A Review of Recent Advancement in Solar Collector Systems for Water Heating

Yogesh Kumar, Manoj Verma, and Harish Kumar Ghritlahre

Abstract Among all the renewable sources of energy, sun is a valuable source of energy. Solar energy is utilized for various purposes, one of which is water heating via solar collectors in domestic and industry related areas. In contrast to other solar energy applications, solar collector systems for water heating require low maintenance and operating costs. They are broadly classified as active and passive solar water heating systems operating in either direct or indirect mode. This paper reviews the recent advancement and improvements in solar water heaters with different kinds of solar collectors, including both concentrating and non-concentrating types. Some previous works have been studied and summarized which deal with improving the efficiency of solar water heating system (SWHS) by changes in collector design with numerous enhancement techniques of heat transfer, leading to choosing the best option from among them for improving heat transfer. In addition, the research gap and the proposed potential improvements for future work have been given in brief.

Keywords Solar energy · Solar water heater · Flat plate solar collector · Thermal efficiency · Collector storage

1 Introduction

Energy is one of the reasons, for which constant research work is being performed by scientists and researchers from all over the world with the aim of saving it. With the increasing population of the world and increasing demand for energy day by day, the consumption of energy on a global scale has become a matter of concern. Natural gas, oil and coal have been found appropriate to use for fulfilling individual energy requirements but the inadequate supply of theses fuels turns out to be the

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major deficiency. There are a variety of alternative renewable energy (RE) sources which can be established with replacement of conventional ones. One of the most significant advantages of RE is no carbon dioxide emissions. Among all RE sources, the energy from the sun is one of the promising sources, as well as globally available and emission free. Solar energy's various uses have been widely discovered, including water heating, air conditioning, drying of grains, light applications and food cooking, etc. [1]. Water heating accounts for about 20% of overall energy usage in an average household. Using solar energy is inexpensive, pollution-free and minimizes power expenses from coal, electrical energy, or other sources, that is particularly beneficial to homeowners who use a lot of hot water regularly [2]. Nowadays water heating is mainly done by using conventional fuels, resulting in ecological effluence and environment alteration due to greenhouse gases (GHG) productions. If the global consumption of the conventional (fossil) fuels continues at such a rate, then earth's fossil fuel asset will be depleted by 2050, and world energy need will be nearly 30–46 TW till 2050 and 2100, correspondingly. Water heating by solar energy is one of the globally acceptable applications due to its easy working principle. The solar water heater is a common device that harnesses solar energy and can be used to replace an electric water heater. This device heats water throughout the day and is usually mounted where sunlight is available. Shielded storage tank is used for storing heated water to be made available for morning uses in homes. SWH is not only a safe, simple and reliable technology, but also reasonable in terms of costs. Water heating systems does not rely on fossil fuels and instead uses solar energy to heat stored water. As a result, it saves money, which is a significant benefit of solar heating systems. Because solar energy is free, no charges from electrical utilities are required. One downside is maintenance and corrosion however most systems do not necessitate much attention. Apart from this it also reduces the CO_2 emission footprint [3–5].

This paper examines the different solar collectors used for water heating purpose. The recent advancements are summarized in the research gaps which will help future researchers to identify relevant areas of research. The study includes an overview of solar water heating systems, both active and passive types, essential components of the system and the most recent solar water heater research and advancements.

2 Solar Water Heating System (SWHS)

When heating medium (such as water or other heat transfer fluid (HTF)) is heated directly and no heat exchanging device is involved then it is known as a direct heating system. When heating medium (hydrocarbon oil, nanofluid, etc.) is heated and transfer of heat involves an exchanging device known as heat exchanger, then it is known as an indirect type heating system. These systems are further divided in two types.

