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Review

Potential applications of inserts in solar thermal energy systems – A review to identify the gaps and frontier challenges

Saman Rashidi[a,*], Mohammad Hossein Kashefi[b], Faramarz Hormozi[c]

[a] Faculty of New Science and Technologies, Semnan University, Semnan, Iran
[b] Department of Mechanical Engineering, Semnan University, Semnan, Iran
[c] Department of Chemical, Petroleum, and Gas Engineering, Semnan University, Semnan, Iran

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ABSTRACT

Solar energy systems are recognized as promising alternatives for fossil fuels due to their economic viability and environmental benefits. Efficient converting and harvesting of solar energy is a key target in solar energy systems. The implementation of inserts is an effective technique to amend the thermal efficiency of solar thermal energy systems. Thereby, the objective of this paper is to carry out a review on the recent investigations on the potential applications of different inserts including baffles, wire coils, vortex generators, and twisted tapes, in different solar thermal energy processes. The latest state-of-the-art developments are deeply discussed and some recommendations are made for further investigation in this field.

1. Introduction

Currently, the energy requirement is increasing due to population growth and industrial developments all over the world. The issues associated with the production of energy directly influence the environment, economic status, and relative living standards. Generally, the energy demand increases with new improvements in social and economic circumstances, which are proportional to economic growth (Kannan and Vakeesan, 2016). A large portion of energy demands especially in developing countries are met by available fossil fuels. Environmental pollution and high cost are two pivotal challenges associated with the current energy resources. Continuous usage of fossil fuels causes global climate change that damages ecosystems of the planet (Schou, 2000) due to the emission of greenhouse gases such as CO_2. Moreover, fossil fuels are not abundant and are limited source of energy. Accordingly, countries are seeking for alternatives suitable for their situations such as their population growth and social patterns together with economic development. Renewable energy sources including wind, solar, geothermal, and biomass energies are promising alternatives for fossil fuels with a bright future. Some of them are available, free to harness, and economically viable. Amongst the renewable energy sources, solar energy is identified as an abundant source of energy (Panwar et al., 2011). Harnessing the solar energy does not have any harmful impact on ecosystem. Moreover, this source of energy is suitable for village, industrial systems, and buildings. Thus, special attention has recently been paid to this source of energy. Harvesting solar energy through high-performance route is one key potential for the research in the field. Usually, systems used for storing or converting the solar thermal energy have low performances and this is a challenge for designers of these systems. Therefore, many researches have been conducted to improve the performance of these systems.

For example, Rashidi et al. (2017) reviewed the potentials of porous materials for enhancing the performances of different solar energy systems. They reported that the optical characteristics of porous materials are key parameters, which should be taken into account when these materials are used in solar systems. They noted that some optical coatings can be used to enhance the optical features of porous materials for solar thermal systems. In other literature resources, some researchers reviewed the potentials of nanoparticles for improving the thermal efficiencies of solar energy systems (Mahian et al., 2013; Kasaeian et al., 2015; Elsheikh et al., 2018; Khanafer and Vafai, 2018). The results of these investigations are listed as follows:

- Employing nanoparticles as a heat transfer fluid in solar collectors has economic and environmental benefits due to the reduction in the amount of CO_2 emission and fuel consumption (Mahian et al., 2013).
- Using nanofluids with larger values of thermal conductivity is a plausible option for improving the performance of solar systems, while using nanofluids with large values of nanoparticle

* Corresponding author.
E-mail address: samanrashidi3983@gmail.com (S. Rashidi).

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concentration does not always enhance the thermal performance of such systems (Kasaeian et al., 2015).
- Using low-cost nanoparticles preparation method is necessary for solar systems (Khanafer and Vafai, 2018).
- The great thermo-physical characteristics of nanofluids can result in a considerable improvement in the thermal efficiency of a solar system. This also results in the diminution in the size of the system (Elsheikh et al., 2018).

Khan et al. (2017) evaluated the potential application of phase change materials for sensible and latent heat thermal energy storage in solar absorption refrigeration systems. They reported that latent heat of fusion, melting temperature as well as thermo-physical properties of phase change materials are main features affecting the energetic performance of these materials used in the solar energy systems. Bazri et al. (2018) reviewed some numerical investigations conducted on the solar collectors coupled with phase change materials considering the potential effects of nanoparticles and fins on thermal performance of the systems. Notably, the phase change materials can be utilised to store the thermal energy in solar collectors, while nanoparticles and fins are implemented to enhance the thermal performance of the system. Their assessments indicated that phase change materials have small values of thermal conductivity. However, this weak point can be addressed by adding nanoparticles including copper, aluminium, and graphite, which offer large thermal conductivity. Moreover, fins can be used to enhance the performance of phase change materials in solar collectors. Thickness, height, and number of fins are key parameters affecting the thermal performance of the system. Panchal and Mohan (2017) reviewed different techniques used for improving the outputs of solar stills. Their investigations revealed that the phase change materials can be used to store the solar thermal energy during daytime and release this energy at nights. This technique is efficient for enhancing the productivities of solar stills. Moreover, they pointed out that the energy absorbing materials are available and inexpensive materials for enhancing productivities of solar desalination systems.

