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Recent developments in integrated collector storage (ICS) solar water heaters: A review

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ABSTRACT

Conversion of solar energy via thermal route is highly efficient, more environmental friendly and economically viable. Integrated Collector Storage Solar Water Heaters (ICSSWHs) convert the solar radiation directly into heat at an appreciable conversion rate and in many cases that happen under concentrated form. These systems are compact, aesthetically attractive and reasonable in construction. They have the potential to reduce environmental impact up to 40% and also have high collection efficiency factor. Despite many advantages, ICS solar water heaters suffer from high thermal losses in the night/overcast sky conditions. Performance of ICSSWH systems is influenced by various parameters such as reflector and absorber types, energy collection and storage arrangements and design parameters of the systems. In this article, various concentrating and non-concentrating ICSSWHs, systems with PCM (Phase Change Material) and heat retention strategies are reviewed. Recent development in the ICSSWHs indicates the potential of reliability of these systems for domestic hot water application at lower cost. The concentrating type ICSSWHs show better collection efficiency at reduced cost, but suffer high night time thermal losses. Further research is needed, especially in CPC-ICSSWHs, for minimizing night time thermal losses.

Contents

Abbreviations: SDHWs, solar domestic hot water system; CENG, compressed expanded natural graphite; PCM, phase change material; TIM, transparent insulation material; CPC, Compound parabolic concentrator; STS, single tanks storage; DTS, double tank storage; ICS, integrated collector storage; ICSSWH, integrated collector storage solar water heater; HX, heat exchanger; CFD, computational fluid dynamics; FPTU, flat plate thermos-syphonic unit

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1. Introduction

Solar energy has tremendous potential to fulfil the world's energy demand [1,2]. Increasingly use of fossil fuels for accomplishing energy need of the society has posed the sever problems of global warming and climate change. An exhaustive and efficient use of solar energy can help to reduce the intensity of the global warming and climate change. In recent past, various new and innovative technologies and systems have been developed to exploit the solar energy directly or indirectly for societal needs and to protect the environment [2–6]. However, some of these technologies have some limitations over the technologies run on conventional fossil fuels [7,8]. Conversion of solar energy via thermal route is highly efficient, more environmental friendly and economically viable compared to other routes of solar energy conversion [9–15]. Solar water heater is one of technologies that convert solar energy directly into concentrated form of heat at an appreciable conversion rate [16]. The SWH technology has many advantages such as negligible global warming potential [17], lower payback period [12], simple and easy to manufacture, and require less maintenance. The technology is suitable to provide hot water adequately for both domestic and industrial sectors [18] and also contributes in protecting the environment significantly [19]. The continuous research in the area of solar water heaters has resulted in many different new and improved systems. Generally, seven types of solar energy systems are used to supply hot water for domestic and industrial applications. Further, considering their designs and operational principles, these systems are mainly divided into following categories: (a) thermo-syphonic [20]; (b) forced circulation type solar water heaters [14]; (c) integrated collector storage (ICS) systems (single unit works as absorber and storage); (d) direct circulation systems, where water is directly circulated through the solar collector; and (e) indirect water heating systems, where a secondary fluid is required to transfer collected heat to water in the storage tank from the collector [21,22]; and (f) hybrid system, where electric heating is provided as a backup unit to ensure the continuous operation of the system [23]. The thermo-syphonic and ICS systems are called passive systems as they do not need a pump or fan for circulation of water, whereas the others are called active systems because a pump or fan is employed for fluid circulation. The thermo-syphonic flat plat and evacuated tubular collector systems can supply adequate hot water for domestic applications [24]. However, these systems suffer from many issues of high heat losses due to conduction, convection, and radiation; leakages through joints; corrosion; requirement of extra space for installation and of high additional expenses because of many components [12,25–28]. At the same time, integrated collector storage solar water heaters (ICSSWHs) are compact systems and do not require piping, separate storage tank and other components. The ICS system is also known as built in storage system or collector cum storage system; therefore, these names are interchangeably used throughout this article. Aesthetically attractive compact structure [29] and cheaper design of the ICSSWH systems make them more suitable for water heating using solar energy especially in rural areas [30]. These systems can also reduce the environmental impact up to 40% [31]. Recently, the energetic and exergetic efficiencies and energy saving potential of the ICS system were estimated around 32%, 23.5% and 65% respectively [32]. Most attractive feature of the ICSSWH systems is integrated storage and absorber in a single unit. They use the surface of the storage tank as an absorber, while in the other systems separate components are required for absorbing the intercepted solar energy and storage of the hot water [33].

Despite so many advantages, these systems could not get sufficient popularity in the society due to high heat losses during night time or overcast sky conditions [29,34]. In recent years, the ICSSWHs have received considerable attention by a few researchers and engineers. They have achieved better thermal performance with various modified designs and effective thermal losses reducing strategies. In this article, authors presented a critical review on the latest developments and improvements in the area of the ICSSWHs. Considering their heat collection and storage principles, we have categorized the ICSSWH systems broadly into three categories i.e. (a) non-concentrating ICSSWHs, concentrating ICSSWHs and ICSSWHs with phase change materials. Further, advancements and newly heat retention and thermal loss reducing strategies, for night time/overcast sky conditions, have been explored and discussed.

2. A brief history of ICS solar water heater (ICSSWH)

The first ICS SWH was demonstrated in late 18th century in the southwest of the USA. The water in the ICSSWH tank type systems was placed out at a few farms and ranches for warming. These systems reportedly produced sufficient hot water on clear days [35]. In 1891, Clarence M. Kemp patented the first commercially manufactured system named"Climax" [36] with an idea to implement it as an ICS SWH. In this system, a metal tank was placed within a wooden box. Top part of the box was covered by a glass cover. The system could heat the water in the tank up to 38.8 °C during sunny days. In 1895, Brooks and Congers, two Pasadena businessmen bought the rights from Clarence to manufacture and sell it in California [37]. Further in 1902, Walker [38] proposed to install the tank in the focal zone of a concentrating mirror. This modified system also had a standby gas fired heater.

The first commercial ICSSWH consisted of four oval shaped cylindrical vessels on a flattened surface facing the sun. The size and shape of the vessel had significant effect on the solar energy collection [39]. Furthermore, Haskell proposed replacement of tubular tanks, placed inside the hot case of commercialized ICSSWH, by a flat tank for maximizing collector area per unit volume of the tank. They fitted tank with spacer elements and fins for achieving better heat removal from the absorbing panel [39]. Later in 1936, a closed and exposed single tank was studied in detail at the Agricultural Experimental station in the University of California, US [40]. In the early 1950s, a closed pipe ICSSWH was commercialized and marketed in Japan. The concept was further improved by introducing cylindrical vessels (a combined collector and storage tank), which is still being used in many commercial designs [41]. Since then, a number of new designs of ICSWHSs have been developed and analysed by many researchers in different parts of the world [28,34,42–46]. A few designs of the