



Influence of heat enhancement technique on the thermal performance of solar water heater for sustainable built environment. Start-of-the-art review

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ABSTRACT

Solar water heater (SWH) is important and low-cost technology for transforming solar radiation into heat energy that is utilized for commercial and industrial purposes. However, due to different advantages, this technology still suffers from poor thermal efficiency and thermal losses from the collector. The various reasons responsible for the poor heat transfer rate of SWH are heat losses from the system and different geometrical shapes of hindrance promoters. The researcher is working on various innovative methods to ameliorate the effectiveness of solar water heating systems (SWHS) by using various heat enhancement methods. The solar thermal conversion efficiency is found to be 70% as compared to solar electrical direct conversion system, which is around 17%. The different heat enhancement techniques, like twisted tape turbulator and their shape, etc., play a very remarkable role in ameliorating the effectiveness of SWHS. This review work abridges the previous research work with different heat enhancement techniques, including the coating effect of pipes, collector design, use of PCM, and different geometrical shapes of turbulence promoters. The twisted tape provides better η as compared to other heat enhancement techniques.

Introduction

Heating water is a heat transfer process that raises its temperature from its initial state. Normally, we use the hot water for various domestic application that include cooking, bathing, cleaning and space heating. In industrial applications water is heated up to steam generation. In domestic applications water is heated in many ways such as heating of water in vessel, kettles, cauldrons, pots or coppers by using fire and electricity. There are several ways to store energy in solar water heaters Utilizing a thermal storage tank, which reserves hot water for later use, is one such technique [1]. Utilizing PCMs, which takes and releasing heat throughout the phase shift process, is an additional strategy [2]. To expand the heat storage capacity, PCMs can be added to the tank or heat exchanger. Utilizing a heat pump is an additional choice; it may draw heat from the air or ground around it and store it in the water tank. Furthermore, some solar water heaters employ electrical storage devices, such batteries, to store any extra energy generated by

the solar panels for later use [3]. The sudden increase in price often realises every human being that how to save the money from your electricity bills. The renewable energy plays a very crucial role how to use the solar energy and utilize this energy in fruitful work. The SWHS comes into work to pay more attention how your home utilizes solar radiant energy. According to the department of energy the normal boilers that we use in our home can use around 14–15% of our monthly budget. The main disadvantage of SWH includes the time consumption and dependency on weather [4]. Then the question arises that how to produce the hot water? Either by utilising the electricity, utilizing the fossil fuel or by utilizing renewable energy? Nevertheless, utilization of electricity is very costly to produce hot water and also one important point is that in some rural area's electricity is not properly available [5,6]. Similarly, using fossil fuels is not a good idea since they are harmful to the ecosystem. In that case, solar radiant vitality is a useful source that may be used to artificially heating the water by developing suitable machines called as SWH [7,8]. Numerous researchers have successfully built and deployed SWH in a variety of locations across the

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Nomenclature		STC	Solar thermal collector
A_c	Area of collector, m^2	SWHS	Solar water heating system
a	Height of turbulator. mm	SWH	Solar water heater
C_p	Specific heat at constant pressure, $J/kg^\circ C$	TES	Thermal energy storage
D	Diameter of tube, mm	<i>Greek symbols</i>	
m_w	Mass flow rate, kg/s	η	Thermal efficiency
$Q_{del.}$	Useful heat delivered, joule (J).	η_s	System efficiency
Q_{loss}	Heat loss, Watts,	G_t	global solar radiation, (W/m^2)
Q_s	Solar yield, (kWh)	η_c	Collector efficiency
Q_{qux}	Auxiliary heating requirement (W)	<i>Subscripts</i>	
Q_w	Useful heat gain. joule (J).	w	Water
R	Radius of circle, mm	sc, i	Solid fluid at Inlet
$T_{sc, i}$	Temperature of solar fluid at inlet, $^\circ C$	sc, o	Solid fluid at outlet
$T_{sc, o}$	Temperature of solar fluid at outlet, $^\circ C$	c	Collector
T_{out}	Water outlet temperature, $^\circ C$	del.	delivered
T_{in}	Water inlet temperature, $^\circ C$	loss	Heat loss
<i>Abbreviations</i>		qux	Auxiliary
LHS	Latent heat storage	out	Outlet
PCM	Phase change material	in	Inlet

world. Several countries, like India, have an abundance of solar radiant energy, with normally 300 sunny days/year and insolation ranging from 4 to 6 kWh/m² per day. In these nations the SWH is much effective appliance for water heating and space heating. Now these days there are various devices are available like SHW, solar air heater, solar cooker [9–11] that utilize the energy received from sun with the same mechanism by heating the absorber surface. The basic component of SWHS is represent in Fig. 1.

The SWHS provide a vast application in domestic and industrial field due to significant innovation in the design and various other advancement for improving the collector performance [12]. The SWHS is set the best examples of solar heat collector in the area of solar energy technology. SWHS attract the attention of lot of scientists due to low

fabrication cost, do not have any global impact on environment and also larger availability of solar radiation in free of cost. The researcher works on different technique for increasing the thermal efficiency of the SWHS [13]. The various technique that involves the improvement in the fabrication using solar collector, improvement in the inclination angle, pipe coating analysis, thermal storage system, thermal insulation etc. [14–17]. Insulation in solar collectors play a crucial part in improving the efficiency of the SWHS. By reducing heat loss inside the collector, insulation helps to keep the water inside the collector at a higher temperature. This means that less energy is required to heat the water to the required temperature, resulting in lower energy bills and a smaller environmental impact. Insulation can also help to protect the collector from damage due to extreme weather conditions, such as frost or high

