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A review of studies using nanofluids in flat-plate and direct absorption solar collectors

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ABSTRACT

With increasing energy demands worldwide, the consumption of fossil fuels has increased unprecedently which are scarce in nature. This has led to environmental degradation and global warming which is a matter of concern. These factors lead to the rise in renewable energy sector in last decade. Among various renewable energy sources, solar energy is most exclusively used because of its ease of availability and least impact on the environment. Flat plate solar collector is most widely used solar collector but is less efficient (low capability to convert solar energy to thermal energy). The use of nanofluid (fluid obtained by mixing nanoparticle in base fluid) in place of base fluid has improved effect on thermophysical properties such as thermal conductivity. The use of nanofluid on flat plate solar collector (FPSC) & direct absorption solar collector (DASC) can be identified as an effective way to enhance the performance of solar collector. With the advancement in nanotechnology and growing thrust over increasing the performance of solar devices a lot of work has been done in this regard. The purpose of this literature review is to summarize the various research work done on the application of nanofluid in solar thermal devices. This review paper identifies the effect of various parameters and the optimum working condition. This paper also identifies the probable challenges we ought to face while developing thermal collector using nanofluids thus identifying the opportunities for future research.

1. Introduction

With the increasing thrust on economic development the energy sector plays an inevitable role [1]. With the unprecedented increase in the demand of energy the gap between the demand and supply is further widening [2]. This leading to higher consumption of fossil fuel which are scarce in nature. Further the over exploitation of fossil fuel leads to environment pollution and global warming which nowadays has become the global concern [3,4]. These factors have motivated the researchers worldwide to go for an eco-friendly energy technology i.e. renewable energy [5–9]. The various renewable sources of energy such as solar energy [10–13], Bioenergy [14–17], Hydrogen energy [18–21], Marine energy [22–25] and Geothermal energy [26,27]. The solar technology nowadays has emerged as an important source for conversion of solar energy into thermal and electrical energy (Solar collector and solar panel) being inexhaustible and ecofriendly [28–32]. It is estimated that the amount of solar energy falling on earth per hour can meet world energy demand for the whole year [33]. However the acceptance of solar energy as an alternate source of energy is not so clear because of its high operation cost and low efficiency and various research was done in this regard [34–37], solar collector is one of such device which converts solar energy into thermal energy using a heat exchanging fluid as absorber fluid [38,39]. Flat plate solar collector are the widely used collector [40]. The effective way of increasing the performance of solar collector is by using nanofluid as absorber fluid instead of conventional fluid. Nanofluid is a fluid consisting of nano-sized particle called nanoparticle [41]. These nanofluids are prepared mainly by using one step and two step methodology. The use of nanoparticles enhances the thermal and optical properties of the conventional fluid [42,43] thus enhancing the performance of solar collector and thereby reducing collector size. A lot of studies has been done regarding enhancement of thermal conductivity using nanofluid [44–47]. The effectiveness of nanofluid as an absorber fluid depends on particle material, particle size, base fluid material, additives, particle shape, temperature, ph value, particle volume concentration and nanofluid stability [48–54]. The nanofluid stability is improved by adding surfactant and ultrasonic processing [55–61]. The size reduction up to 26%can be achieved by using suitable nanofluid. A lot of research has been done to study heat transfer and effect of Brownian motion [62–65]. This paper presents the various research work done in this regard which may be useful for further experimental works.

