



A review of water heating system for solar energy applications[☆]



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ARTICLE INFO

Available online 25 May 2016

Keywords:

Solar energy
Solar water heating system
Solar water heater
Renewable energy

ABSTRACT

Solar energy is one of the widely used renewable energy that can be harnessed either by directly deriving energy from sunlight or indirectly. Solar water heating system, on the other hand, is one of the applications of solar energy that has drawn great attention among researchers in this field. Solar collectors, storage tanks and heat transfer fluids are the three core components in solar water heater applications, which are reviewed in this paper. This paper discusses the latest developments and advancement of a solar water heater based on the three basic components that may affect the thermal performance of the system. It also reviews the development of various types of solar collectors in solar water heater, including both the non-concentrating collectors (flat plate collector, evacuated tube collector) and the concentrating collectors (parabolic dish reflector, parabolic trough collector). All these are studied in terms of optical optimization, heat loss reduction, heat recuperation enhancement and different sun tracking mechanisms. Among the non-concentrating and concentrating collectors, the parabolic dish reflector collectors show the best overall performance. The use of nanofluids as a heat transfer fluid was also discovered in this paper.

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[☆] Communicated by W.J. Minkowycz.

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1. Introduction

Today, fossil fuel has been primarily used to heat and power homes and fuel cars [1]. It is convenient to use coal, oil and natural gas for meeting human's energy needs [2], but the limited supply of these fuels has become the main constraint for people to persist them as the continuous sources on Earth [3,4]. In recent years, high advancement in Malaysia's economy has steered to a vividly increases in energy consumption, particularly electrical energy used in commercial and domestically building [5]. As energy plays a crucial role in the daily needs of humans [6], there are many alternative energy sources that can be used instead of fossil fuels [7,8], and one of them is renewable energy (RE) [9]. RE can be described as energy that can be generated by natural sources such as sunlight; which is a primary source of energy [10]. The major gains of RE is that no fuel is necessarily required, which eradicates the emission of carbon dioxide (CO_2); one of the factors in air pollution. Insufficient fossil fuel supplies and disproportionate gas emissions resulting from increasing fossil fuel consumption have become the worst contribution to the current global energy problem. It was recounted that the present petroleum consumption was 105 times faster than the amount nature can create [11]. Predictably, at this huge rate of consumption, the world's fossil fuel reserves will diminish by 2050 [11,12] and the global demand for energy would turn to be approximately 30 and 46 TW by 2050 and 2100, respectively [13]. Even though the fossil fuels supply more than 90% of energy demand, they indeed convey a vertical figure in environmental cost [14].

In China, the application of RE in buildings is a promising solution toward the conflict between the growing energy demand and environmental protection [15]. It could also provide a solution to the problem, as they are inexhaustible and have less adverse impacts on the environment than fossil fuels [16]. Particularly, solar energy systems are able to offer significant environmental protection such as the reduction of ecological footprints [17]. This energy cannot be exhausted and is constantly renewed. Economical, environmental friendly and safe should be the consideration in making decisions of the type of energy source for future demand. Solar energy can be harnessed either by directly or indirectly deriving energy from sunlight [18]. In reality, the most worthwhile thing about this energy is that it can be used without polluting and harming the earth.

In addition, solar energy is the most highly potential of the alternative energy sources, and universally available sources. It is an attractive concept because of the combination of solar energy and the heat pump [19], which can improve the quality of the energy available and show potential for different applications [20]. The application of solar energy includes water heating in the domestic sector, health institution and tourism sector [18,21]. One of the popular devices that harnesses solar energy which can replace the electric water heater [22] is the solar water heater and its system is called solar water heating system [23, 24]. Therefore, this paper provides a review of various solar collectors in solar water heating systems and its applications. The review consists of an introduction to solar water heater systems including the active and passive systems, basic components of solar water heating and its latest researches and advances of solar water heaters.

2. Development of solar water heating system

The history of the advantages of solar water heating system has been around for many years because it is the easiest way to use the sun to save energy and money. One of the earliest documented cases of solar energy involved pioneers moving west after the Civil War. They would place a cooking pot filled with cold water in the sun all day to have heated water in the evening. The first solar water heater that resembles the concept, and is still in use today, was a metal tank. It was painted black and placed on the roof where it was tilted toward the sun. Practically, the concept really worked but it usually took all day for the water to heat and then as soon as the sun went down, it cooled off quickly

because the tank was not insulated. The different applications of solar energy had been discovered broadly such as utilizing the water heating system [25], solar air conditioning, food drying [26], lighting and cooking [27]. Out of the total energy consumption in homes, almost 20% of water heating is consumed for an average family. This advantageous situation can happen because it is a cost-effective way to reduce energy costs from gas, electricity, or propane sources [28], and also pollution free [29], which is most beneficial to homeowners as they produce large amounts of hot water every day [30].

Subsequently, solar water heater is a device of a solar water heating system that is rightly needed in every home as it has many benefits to people, community and also the environment which functions to heat water and produce steam for domestic (i.e., for bathing, washing, and cleaning) [31] and industrial purposes using solar energy. Its system plays a vital role in collecting energy from the sun through its panels or tubes, followed by the production of hot water [14]. This system is generally installed at the terrace or where sunlight is available and heats the water during the day. Then, the hot water will be stored in an insulated storage tank and ready to be used for household utilities especially in the mornings [31,32]. Indeed, the solar water heater had effectively entered the global market commercially since the 1800s [33]. It is not only a safe, simple and reliable technology, but also reasonable in terms of costs [34]. Acceptance of the technology is usually not an issue for the user as it is a "behind-the-screen" technology [35]. Moreover, simplicity, technological feasibility, and economical and commercial viability are the strengthening factors of solar water heaters which made them popular among the RE products all over the world [36,37]. For instance, the most popular categories of hot water heaters in the China market are electric water heaters, gas water heaters, and solar water heaters [38].

In addition to the system, a collector functions to collect solar energy from sunlight whereas a storage tank stores hot water that has been produced through the system itself. In making sure that the water is always hot, the tank must be insulated well to avoid heat losses, as mentioned earlier [39]. Solar energy can be acquired when the absorber panel coated with selected coating transfers the heat to the riser pipes underneath the panel. The water will pass through the riser to be heated up and then channeled to the storage tank. The recirculation of the same water through the absorber panel in the collector raises the temperature up to 80 °C (maximum) on a good sunny day. This is recognized as a complete system of hot water using solar energy with the use of equipment such as a solar collector, a storage tank and pipelines and is known as the solar water heating system. The existing solar water heater today consists of a cylindrical glass tube that works as the receiver of solar energy and a copper coil through which the water flows, that is placed inside the glass tube and acts as the collector [40]. The technical and environmental performance of a solar water heater is examined using the method of life cycle assessment (LCA) [41,42].

Nevertheless, there is still much to do to improve the performance of solar water heaters which include improving the thermal stratification of the storage tank, enhancing the performance of the collector, boosting the heat transfer techniques (consist of collector designs, collector tilt angles, coating of pipes, fluid flow rates, thermal insulation, integrated collector storage, thermal energy storage, use of phase change materials (PCM) [43], and insertion of twisted tapes) [44], and optimizing the controller. Besides, optimizing the hot water tank structure and enhancing the immersed heat exchange performance is also considered as one of their best ways [45].

3. Solar water heating system

One of the most widely known solar thermal applications is the solar water heating system [46]. The solar water heating system uses natural solar thermal technology [47,48] which is where solar radiation is converted into heat and transmitted into a transfer medium such as water, water antifreeze or air. This system is often feasible for replacement of

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