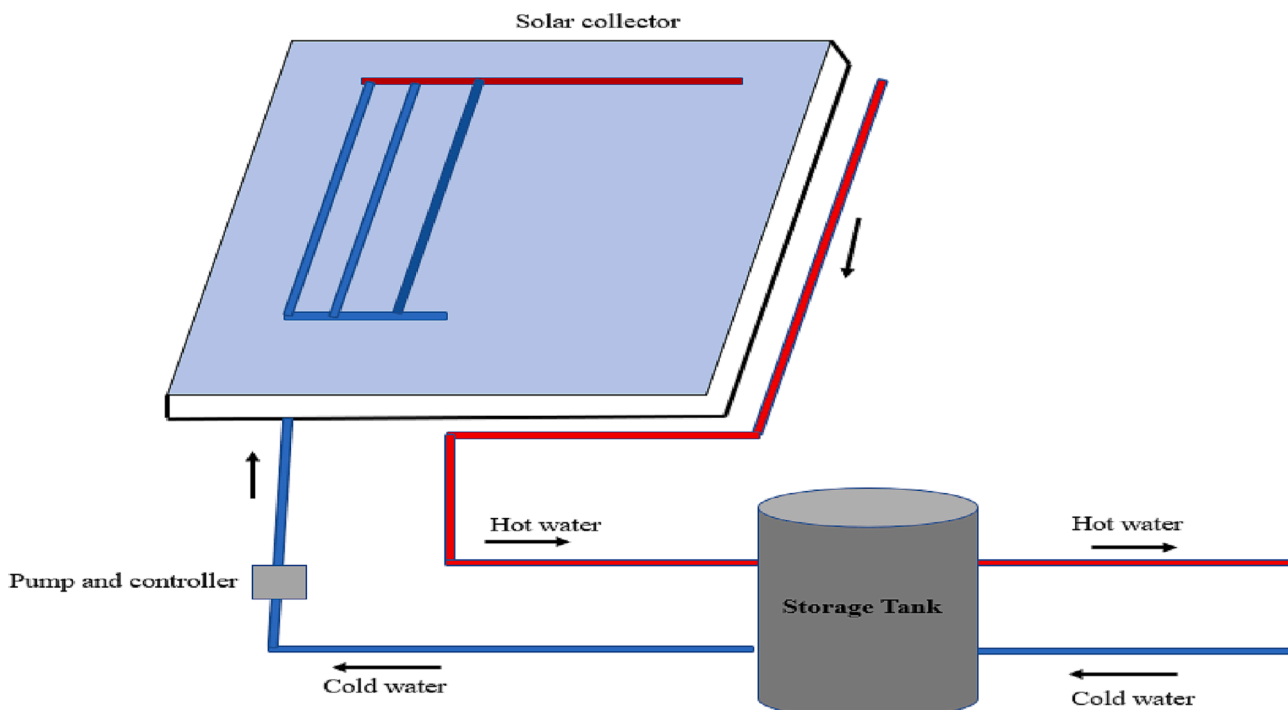


Fig. 1. Basic components of solar water heater.

winds. In this review work the author attempt to examine the different heat enhancement method used in SWHS and their advancement that boost the efficiency of the system.

Then the queries arise in the mind; what are the different types of SWH their significance and where they used? All these answers related to these queries are discussed in the below sub-section.

Classification of solar water heater

Generally, the SWH is divided into two parts i.e., active and passive system and is shown in Fig. 3. In passive technique water is circulated by using thermosyphon system, by buoyance force. This type of technique is normally used where the solar radiation is abundance, mostly in African and Asia [18]. The other methods used the external agents such as pump or fan to move the water from header to footer pipe and the technique is called as active technique [19,20]. Solar water heaters can be classified based on several factors such as the type of collector, the circulation method, and the storage system. Here are some common classifications:

1. Based on the type of collector: Flat and Evacuated tube collector.
2. Based on the circulation method: Thermosyphon and Forced circulation method.
3. Based on the storage system: Direct and Indirect system.
4. Based on the application Domestic and Industrial solar water heater.

These are some typical categories for solar water heaters, and other combinations of these categories may be used to group solar water heaters according to the requirements of their individual designs and applications (Fig. 4).

Requirement for a different heat enhancement technique in SWH

Heating of water can be done mostly in clear days. The η of the traditional SWH was documented as 30–35% [21]. There are various others factor that boost the performance of the SC are collector length, number of pipes, quality of glass materials, thermal insulation etc., may all enhance the thermal efficiency of the SHW. Besides all these techniques one of the major factors is concerned regarding the thermal dissipation for the lower and side of the collector [22]. According to the literature survey it was examined that the 35% of thermal losses from the lower surface of collector. Many researchers used the innovative ideas for lowering the heat losses from the collector.

Inspiration and aim behind this study

The literature shows that the SWH with different type of heat enhancement technique are more beneficial than the conventional system. Hence the different investigator successfully works on these techniques [23,24]. As a result, this review is being conducted to research, analyse and correlate their work.

What are the various types of heat enhancement techniques? Which technique is best for enhancing the thermal enhancement of SWH? This article addresses these questions, and the authors have made efforts to find solutions. There is numerous review work that is accessible in the literature and highlights the use of different heat accretion methods that helps to improve the performance of the SWH. However, there is no work is cited that investigated the best heat accretion technique that will give the fruitful results. As a result, future researchers will have an easier time deciding on the appropriate enhancing strategy. This is the nobility of the current work. The target of the current work is:

- a) To identify the different heat accretion technique applicable to SWH for thermal enhancement.