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Nomenclature

DASC	direct absorption solar collector
FPSC	flat plate solar collector
SDBS	sodium dodecyl benzene sulfonate
SDS	sodium dodecyl sulfate
EG	ethylene glycol
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
f-SWCNTs	functionalized single-walled carbon nanotubes
SWCNT	single-walled carbon nanotube
MWCNT	multi-walled carbon nanotube
CNT	carbon nanotube
Re	Reynolds number
Pr	Prandtl number
Nu	Nusselt number
lpm	liters per minute
lph	liters per hour
$K_{a\lambda}$	spectral absorption coefficient
$K_{s\lambda}$	spectral scattering coefficient
$K_{e\lambda}$	spectral extinction coefficient
ρ	density of the liquid film
c_p	the specific heat
U	the fluid velocity
k	thermal conductivity
I	Solar irradiance
D	dimensionless diameter
q_r	radiative heat flux
$S_{gen.}$	entropy generation
η	collector efficiency
$\dot{m}$	mass flow rate
λ	frictional resistance coefficient
T_a	ambient temperature
T_i	collector inlet temperature
A_C	area of collector absorber plate
G_t	solar radiation
$F_R(\tau\alpha)$	absorbed energy parameter
$F_R U_L$	removed energy parameter
EG	ethylene glycol
SDS	sodium dodecyl sulfate
f_v	volume fraction
k_{nf}	thermal conductivity of nanofluid
k_{bf}	thermal conductivity of base fluid
$\dot{Q}_s$	energy rate engrossed

1.1. Solar collector

A solar collector is a device which absorbs solar radiation and transfer the heat to the absorber fluid thereby increasing its internal energy which can be used for further domestic use. In short solar collector converts solar energy into thermal energy. The mode of heat transfers between the sun and the absorber fluid is mainly radiation. The absorber plate being acting as the heat transfer medium transferring the heat gained by it to the absorber fluid.

There are basically two type of solar collector

1.1.1 Concentrating type: Parabolic Trough (Fig. 1.), Heliostat (Fig. 2.) & parabolic Dish (Fig. 3.)

1.1.2 Non-concentrating type solar collector: Flat plate solar collector

1.1.1. Concentrating (focussing) type collector

This type of collector is used for high temperature requirement up to 400 °C. There could be 50–150 °C rise in temperature of the absorber fluid. The incident radiation is concentrated at a particular point using reflecting surfaces i.e. it consists of a concentrator and a receiver. This consists of a rotatory element so that the sun's rays should always be focused on the absorber tube.

1.1.2. Flat plate solar collector (FPSC)

In this collector no optical concentration is there and this type of collector is used when temperature requirement is of the range 40–100 °C. The temperature rise in this type of collector is of the order of 0–50 °C. This division of collector is most important because of its simplicity in construction, no moving part requirements, ease of maintenance and low operating cost. The major application of this type of collector is in domestic water heating, building heating, crop drying and industrial processing. Schematic of FPSC is depicted in Fig. 4.

1.1.3. Direct absorption solar collector (DASC)

In this type of collector no absorber plate requirement is there. The incident rays fall directly on the fluid and get absorbed by it i.e. there is direct and volumetric absorption in this case There is minimum convective losses in this case and thus efficiency is higher when compared to Flat plate type solar collector. Direct absorption solar collector offers less thermal resistance when compared to Indirect (Flat Plate) type Solar collector. Schematic of DASC is depicted in Fig. 5.

1.2. Effect of various parameter on the performance of Flat Plate solar collector

The various parameters affecting the performance of collector are as follows:

1.6.1 Design parameter: It includes glass cover, Absorber plate material, absorber plate design

1.6.2 Operational parameter: It includes fluid inlet temperature, type of absorber fluid, collector tilt

1.6.3 Meteorological parameter and Environmental parameter: It includes ambient temperature, wind speed, solar flux.

Many researchers have worked on these above parameters. This paper focus on the operational parameter i.e. type of absorber fluid. Low thermal efficiency and low fluid outlet temperature are the common problems encounter when using conventional fluid. For this purpose, researcher now a days are using a new class of fluid called as nanofluid.

2. Nanofluids

2.1. Nanofluid introduction

A nanofluids can be defined as the fluid containing nano-sized particles (1–100 nm). These fluids consist of nanoparticles mixed in the

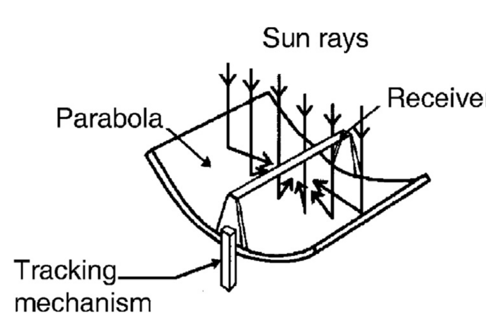

Fig. 1. Parabolic trough.