Renewable and Sustainable Energy Reviews 43 (2015) 750–762

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Spotlight on available optical properties and models of nanofluids: A review

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ARTICLE INFO

Article history:
Received 4 July 2013
Received in revised form
27 September 2014
Accepted 2 November 2014

Keywords:
Nanofluids
Optical properties
Theoretical models
Extinction
Scattering
Absorption

ABSTRACT

Optical characteristics besides unique thermo-physical properties of nanoparticles have encouraged researchers to use nanofluids in solar energy collectors or reservoirs as electromagnetic wave absorbing media. Recently, different analyses and approaches have been proposed by researchers. However, the appropriate electro-magnetic phenomenon of nanofluids is not established till date because of the complex dependence between nanoparticles and base fluids. In this work, optical properties of nanofluids are discussed on the basis of published data; mostly used models are presented along with their limitations and applications.

Contents

1. Introduction

Nanofluids, having remarkable enhancement in heat transfer capacity, are attracting researchers to implement them in solar cultivating systems. Nanoparticles are found to be very good

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http://dx.doi.org/10.1016/j.rser.2014.11.010
1364-0321/

Nomenclature

A	absorbance of the sample
D	diameter of nanoparticles
DDW	double distilled water
E	energy of the pulse
EG, PG	ethylene glycol, propylene glycol
G	experimental geometrical factor
I_0, $I(r)$	intensity of incident light and intensity at distance 'r,' respectively
N	number of scattering particles in the beam path
NPs	nanoparticles
Q_{ext}, Q_a, Q_s	extinction, absorption and scattering efficiencies, respectively
R	radius of particles
TLS	thermal lens signal
V	volume of particle
α	non-dimensional particle size parameter
ε_{eff}, ε_p, ε_f	dielectric constant of nanofluids, nanoparticles and base fluid, respectively
ε', ε''	real and complex components of dielectric constant, respectively
ε	complex dielectric constant of particles (bulk material)
ε_m	dielectric constant of medium/base fluid
θ	scattering angle
κ	thermal conductivity
λ	wavelength of incident light
λ_p	wavelength of probe beam
μ_a, μ_s	absorption and scattering coefficients of suspension/nanofluids, respectively
μ_s'	reduced scattering coefficient of the medium
μ_{eff}	effective attenuation coefficient of the medium
$\mu_{ext,particles}$	extinction coefficient of nanoparticles
$\mu_{ext,basefluid}$	extinction coefficient of base fluid
$\mu_{ext,total}$	extinction coefficient of nanofluid
σ_{ext},σ_s, σ_a	extinction, scattering and absorption cross-sections of suspension, respectively
τ	thermal diffusivity
Φ	fluence rate
ω_0, ω_p	diameter of the probe beam at source and at sample positions, respectively
$a_{n,}$ b_n	defined factors
dn/dT	thermo-optical coefficient of the sample (nanofluids)
e	thermal effusivity
f_v	volume fraction
g	anisotropy factor of the scattering function
k	complex component of refractive index
m	relative complex refractive index of nanofluid
n	real component of refractive index
n_m	refractive index of medium/base fluid
n_p	refractive index of particles
r	distance measured from the source of light
z	special co-ordinate
z_1	distance between the sample and aperture plane
z_c	Rayleigh range

electromagnetic wave absorbers within UV–visible range where 85% of solar energy is dissolved. On the other hand, conventional base fluids absorb the energy laid within infrared region having 15% of solar energy. In this work, published optical parameters for nanofluids are discussed along with recently developed models for nanofluids based on the Rayleigh's scattering theory, Maxwell-Garnett theory and Mie and Gans theory with their mathematical formulations. An overview on the discussed models is also drawn for comparison and investigation for a well-defined model. The aim of this article is to obtain a clear picture of the available optical properties and models in order to estimate the optical properties of nanofluids properly.

The change in the properties of nano-scale materials compared to their bulk might be for their individual atoms. In a nanoparticle, the amount of surface area is larger compared to its volume. This means that there are more atoms on the surface of the particle than inside it and this leads to increase in specific surface energy. For example, in a palladium nanoparticle 1.2 nm in diameter, 76% of the atoms are on the surface of the nanoparticle [1]. Surface atoms act otherwise compared to inner atoms. So, nanoparticles become thermodynamically unstable and have high surface energy when the surface-to-volume ratio increases [2], which makes them a good carrier of energy. A combination of nanoparticles and base fluid as colloidal working medium is expected to have a high impact on the efficiency of solar cultivating systems. A lot of investigations are now run by the researchers all around the world to find out the fundamental optical properties of nanoparticles but few works have been done on nanofluids. Enhancement in the efficiency of various amounts is reported by researchers for different types of solar cultivating systems with nanofluids such as 3% and 5% by Otanicar et al. [3] for direct solar absorber with graphite (30 nm) and silver (20 nm) nanofluids relative to flat solar collector with water as working medium, respectively; 5%–10% by Taylor et al. [4] for dish solar receiver with graphite nanofluid relative to conventional fluid; 28.3% by Yousefi et al. [5] for flat plate solar collector with Al_2O_3/H_2O nanofluids relative to conventional fluid; Kameya and Hanamura [6] have also reported Ni nanofluid as a good working fluid for solar collectors. Risi et al. de Risi, Milanese [7] conducted a numerical study on a solar Transparent Parabolic Through Collector (TPTC) with gas-based nanofluid as the working fluid; the maximum solar-to-thermal efficiency of the TPTC was found to be equal to 62.5%. Based on experimental investigation on the thermal properties of carbon black aqueous nanofluids for solar absorption, Han et al. [8] have reported a temperature increase from 24.4 °C to 38.4 °C of the 6.6 vol.% nanofluid,within 42 min, with that of water reaching only 31.2 °C.

Lot of research efforts have been devoted to optical properties of nanofluids by many researchers. Optical characterization and mathematical modeling for estimating optical properties (absorption, scattering and extinction coefficients, refractive index, etc.) have been done for Al, Ag, Cu, Pt and Graphite in water and therminol VP-1 [4], SWCNHs–water [9,10], Ni–Alkyl naphthalene [6] nanofluids. Dependence of scattering and refractive index of nanofluids on volume fraction and size of nanoparticles was investigated by Prasher and Phelan [11] theoretically. A technique, based on TLS and I-scan, has been proposed for thermo-optical properties estimation and demonstrated for Au–water nanofluids by Ortega et al. [12]. In order to evaluate the scattering and absorption efficiency of gold nanorod nanofluid theoretically, Jeon J et al. [13] have used Discrete Dipole Approximation (DDA). There are similar works on it in medical science literatures as well. However, obtained data for optical properties of nanofluids still are not enough for practical implementation and modeling as they are not free from controversy statements. Furthermore, dependence of nanofluids on size, shape, dielectric constant, dipole moment, surface charge, free and bond electrons, electrostatic repulsive force, substrates, concentration, distribution, etc. of nanoparticles as well