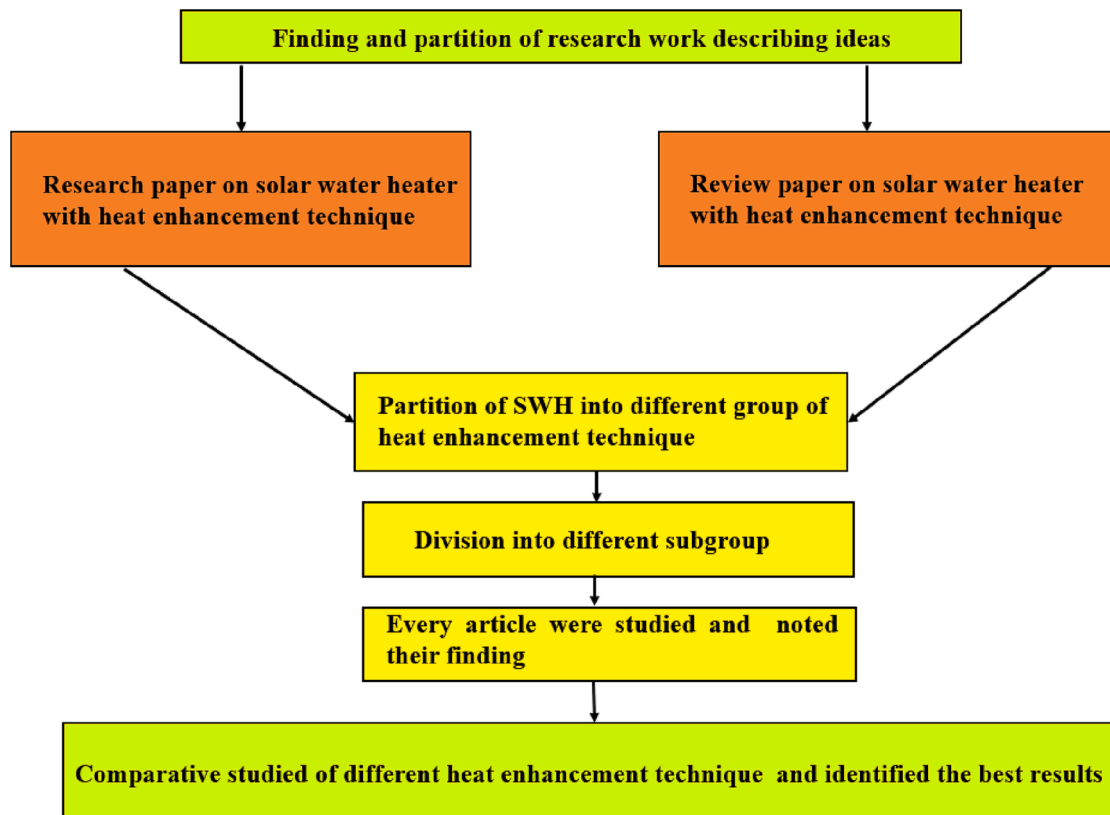


Fig. 2. Methodology used for executing review work.

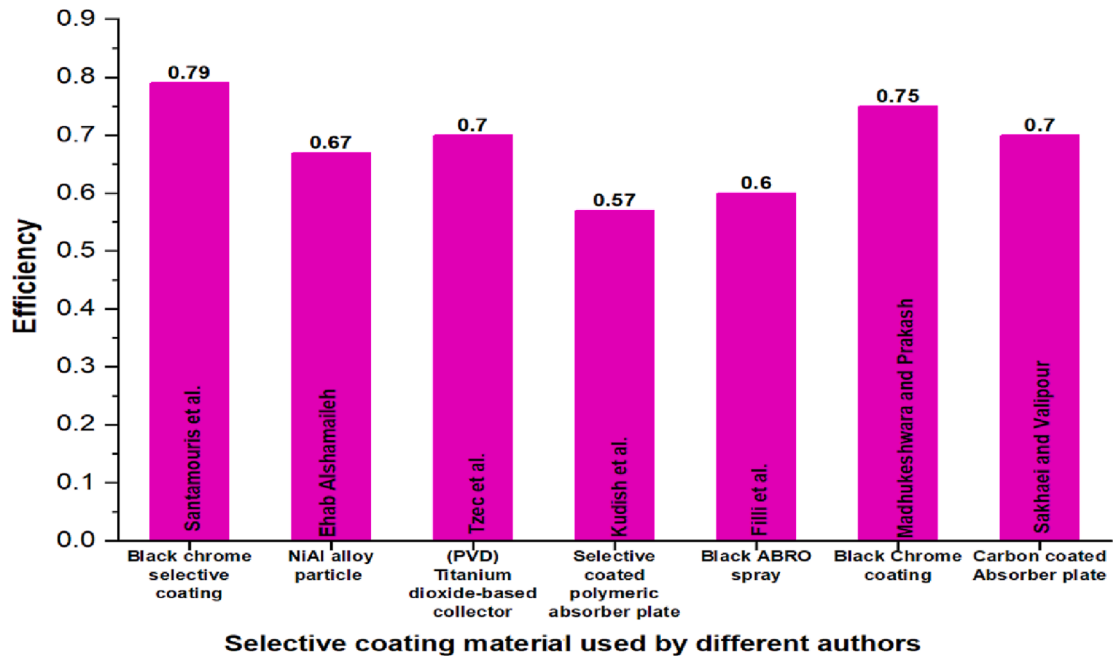


Fig. 3. Different coating material used by author for increasing the efficiency of the SWH.

