Solar Energy Materials and Solar Cells 187 (2018) 123–139

Contents lists available at ScienceDirect

Solar Energy Materials and Solar Cells

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

Advances in solar thermal harvesting technology based on surface solar absorption collectors: A review

M. Imtiaz Hussain[a], Christophe Ménézo[b], Jun-Tae Kim[c,*]

[a] Green Energy Technology Research Center, Kongju National University, Cheonan, South Korea
[b] LOCIE UMR CNRS 5271, Campus Scientifique Savoie Technolac - Bâtiment Hélios, Avenue du Lac Léman, F-73376 Le Bourget-du-Lac, France
[c] Department of Architectural Engineering, Kongju National University, Cheonan, South Korea

ARTICLE INFO

Keywords:
Surface solar absorption collectors
Concentrating collectors
Non-concentrating collectors
Technological advancements and challenges

ABSTRACT

This study presents a critical review of the major research and development work that has advanced surface solar absorption technology and also discusses the applications of this technology in the last 15 years. In a surface solar absorption collector (SSAC), solar radiation is first absorbed on the surface of the collector and then transferred to the circulating fluid. This article reviews a wide range of studies on different SSAC systems with the aim of identifying research gaps to prepare this technology for commercial availability. Moreover, qualitative and quantitative research information on non-concentrating and concentrating SSACs was collected and evaluated in the context of a performance-based assessment, environmental issues, and sustainability concerns. The performance of these collectors mainly relies on the receiver design and thermal storage tanks with different heat transfer fluids. For high concentration collectors, there is an urgent need for new heat transfer and storage fluids to withstand elevated temperatures to minimize the flow instability. A review of the literature suggests that ongoing high quality research on this technology, especially on medium and high concentration collectors, will soon overcome the existing problems bringing this technology into temperature ranges that will make it commercially available. Finally, the scientific challenges and opportunities relevant to this technology are also discussed.

1. Introduction

Energy is the most fundamental and essential part of everyday life; all of the achievements of humankind have been sustained by the use of energy. Energy is part of the economy and the environment and affects our daily lives [1]. It is important in the development civilization and is a prominent issue in politics and diplomacy around the world. The demand for energy is increasing rapidly, which has led to the excessive use of fossil fuels in industrial sectors. It is expected that with the increasing demand, oil consumption might reach 123 million barrels per day by the year 2025 [2]. This excessive use of fossil fuels has resulted in air pollution and global warming. New and renewable energy technologies are sustainable and environment friendly and have a minimal environmental footprint compared to conventional energy technologies, although some issues regarding life cycle analysis still need to be addressed.

Among the different choices of renewable energy technologies, solar energy is of the best options because of such advantages as it is abundantly available, sustainable, and clean and can be produced on a larger scale at a comparatively lower cost than other renewable energy sources [3]. Over the past century, conventional energy sources (fossil fuels) have been used to fulfill most of our energy needs. However, due to issues with environmental pollution, solar energy has emerged as an alternative energy source for supplying clean energy to domestic and industrial sectors. Solar thermal systems that use sun radiation have gained much attention from researchers during the last three decades because of their high efficiency and ability to provide inexpensive domestic and industrial heating [4,5]. Most solar thermal systems harvest energy from available irradiance based on surface solar absorption. Surface solar absorption collectors (SSACs) can be further categorized into two sub-groups depending on the concentration of the incoming solar radiation: non-concentrating and concentrating solar collectors.

Non-concentrating solar collectors have a long history of operation in low and medium temperature range applications (e.g., 60–120 °C) [6]. These collectors are considered the core of solar energy engineering. They are considered as a non-concentrating group because the projected solar flux at the receiver surface is equal to a single-sun. This corresponds to a maximum solar intensity of 1000 W/m^2, which is

* Corresponding author.
E-mail addresses: imtiaz@kongju.ac.kr (M. Imtiaz Hussain), jtkim@kongju.ac.kr (J.-T. Kim).

https://doi.org/10.1016/j.solmat.2018.07.027
Received 9 April 2018; Received in revised form 17 July 2018; Accepted 26 July 2018

subject to strong variations due to the position of the sun according to the annual and daily movements of the earth as well as local conditions (surrounding reflection, weather conditions, etc.). Generally, these collectors have a fixed position at a specified latitude; therefore, they do not require a tracking mechanism to locate the sun's position [7]. In these devices, flat and tubular absorber surfaces are coated with a black color to collect and absorb radiation efficiently, and the solar heat is then transferred through a circulating fluid [8]. Due to their simple design, the non-concentrating systems can be mass-produced at a low manufacturing cost.

On the other hand, concentrating solar collectors possess the capability to provide energy at an elevated temperature that is much higher (above 1000 K) than that of the non-concentrating collectors [9]. They concentrate and redirect the incoming solar radiation from reflecting or refractive surfaces (aperture) into a receiver (placed at focal point or line) [10,11]. Therefore, they usually require one- or two-dimensional sun tracking systems. The energy transfer mechanism (solar radiation to heat) of the concentrating collectors is different from that of the non-concentrating collectors. They first optically concentrate the solar energy by reflection or refraction by a mirror surface or lens, instead of transforming it directly into heat. The intensity of the concentration varies from ten suns to thousands of suns depending on the geometry of the concentrator and receiver. However, non-concentrating collectors also capture part of the diffuse radiation, and because they operate at a lower temperature, heat loss is a less critical issue compared to concentrating collectors. Therefore, concentrating collectors are not as efficient in urban areas because they require a good intensity of direct solar radiation.

