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Performance enhancement of solar collectors—A review

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ABSTRACT

Given rapid depletion of conventional energy sources and environmental degradation caused by their over exploitation, the renewable energy sources are believed to be the future. Technologies utilizing renewable energy sources differ significantly from one another, not only with regard to technical and economic aspects but also in relation to their reliability, maturity, and operational experience in utility scale conditions. Technologies used to harness solar energy have emerged as the most promising and mature since solar energy is abundant, freely available, and it has commercial potential too. This paper presents a review of advancements made in the field of solar thermal technology with a focus on techniques employed for its performance enhancement. It also covers the description of different types of solar collectors to facilitate the systematic understanding of solar thermal technology and the novel modifications realized in each category of solar collectors have been highlighted to promote the use of solar energy in routine activities. Performance enhancement techniques such as geometrical modifications on the absorber plate, use of solar selective coatings and nanofluids have been given a special attention.

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Contents

Abbreviations: BNNT, boron nitride nanotube; CNT, carbon nanotube; CR, concentration ratio; CRS, central receiver system; CSP, concentrated solar power; DC, direct current; ETC, evacuated tube collector; ICS, integrated collector storage; LDR, light dependent resistor; MWNT, multi-wall nanotube; PCM, phase change material; PECVD, plasma-enhanced chemical vapor deposition; PV, photovoltaic; PV/T, photovoltaic-thermal; PVD, physical vapor deposition; SAH, solar air heater; SS/SS-N, stainless steel/stainless steel nitride; SWH, solar water heater; SWNT, single wall nanotube; TE, thermoelectric module; TPCT, two-phase closed thermosyphon

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1. Introduction

It is the age of machines—for either necessity or luxury. Machines need energy to perform tasks. Meeting the ever-increasing demand of energy without degrading the environment has always been concern of scientific community. Generation of energy from limited conventional sources has caused so much environmental degradation that impact is visible in the form of pollution, acid rain, global warming etc. Thus, there is a crying need for producing green and clean energy from renewable sources. Among all the renewable energy resources, the solar energy has emerged as one of the most promising renewable energy resource since it is abundant, freely available, and it has commercial potential too. The conversion of solar energy into different other forms is evident in nature, as shown in Fig. 1. The solar energy is converted into chemical energy by the process of photosynthesis in green plants. The conversion of solar energy into mechanical energy happens during the process of evaporation from water bodies, and change in wind behavior. In addition, there are two broad ways of utilizing the solar energy for the production of energy: (i) solar–electric conversion (converting solar energy directly into electrical energy using photovoltaic solar cell) and (ii) solar–thermal conversion (converting solar energy into thermal energy using solar collector).

A lot of research works have been reported in the literature on solar–thermal systems. A few important review articles highlighting these research works are mentioned in Table 1. Kalogirou [1] conducted an exhaustive review on different types of solar thermal collectors and their applications. The various types of collectors were discussed and presented with their optical, thermal and thermodynamic analysis. The applications of solar thermal systems in diverse areas of technology were illustrated to emphasize the need of its use whenever possible. Barlev et al. [2] presented a review on concentrating collectors, viz. parabolic trough collectors, heliostat field collectors, linear Fresnel reflector, parabolic dish collector etc. They suggested that concentrated solar power (CSP) technology could not only be used for electricity generation, but also for large range of other applications such as desalination of water, industrial heating and cooling, detoxification and disinfection of water etc. Other review articles, listed in Table 1, are focused on any particular type of collector or its specific application and have not discussed different techniques employed for the performance enhancement of solar collectors. For example, the methods like use of artificial roughness, solar selective coating, and nanofluids for enhancing the thermal performance of solar collectors have never been presented collectively.