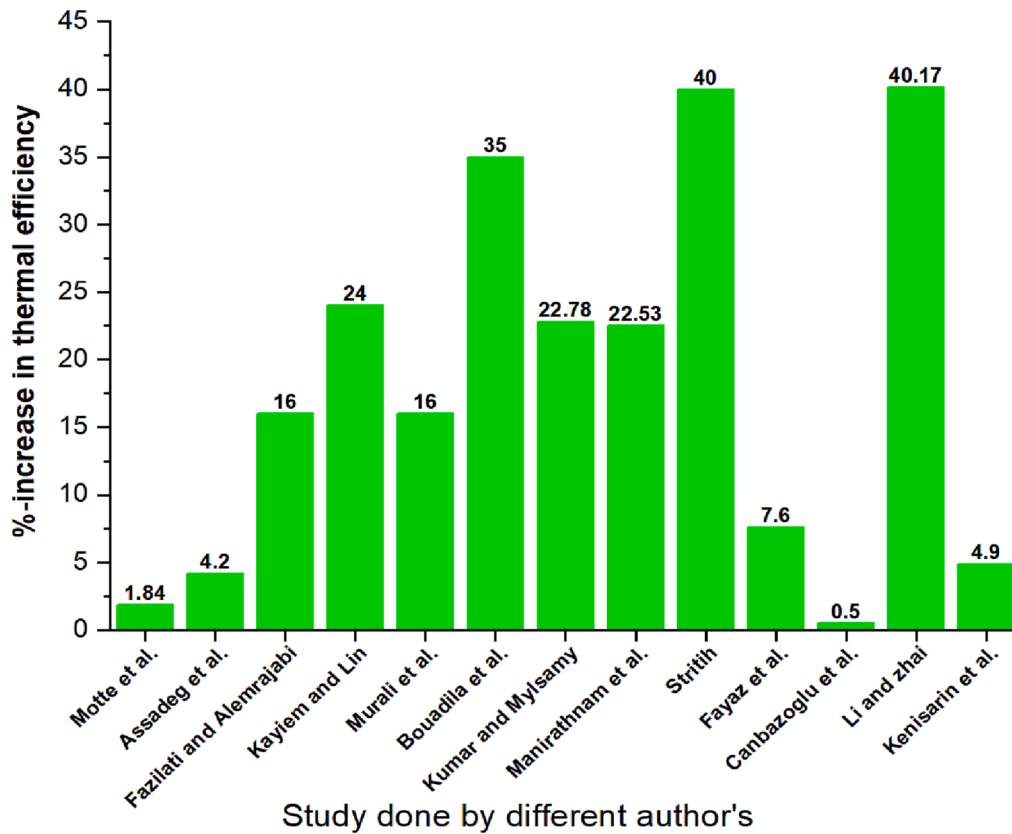


Fig. 4. Enhancement in thermal efficiency by using PCMs.

- b) Comparative study of different investigator that helps to contribute the thermal enhancement of SWH.
- c) To investigate the best heat enhancement methods for SWH.

Methodology

Various research has been published on SWH fitted with different heat enhancement methods were downloaded from the different journals from 2005 to 2022. These papers are further categories into different subgroups. Each group was future divided into various heat

accretion technique. The findings of many experimental papers were compared, and final conclusions were taken. The track utilized to do this review work is depicted in Fig. 2. The main parts of the manuscript are starts with introduction part that include the basic information of SWH, different heat enhancement technique, different heat storage medium, motivation, specific objective and novelty of this review work. After that various heat accretion technique were discussed. The article concludes with the conclusion part and their future scope of work.

Energy performance analysis

The various energy evaluation related to SWHS incorporated: Heat gain, energy in the form of heat delivered, losses induced inside the pipe, solar fraction (S.F), calculated collector and system efficiency.

The heat gain by the system is given by [25]:

$$Q_w = m_w C_p (T_{out} - T_{in}) \quad (1)$$

The energy given by the pipe and to the storage tank is given by [27]:

$$Q_{del.} = m_w C_p (T_{sc,i} - T_{sc,o}) \quad (2)$$

Losses inside the pipe is occurred due to the temperature drop between the pipe and collector output to the storage tank and is calculated is follow [27]:

$$Q_{loss} = m_w C_p (T_{sc,i} - T_{sc,i}) \quad (3)$$

The mathematical formulation of S.F is given by [25]:

$$S.F = \frac{Q_s}{Q_s + Q_{aux}} \quad (4)$$

The collector efficiency was determined as [26,27]

$$\eta_c = \frac{m_w C_p (T_{c,o} - T_{c,i})}{A_c G_t} \quad (5)$$

The mathematical formulation is determined as [27]:

$$\eta_s = \frac{m_w C_p (T_{sc,i} - T_{sc,i})}{A_c G_t} \quad (6)$$

Improvement according to the coating of the materials

In this section, we will discuss the efficiency of the SWH when different types of coatings are used in SWHS. What kind and how much enhancement in the thermal efficiency have been investigated by using different coating materials? The following section delves into the answers to these questions. Different researcher has successfully used the different coating materials in SWHS [25]. The coating used is not vaporise when it gets in contact with heat [26,27].

Santamouris et al. [28] examined the electrodeposit chrome coating that are used for the thermal enhancement of SWHS. The coating results are then evaluated by using the f-chart method. The cost analysis is also evaluated in this work and the optimum coating is decisive by using the change method. The experimental outcomes show that the total amount of energy collector is 7–12% higher than the non-coating surface.