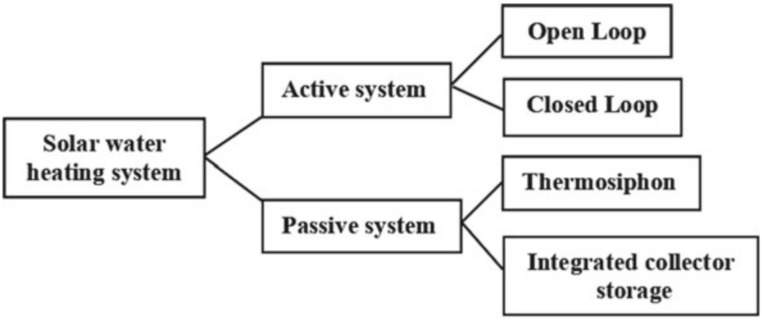

Fig. 1 Types of solar water heating system [6]

2.1 Active Systems

A pump (for circulating heating medium, like water or HTF through collectors), controlling valves and regulators are used in this system. Forced circulation system is another name of active systems. Heating medium gets heated through solar collector, storing units hold heated energy before it is required and then distribution elements distribute the heated energy through medium for end users in a regulated routine in this system. It is again classified in two ways (Fig. 1):

- ***Open-loop (Direct) Active System***
  Open-loop or direct type active system heats the water directly through a solar collector which is pumped to the tank. No heat exchanging devices are used between solar collector and storage tank.
- ***Closed-loop (Indirect) Active System***
  In close loop or indirect type active system, HTF is heated through a solar collector and pumped into the storage tank where heat exchanging devices are used between solar collector and storage tank to transport the heat from HTF to tank water.

2.2 Passive Systems

The concept of this technique is simple: natural convection circulates heating medium in the middle of the solar collector and overhead water tank. After heating of water, its density falls and the lightened water goes to the top of the collector, ready for holding in the tank. When water in the lower part of tank gets cooled, it flows back in to the collector. Thermosiphon method is the best model of passive system.

- Thermosiphon system
- Integrated collector storage.

3 Components of Solar Water Heating System (SWHS)

SWHS is mainly comprised of solar collector, heat exchanger, HTF and storage tanks (Fig. 2). Various HTF have been investigated regarding improvement of the SWHS efficiency. Significant readings on design changes are concluded in the corresponding subsections.

3.1 Flat Plate Solar Collector (FPSC)

A FPSC can be considered as the heart of SWHS and is generally employed on low solar temperature applications. It includes an absorber plate (selectively coated), a transparent glass protection to decrease heat losses from upper side of the absorber plate, HTF, insulation for minimizing heat losses and finally a defensive cover for protecting its components from moisture and dust as shown in Fig. 3.

3.2 Energy Analysis of Collector and Performance Study of SWHS

Energy gained

Useful gained energy (Q_u) from collector is given as:

$$\dot{Q_u} = \dot{m}.C_p.\Delta T = \dot{m}.C_p.(T_{Coll,out} - T_{Coll,in}) \tag{1}$$

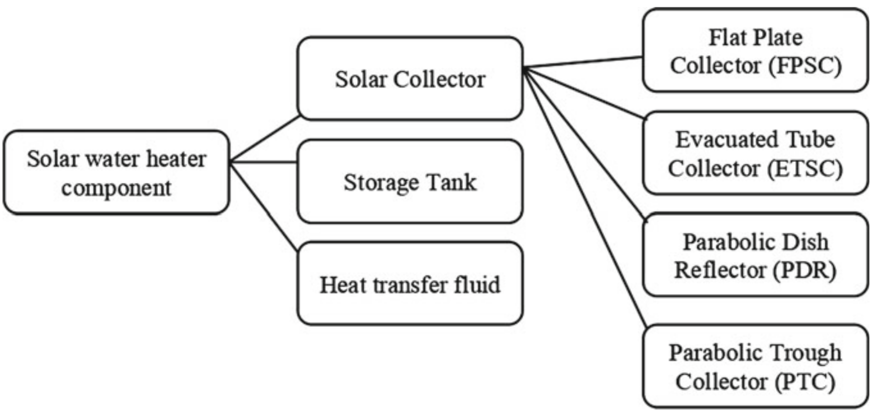

Fig. 2 Components of solar water heating system [6]

