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Progress and latest developments of evacuated tube solar collectors

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ABSTRACT

Solar energy is the most available, environmental friendly energy source and renewable to sustain the growing energy demand. Solar energy is captured by solar collectors and an evacuated solar collector is the most efficient and convenient collector among various kinds of solar collectors. In this paper, a comprehensive literature on why evacuated collector is preferable, types of evacuated collectors, their structure, applications and challenges have been reviewed. Latest up to date literature based on journal articles, web materials, reports, conference proceedings and thesis have been compiled and reported. Applications of evacuated solar collectors in water heating, heat engines, air conditioning, swimming pool heating, solar cooker, steam generation and solar drying for residential and industrial sectors have been summarized and presented. Collector efficiency of different types of evacuated collectors and their performance based on different working fluids have been reported as well. Based on the available literature, it has been found that an evacuated tube collector has higher efficiency than the other collector. An evacuated tube collector is also very efficient to be used at higher operating temperature. There are few challenges that have been identified and need to be addressed carefully before installing an evacuated tube solar collector. However, after critically analyzing the available literature, authors have presented some future recommendations to overcome the barriers and for enhanced performance of an evacuated tube solar collector.

Contents

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1. Introduction

The most available source of renewable energy on earth is solar energy as the earth receives millions of watts of energy everyday coming from solar radiation. However, only a fraction of it in the form of day lighting and photosynthesis is used by the natural world, one third is reflected back into space and the rest is absorbed by land, oceans and clouds. Thus, it is very reasonable to collect solar energy and utilize it efficiently to generate electric power, heat and also for cooling purposes in a viable way. The effect of using solar energy on the environment for a variety of applications is minimal as it produces no harmful pollutants. Besides environmental consciousness, dwindling of traditional energy sources marks solar energy as the appropriate energy source to meet the increasing demand of energy worldwide. Researchers have investigated and developed technologies on how to harvest solar energy to serve human beings and are still considering new technologies to maximize the collection and utilization of solar energy [1].

There are particular challenges in the effective collection and storage of solar energy though it is free for taking. As solar radiation is only available during daytime, the energy must be collected in an efficient manner to make use of most of the daylight hours and then must be stored. Solar thermal collectors are the existing components to capture solar radiation which is then turned to thermal energy and transferred to a working fluid subsequently. Therefore, solar collectors are the main and most critical components of any solar system [2].

There are basically two types of collectors, stationary and tracking [3] (Fig. 1). Different collector configurations can help to obtain a large range of temperature for example, 20–80 °C is the operating temperature range of a flat plate collector (FPC) [4] and 50–200 °C is for an evacuated tube solar collector (ETSC) [5,6]. The most productive and mostly used solar collectors are FPCs but these collectors have comparatively low efficiency and outlet temperatures. FPC is popular due to its low maintenance cost and simple design.

However, FPC has two major drawbacks:

i. convection heat loss through glass cover from collector plate and
ii. absence of sun tracking.

ETSCs have considerably lower cost and heat loss than the standard FPCs [7,8]. On the other hand, an ETSC overcomes both these drawbacks due to the presence of vacuum in annular space between two concentric glass tubes, which eliminates sun tracking by its tubular design. Conventional FPCs are mainly designed for sunny and warm climates. Their performance reduces during cold, windy and cloudy days and they are greatly influenced by the weather as moisture and condensation cause early erosion of internal materials which might cause system failure. In contrast, ETSCs have outstanding thermal performance, easy transportability and expedient installation. In addition, ETSCs are suitable for unfavorable climates [9,10].

This paper presents a review of previous studies on ETSC, their applications, and suitability in solar thermal engineering systems. The former studies on ETSC mainly related to their suitability and performance in various applications. Therefore, this review mainly investigates the performance of ETSC for domestic and industrial applications, factors that influence the collector efficiency, challenges of using this collector as well as economic consideration regarding the usage of this collector. Some suggestions are also made for future research in this field. There is no review on ETSC till now and thus this is the first systematic review paper on recent developments of ETSC and their applications according to the authors' opinion. Finally, it is the authors' hope that this review will be useful to find more about ETSC, their applications, and challenges and the future recommendations will help in future research work.

2. Evacuated tube solar collector (ETSC)

A variety of technologies exist to capture solar radiation, but of particular interest of authors is evacuated tube technology. Numerous authors [3,11,12] have noted that ETSCs have much greater efficiencies than the common FPC, especially at low temperature and isolation. For instance, Ayompe et al. [13] conducted a field study to compare the performance of an FPC and a heat pipe ETSC for domestic water heating system. With similar environmental conditions, the collector efficiencies were found to be 46.1% and 60.7% and the system efficiencies were found to be 37.9% and 50.3% for FPC and heat pipe ETSC, respectively.

An ETC is made of parallel evacuated glass pipes. Each evacuated pipe consists of two tubes, one is inner and the other is outer tube (Figs. 2 and 3). The inner tube is coated with selective coating while the outer tube is transparent. Light rays pass through the transparent outer tube and are absorbed by the inner tube. Both the inner and outer tubes have minimal reflection properties. The inner tube gets heated while the sunlight passes through the outer tube and to keep the heat inside the inner tube, a vacuum is created which allows the solar radiation to go through but does not allow the heat to transfer. In order to create the vacuum, the two tubes are fused together on top and the existing air is pumped out. Thus the heat stays inside the inner pipes and collects solar radiation efficiently. Therefore, an ETSC is the most efficient solar thermal collector [12].

An ETSC, unlike an FPC, can work under any weather conditions while it provides acceptable heat efficiency.

2.1. Why an evacuated tube solar collector (ETSC) is preferable?

According to many researchers [3,11,12] ETSCs have much more higher efficiencies than FPCs. ETSCs can collect both direct and diffuse radiations. Besides excellent thermal performances, ETSCs have convenient installation and easy transportabilty.

Applications like desalination of sea water, air conditioning, building heating, refrigeration, and industrial heating require higher temperature and the performance of an ETSC is better than an FPC for high temperature operations [15]. ETSCs are also able to operate other higher temperature applications such as instantaneous gas heater, boost element integrated single solar tank system, and boost tank incorporated solar pre-heaters [16].

Mangal et al. [17] mentioned that the peak energy output is provided by an FPC only at mid-day when the sun is perpendicular to the surface of the collector whereas the evacuated solar tubes are able to track sun passively throughout the day as for cylindrical