Ehab AlShamaileh [29] used the metal lic particle of nickel-aluminium (NiAl) alloy used in the black paint for increasing the thermal absorption of SWHS. The different behaviour of the NiAl alloy coating is examined by using the UV-V is spectroscopies. The characterization of the coating chemical composition by using the XRD (X-ray diffraction) and thermo-gravimetric analysis. It was found from the experimental results that the selective coating enhances the temperature of the water by 5C throughout the year as compared to black coating.

Lizama-Tzec et al. [30] perform the experimentation by using the nickel and black paint and copper as the coating agent on collector. The experimental outcomes show that nickel and black paint coating agent shows good results as compared to the copper-oxide.

Kudish et al. [31] works on the simulation studied of the solar collector (SC) by using the selective coating in double wall SC. The author concludes from the studied that the working of the collector depends on selective coating and the fabrication parameters that include channel height of the selective coating, m_w , gap between the absorbing surface and the glazing part and glazing materials. The finding involve that performance of the collector is found in the range of 50–60% and the average temperature of fluid is exceeded in 60C.

Sakhrieh and Ghandoor [32] experimentally examine the five types of SC with different type of selective coating to analyse the enhancement in collector efficiency. The outcome shows that the evacuated tube has the optimum collector efficiency after that black and blue coated SC shows the best performance.

Barbosa et al. [33] works on the three types of materials like PVC (polyvinyl chloride) tubes, PET (Polyethylene terephthalate) bottles and long-life packaging used in the S-FPC. In the first case the absorber tubes are connect in series, the second one is connected in parallel. The heating reservoir for both of these systems are made from High-density polystyrene and is coated with Expanded polystyrene. The optimum temperature of the system reaches up to 50C. The outcomes analysis shows that the cost of this heating system are 6 times less than the conventional system.

Filli et al. [34] works on the normally available absorber and anti-reflecting coating reflecting coating materials has been testing and compare with the normal black paint used in SWH. The materials of the plate are made of aluminium/copper and the different types of coating used are blackboard, commercial and ABRO black paint. It has been found from the experimental work that the black ABRO paint is effective and the maximum range of the temperature of the water goes to 75C. Madhukeshwara and Prakash [35] experimentally examine the different type of surface coating used in the SWH. There are three type of surface coating named black chrome coating, matt black and sol chrome coating used in this experimental work. The experimental works shows that the black chrome is much effective against other coating.

From the above examination taken from the literature the surface coating is important tools for thermal enhancement and directly increase the temperature of the water. The different authors work on different surface coating materials to raise the temperature of water. The Fig. 3 show the comparative study of different researcher that works on the different type of coating materials used in SWH.

According to the PCM used in SWH

PCM helps to raise the temperature of the working fluids (water), stored heat energy during the day light and delivered it during nights. This concept is very helpful for the thermal enhancement of SWHS. Now these days there are various research work is going on for the utilization of the PCM as the heat storage technique. In this section the author provides the brief description of the PCM used by various authors in their work for the thermal enhancement of the SWHS.

Previous literature work on PCM used in SWHS

From the last some years there are numerous techniques have been examined by distinct researcher to accelerate the performance of the SWHS by utilization various enhancement techniques. There is another method for improving the performance of the SWHS by using the PCM which shows more practical in energy storage application. PCMs gather the thermal energy by converting the enthalpy of the materials during the transition of phase. PCMs has the ability to gather the heat energy without converting the temperature. There is various review on the utilization of PCMs has been done. There are basically two main reasons for the utilization of PCM in SWHS: the first reason shows that during sunset and short cloudy times PCMs release the heat that is stored during the day time and the second reason is to lower the thermal losses that can occur due to higher temperature of fluids. The various researcher

finds the low thermal conductivity as the limitation for the overall η of system by using PCM.

Aggarwal et al. [36] works on developing the HT by using the PCM and reflector in ETC with nanofluids used as the working fluids. Motte et al. [37] investigate the influence of the PCM used in the integrated SC. Assadeg et al. [38] investigate the energy and exergy examine of SWHS by using the PCM. The range of the m_w varies from 0.01 kg/s to 0.15 kg/s. Das et al. study the novel PCM based composed materials for using the TES application. The characteristic and the properties of the energy materials are evaluated by using the various experimental and analytical analyses. The mixing of the PCM and biochar found to be 6.4% by wt. The outcome shows that the thermal conductivity is increased by 17.27% higher by using the PCM. Das et al. [39] study the novel PCM based composed materials for using the TES application. The characteristic and the properties of the energy materials are evaluated by using the various experimental and analytical analyses. The outcome shows that the thermal conductivity is increased by 17.27% higher by using the PCM. Fazilati and Alemrajabi [40] examine the influence of PCM for ameliorate the heat transfer. Wu et al. [41] works on the overall effectiveness of SWH with/without PCM. Depending on the strength of solar radiation in different seasons and climate circumstances, several working modes can be selected. In this investigation, a test rig has also been constructed to measure performance of the systems. The system with PCM is shown to have significantly superior performance under similar operating conditions.

Chaabane et al. [42] studied the integration of collector storage SWHS under the influence of PCM. In this experimental work, two numerical models are constructed.

Kayien and Lin [43] evaluated the overall performance of SWH under the impact of PCM. The result shows that utilising TES with paraffin wax improves the system significantly; however, using nanocomposite does not improve the system significantly. Murali et al. [44] studies the influenced of PCM in incorporated thermosyphon SWHS. Bouadila et al. [45] numerically examine the enhancement of LHS for SWH by using the PCM. Kumar and Mysamy [46] experimentally examine the impact of PCM on SWHS. Paraffin wax and nanocomposite of 1.0% for SiO₂ used as a PCM for the experimentation. The result reveals that the efficiency is increased by 75%. Saw et al. [47] examine the overall effectiveness of integrated SC under the effect of PCM. The current study used PCM and nano-enhanced PCM to conduct an outside experimental assessment of a S-FPC. PCM, solar, nano-enhanced PCM, Computational fluid dynamics, integrated, nanoparticles are some of the terms used in this paper.