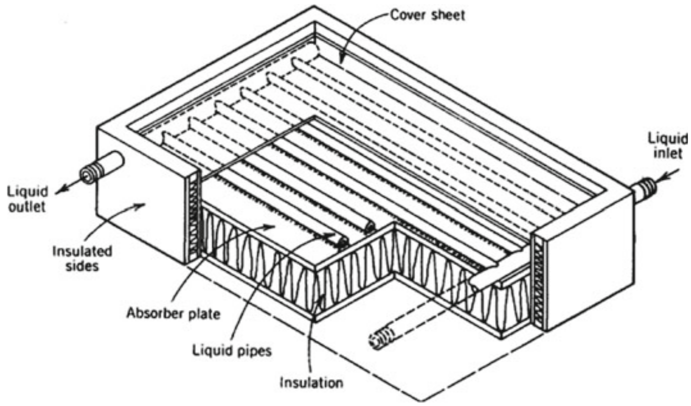

Fig. 3 A typical liquid flat plate collector system [7]

If intensity of sun radiation (G_t) is incident on collector's aperture plane area (A_C) then total radiation acknowledged by collector (Q_{in}) can be given as:

$$\dot{Q_{in}} = A_c.G_i \tag{2}$$

Collector efficiency (η_{coll})

Performance of SWH is evaluated by, its efficiency, which is calculated by the ratio between useful heat energy attained (Q_u) and heat energy in collector surface:

$$\eta_{Collector} = \frac{\dot{Q_u}}{A_c.G_i} = \frac{\dot{m}\,.C_p.(T_{Coll,out} - T_{Coll,in})}{A_c.G_i} \tag{3}$$

Collector heat removal factor (HRF) (F_R)

HRF (F_R) is defined by the following equation:

$$F_R = \frac{\text{Factual useful energy attained at collector surface}}{\text{Maximum available useful energy attained} \atop \text{(If whole collector will be at the heating medium inlet temperature)}} \tag{4}$$

$$F_R = \frac{\dot{m}\,.C_p.(T_{Coll,out} - T_{Coll,in})}{A_c\left[G_i.\tau.\alpha - U_L\left(T_{Coll,in} - T_a\right)\right]} \tag{5}$$

where:

Q_{in} Intensity of sun radiation acknowledged by solar collector W;
C_p Specific heat of HTF, kg/s;
$T_{coll,in}$ Temperature of entering water on collector (°C);

$T_{coll,out}$ Temperature of water out from collector (°C);
T_a Ambient temperature (°C);
U_L Overall heat loss coefficient of collector W/m^2;
α Absorption coefficient of plate.
τ Transmission efficiency of glazing.

4 Literature Survey of Solar Water Heating System

Yassen et al. [8] modified design of normal solar collector for household use into an incorporated kind with a ribbed receiver face. Another benefit of this change is its use as a storing reservoir as a replacement of copper tube. A larger storage tank with minimum area was obtained. Examined with different MFR, i.e., 0.0.005 kg/s, 0.0091 kg/s and 0.013 kg/s, it attained regular thermal efficiency of 59%, 65% and 67%, respectively. Author also observed losses at night and suggested proper insulation for avoiding the same.

Visa et al. [9] developed a triangle flat plate SWH with examined area 0.083 m^2 of absorber plate, provided hollow space at base side to circulate water in the middle of top side receiver and base side plate. In this design riser tube was not considered. Selective coatings were used of three individual colors black, green and orange. After examination it was found that black color coating had higher efficiency of about 55%.

Another design modification was performed by El-Assal et al. [10] using side reflector and gave suggestion about left and right attached reflectors tilt angle. The author proposed for left, during cold and summer seasons, 38° and 68° angles and for right 43° and 74.5°, respectively. Improvement in efficiency and exit temperature attained was 58% and 12 °C higher.

Shadow effect on incident solar energy was examined by Farhadi and Taki [11] and resulted in showing that tilt angle, latitude, collector length, collector height and width are the major factors which affect the incident solar energy. They concluded that reducing shadow effect increases the width of the flat plate SWH; provide length or width 70 times of its height for minimizing shadow.

