Renewable and Sustainable Energy Reviews 62 (2016) 767–792

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Applications of nanotechnology to improve the performance of solar collectors – Recent advances and overview

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ARTICLE INFO

Article history:
Received 7 March 2015
Received in revised form
9 February 2016
Accepted 26 April 2016

Keywords:
Nanotechnology
Solar collector
Literature review
Renewable energies

ABSTRACT

This paper gives a comprehensive overview about the recent advances related with the application of the nanotechnology in various kinds of the solar collectors. Papers reviewed including theoretical, numerical and experimental up to date works related with the nanotechnology applications in the flat plate, direct absorption, parabolic trough, wavy, heat pipe and another kinds of the solar collectors. A lot of literature are reviewed and summarized carefully in a useful tables (Tables 1–7) to give a panoramic overview about the role of the nanotechnology in improving the various types of the solar collectors. It was found that the use of the nanofluid in the solar collector field can play a crucial role in increasing the efficiency of these devises. We think that this paper can be considered as an important link between the nanotechnology and all available kinds of the solar collectors. From the other side, further researches are required to study the effect of nanotechnology to enhance the solar collector industry over the next several coming years.

Contents

1. Introduction

Solar energy (or radiant light and heat from the sun) is currently one of the most important sources of clean, free, inexhaustible and renewable energy with minimal environmental impact. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW [1]. About 30% of the solar power actually reaches the earth and at every 20 min, the sun produces enough power to supply the earth with its needs for an entire year [2]. The solar energy can be defined as the energy which comes from the sun and can be converted into electricity and heat. It has

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http://dx.doi.org/10.1016/j.rser.2016.04.050
1364-0321/

Nomenclature

Symbol description unit

A	surface area of solar collector [Eq. (2)], [Eq. (5)] and [Eq. (10)] (m^2)
A_c	reduction in the size of collector's area [Eq. (1)] (m^2)
C_p	specific heat of the working fluid [Eq. (1)] (kJ/kg °C)
C_{pro}	water production cost [Eq. (4)]
c_w	specific heat of water [Eq. (7)] (kJ/kg °C)
c_p	specific heat of nanoparticle [Eq. (7)] (kJ/kg °C)
F_R	collector heat removal factor [Eq. (2)] and [Eq. (6)]
f	plant availability [Eq. (4)]
G_t	solar radiation on solar collector [Eq. (5)] (W/m^2)
h	local heat transfer coefficient [Eq. (2)] (W/m^2 K)
I_b	global solar radiation [Eq. (10)] (W/m^2)
I_T	incident radiation or total radiation [Eq. (1)] and [Eq. (6)] (W/m^2)
I	intensity of solar radiation [Eq. (2)] (W/m^2)
$m\cdot$	mass flow rate of the working fluid [Eq. (1)] (L/s)
m_w	mass flow rate of water [Eq. (7)] (kg/s)
m_p	mass flow rate of nanoparticle [Eq. (7)] (kg/s)
Nu_{av}	average Nusselt number [Eq. (3)]
n	number of the panels in the collecting system [Eq. (9)]
Pr	Prandtl number [Eq. (3)]
P_{net}	system collecting power [Eq. (9)] (W)
Q_{usfl}	actual useful energy gain [Eq. (2)] (W)
Q_u	rate of useful energy gained [Eq. (5)] and [Eq. (10)] (W)
Q_{cpc}	solar energy radiating on one CPC plate [Eq. (9)] (W)
Re	Reynolds number [Eq. (3)] and [Eq. (8)]
SAR	specific absorption rate [Eq. (7)] (kW/g)
TCO	total cost of ownership [Eq. (4)]
T_{fi}	fluid inlet temperature [Eq. (6)] (°C)
T_{in}	fluid inlet temperature [Eq. (1)] (°C)
T_{out}	fluid outlet temperature [Eq. (1)] (°C)
T_a	ambient temperature [Eq. (2)] and [Eq. (6)] (°C)
T_m	fluid mean temperatures [Eq. (2)] (°C)
U_L	overall loss coefficient of solar collector [Eq. (6)] (W/m^2 K)