Classification of PCMs

On account of phase change state, the PCMs are classified into three main division: S-S, S-Land L-G PCMs. Based on these three categories the solid to liquid PCMs are most important for TES. The solid to liquid are grouped into three-part organic, inorganic and eutectics PCMs.

Paraffin based PCM combined with STES to increase the performance of the system. Alternatively, it can be coupled with the SWHS by providing the continuous heat supply to the collector. In this approach, the PCM get charged with the heat generation and supply to the heat transfer fluid. Table 1 show the utilization of different PCM at particular application.

The current study will be a valuable reference point and source of knowledge for future research on SWHS with LHS.

Classification on the basis of type of storage

On the basis of energy storage, SWHS can be classified into two main parts SHS type of SWHS and LHS type of SWHS.

Sensible heat storage type of SWHS

The energy stored is depend on the variation in temperature of the

Table 1

The utilization of different PCM at particular application.

S. No.	PCM type	Temperature range of PCM	Type of system	Operation	Ref.
1	RT65	56-65C	S-FPC	SWHS	[48]
2	Paraffin	57-59C	S-FPC	SWHS	[43]
3	Paraffin	63C	S-FPC	SWHS	[49]
4	Trtriacontane	71C	S-ETC	SWHS	[50]
5	Paraffin	57-61C	S-ETC	SWHS	[51]
6	Paraffin	61C	TES-HTF	SWHS	[52]
7	Paraffin	61C	TES-HTF	SWHS	[53]
8	Paraffin	61 ± 2 °C	TES-HTF	SWHS	[54]
9	Paraffin	54–61 °C	TES-HTF	SWHS	[55]

materials and proportional to the product of heat and temperature variation. The amount of stored energy depends on temperature change, specific heat and quantity of materials stored.

$$Q_w = m_w C_p (T_{out} - T_{in}) \tag{7}$$

Sensible heat type of SWH used water as the heat changing medium. The best example of this type of system are S-FPC.

The world first SWH was patent by M. Kemp in 1891 [56]. This system contains the wooden box covered with glass and also consist of metal tank. This system can produce the hot water by 39C. Now still this concept is used today by many researchers in the form of Integrated type of SWH. The advanced version of SWH is construct by Bailey in 1990 [57]. In this system two separate component was made: a STC and storage water tank. Bailey's was the first whose system use the insulated storage tank and works on the principle of thermo-syphon system.

Japan first commercial SWHS was fabricated by Yamamoto in 1947 [58]. He gets an inspiration by analysing the large water bath tub covered by glass sheet and is exposed to sun for the whole day when he visiting the rural area. After that in 1950s modern closed pipe system was introduce in Japan.

Latent heat storage type of SWHS

LHS systems maintain a consistent temperature by changing the phase of the substance. This storage type has a higher storage capacity compared to sensible heat storage systems. PCM are a prime example of LHS, where thermal energy can be transferred between solid and liquid states. They can store the thermal energy from 5 to 15 times per unit volume much greater than SHS. The heat storage ability of the LHS with combination of PCM is given by equation below:

$$Q = mL \int_i^m C_{p,s} \Delta T + \int_m^f n$$

Two hot water systems are in place to provide continuous hot water supply. The first system uses a tank-in-tank storage configuration, while the second employs an integrated storage system that operates 24/7. Table 2 shows the different thermal properties of the organic materials that are found from the literature survey. In the table below there are some aberrations that are denoted as T_f that is aberrated for fusion temperature, H_{fusion} for latent heat of fusion, C_{psol} and C_{pliq} for heat capacities for solid and liquid, K_{sol} and K_{liq} for thermal conductivity for solid and liquid.

Enhancement of SWHS by using the different turbulence promoter shapes

Thermal accretion in a single phase for the low Re is a serious subject of research over the last few years. There are various operation involving the heat exchanger, biomedical devices, SWH, etc. Many approaches depend on the active and passive technique that has found dependency on these application for increasing the heating effect. Among the various

Table 2
Thermal properties of the organic materials.

Material	T_f	H_{fusion}	$C_{psol.}$	$C_{pliq.}$	$k_{sol.}$	$K_{liq.}$	References
GR25	23–24	45.4	1.3	–	–	–	[59]
PEG600	22	127.3	–	2.5	–	0.190	[60]
n-octadecane	26	243.6	1.93	2.19	0.35	0.14	[61]
n-eicosane	36	242	2.0	2.03	0.16	0.16	[61]
P116	47	225	2.5	1.9	0.25	0.25	[61]
Butyl-stearate	19	140	–	–	–	–	[62]
ERMEST2325	18–20	138	–	–	–	–	[63]
RT27	27–28	180	1.8	2.5	0.2	0.2	[64]
MICRONAL26	26	110	–	–	–	–	[65]
RT20	22	172	–	–	–	–	[66]
GR41	42	62	–	–	0.16	0.16	[67]
MPCM28-D	28	190	–	–	–	–	[68]
Non-eutectic capric-lauric	19.2	148	–	–	–	–	[69]

method on can find the system that involves the swirls generation by providing the turbulence promoter. Turbulence promoter provide mixing of fluids and destruct the development of boundary layers formation which can leads the effectiveness of heat transfer rate. Due to limited number of resources, it is very important to find the alternative that can utilize the energy in different forms throughout the worldwide for the progress of economic and industrialization (Table 3).