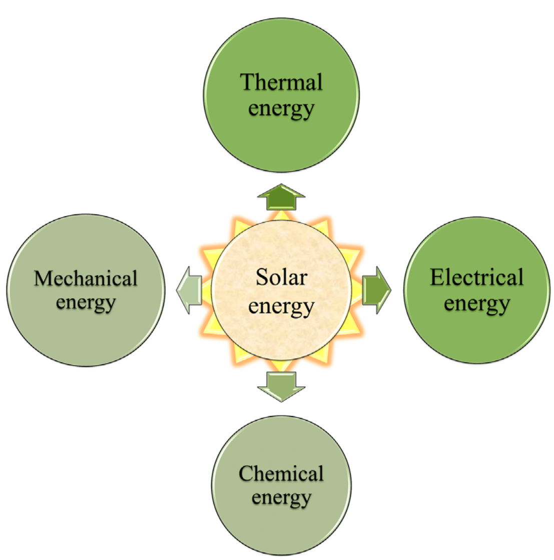

Fig. 1. Conversion of solar energy into other forms of energy.

This paper presents an overview of solar–thermal technology with an emphasis on methods adopted for enhancement of its performance. It also covers the description of different types of solar collectors to facilitate the systematic understanding of solar thermal technology and the novel modifications realized in each category of solar collectors have been highlighted to promote the use of solar energy in routine activities.

2. Solar collectors

Solar collector is a device that collects thermal energy of solar insolation by absorbing them. The thermal energy thus stored is carried away by a flowing fluid and utilized for some specific purposes. Fig. 2 shows the classification of solar collectors. The solar collectors are broadly classified as non-tracking and tracking collectors. The non-tracking collectors are kept at rest and also known as fixed or stationary collectors, whereas tracking collectors are designed to track the movement of sun so that the incoming solar radiations always fall perpendicular to them. The tracking solar collectors are further classified as one axis tracking and two axes tracking collectors. Non-tracking collectors are categorized as flat plate, evacuated tube and compound parabolic collectors. Parabolic trough collector, cylindrical trough collector, and linear Fresnel reflector fall under the category of single axis tracking systems, whereas central tower receiver, parabolic dish reflector, and circular Fresnel lens belong to dual axes tracking systems.

The collector that uses water as working fluid is termed as solar water heater (SWH), whereas the collector utilizing air as working fluid is called solar air heater (SAH). A solar water heating (SWH) system comprises of the solar collector as well as the storage tank. The solar water heating systems are further classified as passive SWH systems (do not require external pumping agency and the flow takes place due to thermo-syphonic action) and active SWH systems (require pumping agency to circulate fluid through them). An integrated collector storage system (ICS) has both the collector and storage tank as single unit. Tang et al. [3,4] investigated effects of temperature of water in the storage tank, structural and performance parameters of a thermosyphon on domestic SWH at clear nights. It was suggested that vertical cylindrical tank instead of horizontal cylindrical tank should be used for freeze protection. It was also found that an absorber with solar selective coating prevents freezing at clear nights too.

Hossain et al. [5] reviewed on SWH collector and thermal energy performance of circulating pipe, and summarized the findings about the thermal performance of the flat plate, concentrating, and other collectors of solar water heater with a mantle heat exchanger. They proposed an energy equation, which included a heat exchanger penalty factor. Shukla et al. [6] presented a review on the recent progress made in SWH technology. It was reported that the heat pump-based SWH could be a potential water heating system in the regions where solar energy is sparse. The performance of such systems was found to be influenced by the type of refrigerant employed. Shukla et al. [7] made a thorough survey on the use of phase change material (PCM) in solar water heating systems or heaters (SWHs). It was concluded that only preliminary designs of PCM-based SWHs were available. An inbuilt thermal storage could be an alternative to the present day solar water heating system. Ogueke et al. [8] reviewed solar water heating systems for domestic as well as industrial applications. It was concluded that despite their higher efficiency, active SWHs were not as popular as passive SWHs. Jaisankar et al. [9] surveyed on various heat transfer enhancement techniques for increasing the thermal efficiency of SWH. They suggested that an extensive research is required on parallel flow solar collector, the shape of

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