2. Methods

A comprehensive search of peer-reviewed journals and other relevant existing literature was performed using a wide range of keywords including surface solar absorption, solar thermal collectors, concentrating collector, non-concentrating collectors, absorber materials, types of absorbers, sustainability concerns, technology improvements, and application advancements. Various databases were searched including Elsevier, ASME Digital Collection, Wiley Online Library, Springer, Google Scholars, and Scholar Portal Journals. The reference section of each academic article was further searched to find other articles. Literature relevant and suitable to the scope of this research was managed and collected through document analysis and review techniques. Based on the concentration of the solar flux at the absorber surface, the articles were categorized as one-sun surface absorption collectors [12–21] and multi-sun surface absorption collectors. The articles relevant to the multi-sun group were further categorized into the following subgroups: (i) low-concentration [22–26], (ii) medium-concentration [27–43], and (iii) high-concentration collectors [10,44–47]. The peer-reviewed articles in the last fourteen years (2004–2017) that describe new methods and techniques were categorized as major technology developments relevant to this study [7,38,48–65]. To provide a comprehensive overview of application advancements in this technology in the context of real world challenges, several published peer-reviewed articles from 2013 to 2017 were uncovered [66–75]. This study used a mixed research technique, integrating both qualitative and quantitative research findings to better understand and identify the challenges in future work. The aim of this review article is to answer fundamental and key research questions related to the advancement of SSAC technology and its applications.

3. Surface solar absorption collectors

In these collectors, the sun's rays strike the absorber surface, which heats up, and then transfer the heat energy through the absorber to the fluid. In other words, the fraction of solar radiation received by the heat transfer fluid depends entirely on the absorber, which separates the fluid from direct contact with the sunlight shown in Fig. 1. Due to extra solar heat accumulation at the absorber surface, variation in the flow rate of the working fluid is inevitable. Therefore, proper selection of an absorber material and working fluid has an important role in the heat flow collection.

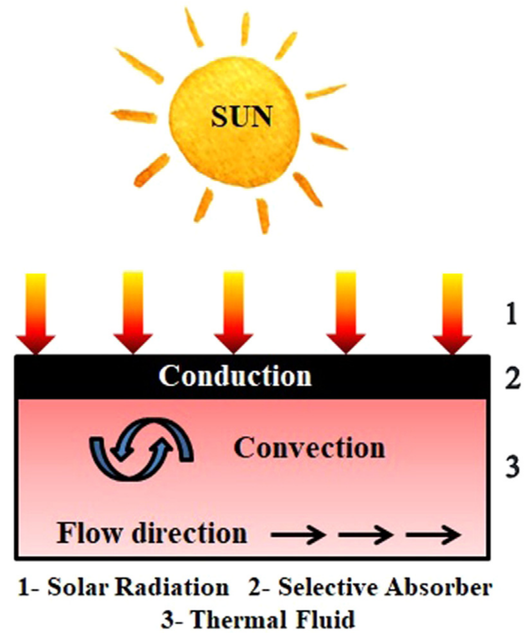

Fig. 1. Schematic of the surface solar absorption process.

The rate of the solar flux density at the absorber surface is different for non-concentrating and concentrating solar systems. In the context of surface absorption collection, the non-concentrating and concentrating solar collectors are also known as one-sun and multi-sun surface absorption collectors, respectively. The classification of various SSAC systems is shown in Fig. 2.

3.1. One-sun surface absorption collectors

The one-sun surface absorption collectors are also called non-concentrating solar collectors. Due to having a similar area for intercepting (through aperture) and absorbing solar radiation, these solar collectors have a concentration ratio of unity. Therefore, the net radiation flux remains unchanged in the photo-thermal process. The non-concentrating collectors occupy a major share of the solar energy market because of their design and simplicity. Various types of one-sun surface absorption collectors available in the market will be discussed here. These types of collectors mainly consist of flat plate and evacuated tube collectors.

3.1.1. Flat plate collector

The flat plate collector (FPC) is the most important member of the photo thermal conversion family. This type of collector is readily available in the market and widely used for low to medium temperature heating applications such as heating water for homes and indoor swimming pools. The FPCs include fixed position or stationary collectors that require no solar tracking system. Due to its fixed position, the FPC receives comparatively less energy per unit collector area, but its ability to absorb both diffuse and direct solar radiation outweighs this disadvantage. Based on the heat transfer fluid, the FPC can be divided into two categories, liquid and air types, respectively.

The assembly of a FPC is most commonly consists of a glazing, an absorber plate, a tube array, and an insulated box shown in Fig. 3. After passing through the transparent glass, the incident solar radiation is intercepted and absorbed at the selective coating on the absorber