.03.012
0927-0248/

CNTs dispersed water based nanofluids, and showed that the CNTs dispersed nanofluids are more efficient to convert light energy into heat energy than $TiO_2$ dispersed nanofluids [23]. Therefore, CNTs dispersed nanofluids are more effective in the application of solar collectors. Gan et al. compared the optical properties of MWNTs, carbon and aluminium nanoparticles dispersed ethanol based nanofluids, and concluded that nanofluids containing MWNTs result in better absorption of light than aluminium and carbon dispersed nanofluids [24]. Recently, Karami et al. investigated the optical properties of CNTs dispersed in water, and showed that the small fraction of CNTs remarkably changes the optical and radiative properties of base fluids, which further helps in improving the efficiency of solar collectors [25]. Many researchers have studied the thermal conductivity and heat transfer properties of graphene nanofluids and showed the significant improvement in heat transfer properties [26–28].

As-synthesised CNTs and rGO are hydrophobic in nature. Therefore, to get the uniform dispersion in polar solvents like DI water, EG, it is necessary to make them hydrophilic. Suitable functionalization over the surface of CNTs and rGO imparts hydrophilic nature. However, functionalization will result in restacking of graphene nanosheets [29]. This restacking leads to the problems, which include sedimentation in nanofluids. In addition to this, restacking deteriorates the intrinsic high thermal conductivity of graphene nanosheets. In case of CNTs, functionalization leads to the further complications including agglomeration in nanofluids. Moreover, CNTs nanofluids show the problem like aggregation arises due to curvature and self-entanglement of CNTs. Therefore, the most important concern in CNTs nanofluids is to overcome the problem of aggregation of CNTs. Incorporation of CNTs between two graphene nanosheets helps to reduce the intrinsic van der Waal forces which are responsible for the aggregation [29]. In addition to this, intercalation of CNTs eliminates the problem of restacking of graphene nanosheets [30–32]. Thus the incorporation of highly conducting CNTs between the two graphene nanosheets will resolve the problem of sedimentation; agglomeration as well as the intrinsic thermal conductivity of graphene nanosheets will be unaltered. This results in effective utilisation of the thermal conducting properties rGO along with excellent absorption property of CNT [21,22]. Therefore, hybrid structures of CNTs and rGO have gained the attention in various fields such as nanofluids, sensors, lithium-ion battery, fuel cell etc. [33–36].

Here, we report the synthesis of nitrogen doped hybrid structure of carbon nanotubes and reduced graphene oxide (N-(rGO-MWNTs)). Thermal conductivity and UV–visible spectroscopic studies have been carried out by dispersing specific amount of N-(rGO-MWNTs) in DI water and EG with the help of surfactants polyethylene glycol (PEG) and sodium lauryl sulphate (SLS) in 2:1 ratio. Results show the remarkable enhancement in thermal and optical properties of N-(rGO-MWNTs) nanofluids compared to base fluids.

## 2. Material synthesis and nanofluids preparation

The synthesis of N-(rGO-MWNTs) based nanofluids is a two step process (Fig. 1). First N-(rGO-MWNTs) was synthesised by pyrolysis of polypyrrole wrapped hybrid structure consisting rGO and MWNTs [32], and then it is further dispersed in a base fluid like DI water and EG. Hydrogen exfoliation technique [37] was

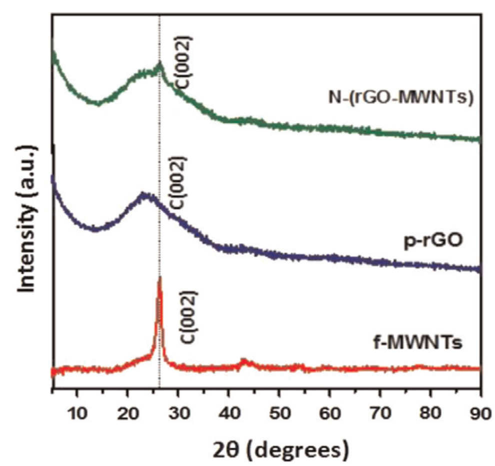


**Fig. 2.** X-ray diffraction pattern of f-MWNTs, p-rGO, N-(rGO-MWNTs).

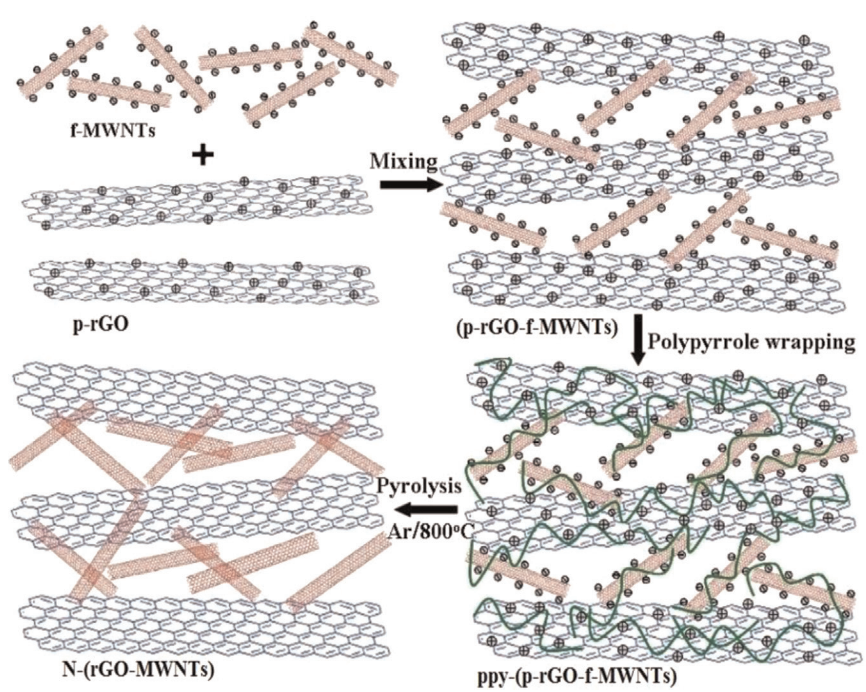


**Fig. 1.** Schematic diagram showing the synthesis of N-(rGO-MWNTs).