The population growth can increase the usage of energy and the resource on the earth are get exhaustible. Other side, depletion of fossil fuel is a major threat to life on earth. On account of many alternatives, solar energy has provided the great attention for meeting the continuously increasing energy demand on earth. The easiest method for the usage of solar energy for heating application to convert it into the thermal application by using the SC. SWH is flat plate collector that are generally used for heating the water. SWH is considered to be the most compact water heating system. The fabrication of SWH is cheaper and is simpler to use. The SWHS are found its application in Homes, Hospital, Restaurants, Swimming pools, Industries etc. In order to make the SWHS more effective, performance of the system needs to improve by using the different heat enhancement technique (Table 4).

For the better performance of the HT rate different types of turbulence promoter are place repeatedly on the HT rate that hindered the boundary layers formation. Inserting turbulence promoter can significantly disturbs the m_w . In general, by increasing the HT rate that can accompanied with increase in f . In this work an attempt performed by the author to provide the useful information related to SWHS with turbulence promoter and provide information regarding shape of obstacle for providing maximum heat and minimum heat losses.

Conventional solar water heater

It's decisive to examine the η of the SWHS by construct an efficient system. Thermal performance related to the HT rate in the collector and hydraulic performance is related to the pressure drop in the pipe. A details description of conventional SWHS are described by Soteris A.

Table 3
Inorganic PCMs in the literature.

Material	T_f	H_{fusion}	$C_{psol.}$	$C_{pliq.}$	$k_{sol.}$	$K_{liq.}$	References
Eutectic salt	33	217	–	–	–	–	[70]
SP-25-A8	26	180	2.5	–	0.6	0.6	[71]
Calcium chloride hexahydrate	27–29	175	2.4	1.4	1	1	[72]
Sodium thiosulfate pentahydrate	42–48	210	1.46	2.4	–	–	[73]
U1	30–32	131	–	–	–	–	[74]
U2	27	188	1.4	1.4	1.09	0.54	[75]
CaCl ₂ ·6H ₂ O	29	191	–	–	–	–	[76]

Table 4
Previous work based on PCM.

S. No.	References	PCM Type	Melting point temperature (C)	Thermal Efficiency
1.	[37]	Myristic acid 51	51 °C	The thermal efficiency is increased by 1.84% for SF, 2.71% for SF + and 6.10% for SF++.
2.	[38]	Silicon carbide	30- 40C	The thermal efficiency is increased by 2.5 to 4.2%.
3.	[40]	Commercial grade	55 °C	The thermal efficiency was improved by 16%.
4.	[42]	Myristic acid and RT42 graphite	12 °C	
5.	[43]	20-nm copper powder	60.5 °C	The thermal efficiency increased by 24%
6.	[44]	Paraffin wax grade 56	56 °C	The thermal efficiency improved by 10–16%
7.	[45]	Paraffin in integrated cavities	56.3 °C	The thermal performance increased by 25–35%
8.	[46]	Si O ₂	37°-39.6 °C	The thermal efficiency was increased by 22.78%
9.	[77]	Sci and cuo	53°-56 °C	Thermal efficiency increased by 22.53%
10.	[78]	Palmitic acid	0.1,0.2 and 0.3 wt%	
11.	[79]	paraffin	30 °C	Thermal efficiency improved by 40%
12.	[80]	Sodium thiusulfate pentahydrate	45 °C	Thermal efficiency increased by 0.5 %
13.	[81]	Graphite and Erythritol	50 °C	Thermal efficiency increased by 40.17%
14.	[82]	Graphite ad plmatic acid	53–57 °C	Thermal efficiency is improved by 3.79–4.9%

Kalogirou [83].

Solar collector

A solar collector is kind a HE that converts the I_{rs} into useful work

done by using the circulating medium or fluids. Basically, the SC is classified into three main categories. In the first category photovoltaic collector that use the semiconductor materials and convert the solar radiation into electricity. The second category comprise PVT collector integrated with thermal that convert the solar energy into electric and thermal energy. The third category involves the STC that convert the solar energy into heat energy by using different fluids. The Table 5 below shows the recent studies on SWHS with different types of heating system (Table 6).

Design factor

This is very important parameter for the thermal enhancement of the S-FPC. The design factor includes number and diameter of tubes, collector length and width, extended surface and fins, insulation thickness and variation of mass flow rate are the major factor that are responsible for the thermal enhancement of S-FPC [99]. Fins, or extended surfaces, are frequently employed in solar collectors to improve heat transmission [99]. Fins are often constructed of copper or aluminium and are thin, elongated structures that are affixed to the surface of the solar collector. The collector's surface area is increased by the inclusion of fins, enabling more effective heat transmission from the absorber plate to the surrounding fluid [100]. The performance of the system's total heat transmission is enhanced by fins because they raise the h_c . Extended surfaces in solar collectors have the potential to considerably increase their efficiency and decrease the quantity of material required for the collector, making them a viable and sustainable option for the production of solar thermal energy [101].