Singh et al. [12] designed and experimented with changing tilt angle and flow rates. Experiment results show that efficiency increased with increasing flow rate at certain times then started decreasing and efficiency decreased with increasing wind speed. Author also stated about factors which affected the performance of solar collector such as absorber plate (it should use materials which can absorb maximum radiation), emissivity of glass cover and its number used, tilt angle and weather situation.

Isravel et al. [13] successfully performed experiment for performance enhancement of SWH with parabolic trough collector (PTC). The experimental setup contains copper (Cu) receiver tube, stainless steel (SS) reflector and structure for support. This experiment was conducted with modification on ring attached twisted tube (RATT) by improved twist ratio and center cut of aluminum twisted tapes and resulted in 24% efficiency improvement than normal twisted tape and 5% on RATT.

Weerasekera et al. [14] experimented with prototype of regularly fabricated PTC-SWH for domestic water heating applications. Experiment was conducted with two types of evacuated receiver tubes (Cu and SS) and two working fluids {diatherm (Therminol–VP 1) and water}. Experiment concluded that diatherm provided 51% greater efficiency than water, responding time of diatherm was low (maximum response rate recorded 0.18 ^{0} C/min) on temperature increase and suitable operation done with low mass flow rate.

Tabassum et al. [15] designed, developed and evaluated PTC-SWH with three different reflection materials–aluminum sheet, aluminum foil and mirror film. Experiment result shows that mirror film has potential to provide better hot water outlet compare to the other two reflectors and average recorded efficiency during experiment was 48%.

Bhakta et al. [16] conducted experiment for performance improvement of SWH using cylindrical type parabolic concentrated collector with nail twisted tube (NTT) and Cu receiver tube for NTT pitch ratios such as 4.787, 6.914 and 9.042. Experiment resulted in highest useful heat gain for twist ratio 4.787. They concluded that nail twist pitch ratio was the key factor to affect and enhance system performance.

Aramesh et al. [17] Comprehensive reviewed of recent experimental work on the development of solar cooking technology were reported and different designs and configurations of solar cookers were compared for their performance. Different solar collectors such as direct type FPSC and direct and indirect type PTSC were discussed. By investigating the performance of different design solar cookers, author concluded that using parabolic concentrating collector have the highest efficiency.

Sathe and Dhoble [18] reviewed recent developments in photovoltaic thermal techniques (PVT) and described the numerical and experimental work done by various researchers on conventional air and water-based PVT systems and typical building integrated PVT systems based on some novel technologies like PCM, heat pipe and nanofluids to understand overall development in PVT technology.

Sadhasivam et al. [19] conducted a numerical investigation where heat exchanger test set up was configured as a closed circle framework, comprising of a test section having rectangular cross-Sect. (200 cm^2) with length and width of 20 mm and 10 mm, respectively, and was produced utilizing copper sheet (1 mm thickness); and the overall length were 1000 mm, a storage tank (14 L), a pump, a detour line, a water cooler and a flow meter. Investigations were carried out using computational fluid dynamics (CFD).

5 Research Gap and Future Work

Based on the literature review, some research gaps have been identified for further research work:

- Optimization and modification of collector design shows enhancement in efficiency by reducing the heat losses and pressure drop.

- Coating is the key factors for efficiency increment. Further work can be done to find novel coating materials for improvement.
- Reflective material enhances the water heater performance, so can work with novel reflective materials for further enhancement.
- More cooling for PV panel ensures its high electrical efficiency.
- Nanofluid-based PVT system exhibited some good results.
- Use of PTSC coupled with FPSC/ETSC collector can further work for domestic hot water heating applications.
- Phase change materials can be used efficiently for thermal management of PV system.

6 Conclusion

This paper effectively reviews a variety of solar water heating collectors. It has been observed that SWHS mainly consists of absorber plates, (frequently prepared of copper, steel or aluminum), transparent glazing cover, working fluid, circulating pipe/channel, insulation, component holding frame and storage tank. Modification in collector design (collector structure, material and absorber design), various types of coating for absorber, use of polymer material, enhancing device, various PCM employment, nanofluids greatly enhance the efficiency of solar collector and solar water heater. The identified research gaps are the outcome of the paper. Future researchers will be able to find appropriate research fields based on these research gaps.

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