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A review on the applications of nanofluids in solar energy field

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ABSTRACT

This study provides a critical synthesis on the applications of nanofluids in various types of solar thermal systems. Nanofluids have received attention in recent years due to its importance in various industrial applications especially in the renewable energy field. This work presents the most recent advances of nanofluids in thermal energy storage systems, solar collectors, solar stills, and photovoltaic/thermal systems. With the application of nanomaterials, the efficiency of photovoltaic can increase substantially while reducing the production costs of electricity and manufacturing. This review is structured in three parts: the first part focuses on presenting the latest results for the thermal conductivity, viscosity, specific heat, and the thermal expansion coefficient of nanofluids reported in the literature. The second part of this review is allocated to the applications of nanofluids in different types of solar systems such as solar collectors, solar stills, thermal energy storage systems, and photovoltaic/thermal systems. Finally, the challenges and the bio-engineering safety concerns of using nanofluids in solar energy systems are discussed.

1. Introduction

Nanoparticles have been used extensively in various industrial and biomedical applications. A great deal of interest was centered on the applications of nanoparticles in the energy sector. Nanoparticles can play a significant role in various areas of energy sector such as energy conversion (e.g. fuel cells, solar cells, and thermoelectric devices), energy storage (e.g. rechargeable batteries and super-capacitors), and energy saving (e.g. insulation such as aerogels and smart glazes, efficient lightning such as light-emitting diode and organic light-emitting diode). Latest progress in nanotechnology led to the development of a new type of heat transfer fluids called Nanofluids produced by dispersing nanoparticles (10–50 nm) in conventional fluids [1]. Nanofluids exhibit the potential to considerably enhance heat transfer rates in various areas such as nuclear reactors, industrial cooling, transportation industry, micro-electromechanical systems (MEMS), nanoelectromechanical systems (NEMS), electronics and instrumentation, and biomedical applications [2,3]. Enhanced thermal conductivity may translate into higher performance and lower operating costs.

Many investigations on heat transfer augmentation using nanofluids have been studied by researchers both experimentally and theoretically [2–15]. Also, several review papers on nanofluids have also been published [4]. The global market of nanofluids for heat transfer applications is estimated by Commissariat à l'Énergie Atomique (CEA-France) to be more than 2 billion dollars per year [16]. Though different researchers have reported that nanofluids exhibited larger heat transfer improvement compared with traditional fluids, conflicting results on nanofluids performance were documented [4]. For example, various thermal conductivity enhancement ratios were reported for different particle-diameter sizes d_p and volume fractions φ_p [4]. Table 1 demonstrates a comparison of the experimental thermal conductivity augmentations of metallic and non-metallic nanofluids reported in the literature. Khanafer and Vafai [4] presented a comprehensive review on the variations within the thermophysical properties of nanofluids. They illustrated in their study that the experimental results for the effective viscosity and thermal conductivity of nanofluids reported by many authors in the literature were in disagreement. Correlations for the viscosity and thermal conductivity of nanofluids were obtained using the reported experimental results as shown in Table 2.

The optical and radiative characteristics of nanoparticles received less attention in the literature compared with studies on the thermal conductivity of nanofluids. Recently, researchers have

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Nomenclature

A	area
c	specific heat capacity
d_p	particle-diameter size
CNTs	Carbon nanotubes
CSP	concentrated solar power
DASC	direct-absorption solar collector
DSSS	double slope solar still
EG	ethylene glycol
G	solar radiation
HTF	heat transfer fluid
k	thermal conductivity
MEMS	micro-electromechanical systems
PV/T	photovoltaic/thermal
Q_u	useful energy
T	temperature
TES	thermal energy system

Greek Symbols

φ_p	volume fractions
β	thermal expansion coefficient
λ	wave length
μ	viscosity
ρ	density

Subscripts

a	ambient
f	fluid
i	inlet
p	nanoparticle
eff	effective

Table 1
Comparison of the experimental thermal conductivity of nanofluids enhancements of metallic and non-metallic nanofluids reported in the literature.

Reference	Base Fluid	Particle	d_p nm	φ_p %	Thermal conductivity Enhancement
[15]	water	Al_2O_3	38.4	4	9% (21 °C), 16% (36 °C), 24% (51 °C)
[15]	water	CuO	28.6	4	14% (21 °C), 26% (36 °C), 36% (51 °C)
[17]	water	Al_2O_3	131	4	24% (51 °C)
[18]	water	Al_2O_3	13	4.3	32.4% (31.8 °C)
[18]	water	Al_2O_3	13	4.3	29.6% (46.8 °C)
[18]	water	Al_2O_3	13	4.3	26.2% (66.8 °C)
[18]	water	SiO_2	12	2.3	1.1% (31.8 °C)
[18]	water	SiO_2	12	2.3	1% (46.8 °C)
[19]	water	CuO	23.6	3.4	12%
[19]	EG[a]	CuO	23.6	4	23%
[19]	water	Al_2O_3	38.4	4.3	11%
[19]	EG[a]	Al_2O_3	38.4	5	19%
[20]	water	CuO	23	9.7	34%
[20]	EG[a]	CuO	23	14.8	54%
[20]	water	Al_2O_3	28	5.5	16%
[20]	EG[a]	Al_2O_3	28	5	24.5%
[21]	water	Al_2O_3	11	1	14.8% (70 °C)
[21]	water	Al_2O_3	47	1	10.2% (70 °C)
[21]	water	Al_2O_3	150	1	4.8% (60 °C)
[21]	water	Al_2O_3	47	4	28.8% (70 °C)
[21]	water	Al_2O_3	47	1	3% (21 °C)
[22]	water	CuO	29	6	36% (28.9 °C)
[22]	water	CuO	29	6	50% (31.3 °C)
[22]	water	Al_2O_3	36	6	28.2%
[22]	water	Al_2O_3	47	6	26.1%
[23]	water	Al_2O_3	20	5	15%
[24]	water	Al_2O_3	11	5	8%
[24]	water	Al_2O_3	20	5	7%
[24]	water	Al_2O_3	40	5	10%
[25]	water	Cu	100	7.5	78%
[26]	water	Au	10–20	0.03	21%
[26]	water	Ag	60–80	0.001	17%

[a] EG: Ethylene Glycol.

addressed the potential applications of nanofluids in thermal storage and solar thermal collectors. The addition of nanoparticles leads to the scattering of the incident radiation which results in higher levels of absorption within the fluid [27–29]. The optical properties of the effective fluid were found to be significantly dependent on the particle size and shape as well as on the optical properties of the base fluid and nanoparticles [29].

The objective of this review is to identify the use of nanofluids in various types of solar collectors, thermal energy storage systems, photovoltaic/thermal systems, and solar stills. Furthermore, the challenges and the safety concerns of using nanofluids in solar energy systems are discussed. This work presents an overview of the contribution of nanofluids in these sectors towards more sustainable ways to store energy.

2. Applications of nanoparticles in solar systems

This section discusses the applications of nanoparticles in various energy sectors that engage the application of solar radiation as an energy source. This energy source can be used in photovoltaic/