An interesting route for enhancing the thermal efficiencies of solar systems is the installation of various inserts including baffles, wire coils, vortex generators, and twisted tapes in these systems. As a passive technique, the installations of inserts have attracted the attentions of many designers of thermal systems since inserts are easy to install and operate and also their affordability is exclusive (Khoshvaght-Aliabadi et al., 2014; Hosseinirad and Hormozi, 2017; Hosseinirad and Hormozi, 2018).

Such techniques have no movements and do not require any external source of energy.

The concepts of inserts are presented as follows:

- Twisted tapes are usually made by metallic strips. These strips are twisted in some special forms and dimensions and can be placed across the flow. These devices are also employed as swirl flow equipment and act as turbulators employed to impart swirl flow, which causes an enhancement in heat transfer rate. Pitch and twist ratio are the main factors employed to investigate the efficiencies of these devices. Pitch of these devices is the length between two points on a surface, parallel to the axis of strip. Moreover, twist ratio of them is the ratio of pitch to inside diameter of the pipe.
- Vortex generators generally take configurations of tiny protrusions, which may be placed into the main wall of the duct by punching, attaching, stamping, mounting, and embossing. Improvement of heat transfer by employing vortex generators is related to many factors including their shape, geometry, location from the leading edge of the test channel, and attack angles. Delta wing, rectangular wing, delta-winglet, and rectangular winglet are basic configurations of vortex generators. These shapes are shown in Section 3.2 of this paper.
- Baffles are blades with rectangular, square, triangular, helical or wedge shaped which can be inserted into the heat transfer devices to interrupt the hydraulic and thermal boundary layers. Indeed, the fluid, flowing over the baffles, strikes the duct surface which can enhance the local heat transfer rate. Baffle spacing, baffle height, and perforations are the important factors employed to investigate the efficiencies of these devices. Note that perforations are the holes created on baffles to decrease the resistance against the flow.
- Wire coil inserts are made by firmly wrapping a coil of spring wire on a rod. Wires create a helical roughness as the coil spring is pulled up. Wire coil pitch and shapes of their cross section are two parameters, which affect the performances of these devices.

Many efforts have been made to employ this technique in different solar systems. Thereby, the main objective of the present work is to provide some information about the potentials of various inserts in solar energy systems by reviewing the state-of-art bibliographies. The mechanism, advantages, and disadvantages of each insert are investigated and briefly discussed. Finally, some recommendations together with a pathway for future researches are introduced.

2. Status of some countries in usage of solar thermal energy systems

Wang et al. (2018) performed an overview on the various kinds of

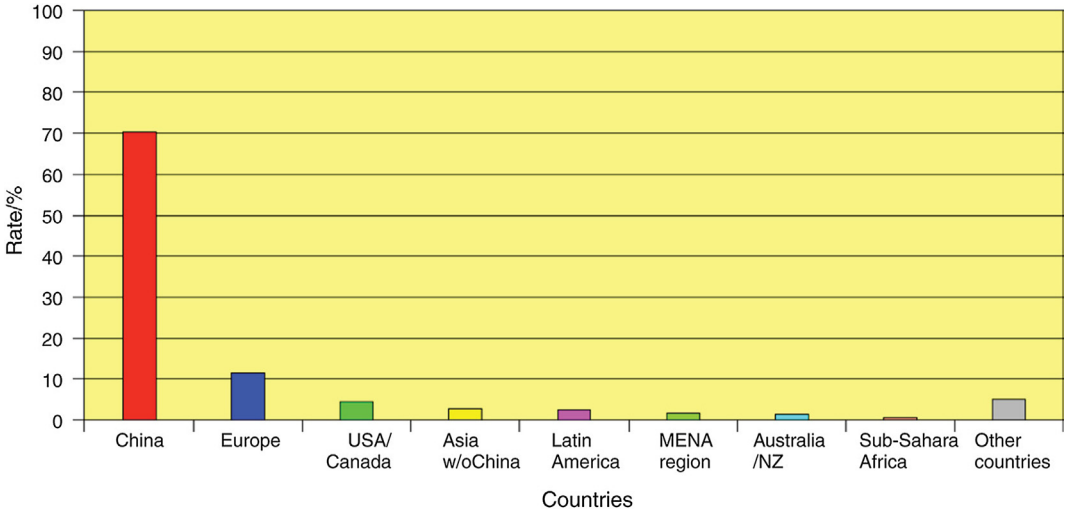

Fig. 1. Total installed capacity of water and air heaters at various economic areas adapted from Wang et al. (2018) with authorization from the publisher.

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