Greek symbols

α	absorptivity [Eq. (6)]
κ	absorption rate of the absorber [Eq. (2)]
τ	transmissivity [Eq. (6)]
φ	nanoparticles volume fraction [Eq. (8)]
η	efficiency of the collector [Eq. (1)] and [Eq. (8)]
η_i	efficiency of the collector [Eq. (6)] and [Eq. (10)]
η_{net}	system collecting efficiency [Eq. (9)]
λ	rate of transmission of the solar collector cover [Eq. (2)]
ΔT_n	temperature rise at the same time interval for nanofluid [Eq. (7)] (°C)
ΔT_w	temperature rise at the same time interval for water [Eq. (7)] (°C)
Δt	time interval [Eq. (7)] (s)

produced energy for billions of years, so the utilization of solar energy and the technologies of its materials has received much attention especially in the last ten years [3,4]. For example, some studies have indicated that about 1000 times from the global energy requirements can be achieved by using the solar energy; however, only 0.02% of this energy is currently utilized [5]. The main reasons of this huge attention in the solar energy applications are due to the growing demand of energy, limited availability of fossil fuels and environmental problems associated with them such as carbon dioxide emissions. Moreover, the rapid increase in the human population can be considered as an additional serious problem, since the global population has increased by nearly 2 billion with a major contribution from developing countries [6]. Furthermore, it is proved that the consumption rate of fossil fuels by humans is much faster than they are replaced by geologic processes. In fact, the sun radiates every day, enormous amount of energy and the hourly solar flux incident on the earth's surface is greater than all of human consumption of energy in a year [7]. In spite of this huge amount of available solar energy, approximately 80% of energy used worldwide still predominantly comes from fossil fuels such as coal, petroleum and natural gas [8]. The present work gives a comprehensive overview about the recent advances related with the application of the nanotechnology in different types of the solar collectors. Papers reviewed including theoretical, numerical and experimental up to date works related with the nanofluid applications in the flat plate, direct absorption, parabolic trough, wavy, heat pipe and another kinds of the solar collectors. A lot of literature are reviewed and summarized carefully in a useful tables (Tables 1–7) to give the reader a panoramic review about the role of the nanofluid in improving the various types of the solar collectors.

1.1. Concept of nanofluid

Nanofluid or suspensions of nanoparticles in liquids is defined as a mixture of a normal fluid such as (water, oil, ethylene glycol and molten salts) with a very small amount of solid metallic or metallic oxide nanoparticles or nanotubes which was first suggested by Choi [9] in 1995. It was considered as the new generation of advanced heat transfer fluids or a two-phase system which used for various engineering and industrial applications due to its excellent performance. Some of these applications including nuclear reactors, transportation industry, cooling of transformer oil, electrical energy, mechanical, magnetic, cooling of microchips, solar absorption and biomedical fields [10]. It is well known that metals have higher thermal conductivities than those of fluids. For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than that of engine oil [11]. The first decade of nanofluid researches was primarily focused on measuring the thermo-physical properties of these fluids such as the thermal conductivity, density, viscosity and heat transfer coefficient [12]. Nanofluid have a good properties of radiation absorption and it has a high thermal conductivity. For example, the thermal conductivity at the room temperature of individual multi-walled carbon nanotubes (MWCNTs) were found to have values greater than 3000 W/m K [13]. Moreover, Assael et al. [14] indicated that about 1% volumetric fraction of MWCNT was enhanced the thermal conductivity of water by about 40%. In order to prepare nanofluids by dispersing nanoparticles in a base fluid, a proper mixing and stabilization of the particles is required. The size of nanoparticles is very small and in the range of 1–100 nm [15] which is about one-thousandth the diameter of a human hair. It is highly recommended not to add large solid