Variation in the shape and design of the collector have been examined by many researchers from the past many decades. In this article the author attempts to examine the recent development in the SWHS. Yao et al. [102] works on the performance of evacuated tube SWH with twisted tape inserted inside the tube. The geometrical parameter includes the twist ratio (TR) varies from 2.5 to 4. The experimental outcomes shows that the higher heat transfer (HT) rate is found at TR of 4. Jaisankar et al. [103] works on the forced circulation SWHS by using the helical twisted tape. The Reynolds number varies from 3000 to 23,000 and TR varies from 3 to 6. The experimental outcomes found that the HT by using the twisted tape is better as compare to plain tube collector. The efficiency of the collector is found to be optimum at helix 3. Bhattacharyya et al. [104] works on the different design of entrance angle of twisted tape in SWHS. The examination has been examined for different entrance angle = 180-140, TR of 18-30 with Reynolds number variation of 100-20,000. The results show that the optimum enhancement is found at entrance angle of 180with TR of 18. Feizabadi et al. [105] examine the η of the twisted tape inserted inside the U-tube. Two type of twist tape having TR of 2 and 6 are consider for experimental

examination. The outcome shows that the TR of 2 shows the better performance during experimental examination. Jaisankar et al. [106] experimentally examine the η of the left-right twisted tape fitted in SWHS. The various geometrical parameter includes Reynolds number from 3000 to 23,000 and TR varies from 3, 4, 5 and 6. During experimental results it was conclude that the optimum HT augmentation is found for TR 3 (Table 7).

Twisted tape

The motive of insertion of this twisted tape to produce the swirl generation and secondary flow. The influence of twisted tape on improvement in efficiency of SWHS are studied by Jaisankar et al. [103]. The author performs the experiment by consider the parameter left-right 3, helix 3. During the experimental work the author conclude that during the examination the left-right and helical twisted tape are operating at the same TR of 3, maximum HT and thermal augmentation are attained at left-right TR of 3. The maximum HT and friction factor with left-right TR of 3 are 375% and 142% optimum than the plain tube. Ananth and jaisankar [113] experimentally examined the η of SWH by using the twisted tape with rod and spacer. The experiment was performed with full length TT with TR of 3 with rod length of 125, 250 and 500 mm have been examined. The outcome shows that the optimum thermal efficiency is found to be 1.15. Puthilibai et al. [114] examined the impact of the TT turbulator in SWHS. The authors used aluminium twisted tape used in the water heating system. The maximum temperature attains by using the TT is 75C at 3.30 pm. Eiamsa-ard [115] examine the influence of peripherally-cut twisted tape in water heating system for the thermal augmentation along the pipe. There are different peripherally-cut twisted tape with constant TR of 3.0 with three tape depth ratios of 0.11, 0.22 and 0.33. The maximum thermal enhancement is found to be 1.29 peripherally-cut tape at the depth ratio, DR = 0.33 and WR = 0.11. Jaramillo et al. [116] experimentally analysis the thermal enhancement of SC by using the twisted tape turbulator. The value of the TR varies from varies from 1 to 5. The optimum thermal efficiency is found at TR of 1. The heat enhancement and friction during the experimental work are examined by Kumar and Parsad [117] by inserting the twisted tape inside the absorber pipe. The experiment was performed at various TR of 3-12. The outcomes results shows that the maximum enhancement is found to be 18-70% by using the twisted tape. Saravanan et al. performed the experiment by using the V-cut twisted tape in thermosyphon SWH. The geometrical parameter is considered include the TR of 3,4 and 5. The experimental outcomes show that at lower value of TR of 3, the thermal augmentation is maximum. Jaisankar et al. [118] experimentally studied the thermal performance of the HT and friction factor characteristics of thermosyphon SWH. The authors used the twisted tape turbulator as a heat

Table 5
Recent studies on SWHS with different types of heating system.

System	Reference	Simulation work	Experimental work	Type of collector	Working fluids	Thermal efficiency/ CP.
Direct circulation system	[84]	✓	✓	ETC's	water	-
	[85]	✓	×	ETC's	water	$\eta = 34\%$
Indirect circulation system	[86]	✓	✓	V-trough reflector	water	$\eta = 74\%$
	[87]	✓	✓	FPC with tubes	R-12	CP = 2.4-4.0
	[88]	✓	✓	Evaporator collector	Air	CP = 6.0, $\eta = 0.78\%$
	[89]	✓	✓	Tube-in-sheet type	R-134a	CP = 1.7-2.5
	[90]	✓	✓	FPC	R-22	CP = 3-6, $\eta = 0.3-0.5\%$
ICS system	[91]	✓	✓	FPC storage	water	$\eta = 49\%$
	[92]	×	✓	Storage In-built	water	$\eta = 26-34\%$
	[93]	✓	✓	CPC	water	$\eta = 64\%$
	[94]	yes	✓	CPC	water	$\eta = 63\%$
Thermosyphon system	[95]	×	✓	FPC	R-134a	$\eta = 48\%$
	[96]	×	✓	FPC	water	$\eta = 54\%$
	[97]	×	✓	Evacuated pipe	water	$\eta = 60\%$
	[98]	yes	✓	Evacuated pipe	water	$\eta = 45\%$

Table 6

Observation of principle examination of passive methods in laminar and turbulent flow.

References	Fluid	Name of heat enhancer device	Parametric range	Remarks
[107]	water	Louvered strip	$6000 < Re < 42,000$	The Louvered strip are used as a heat enhancing device in, HE. The enhancement in Nu and friction losses for inclined Louvered strip 284% and 413%. The overall enhancement ratio is found to be 9–24% by using Louvered strip.
[108]	water	helical ribs	$15,000 < Re < 60,000$	Helical ribs working as a heat transfer device in horizontal tubes. The outcomes show that the optimum η was 2.20 with helical rib depth of 1.50 mm
[109]	Water	Discrete ribs	$15,000 < Re < 60,000$	Discrete double inclined ribs tube used as a turbulence promoter. The heat enhancement is found to be 100–120% by using discrete ribs.
[110]	Water	Twisted tape	TR = 5 and 7, $2000 < Re < 12,000$	Twisted tape are used to examine the HT and fluid flow characteristics. The author used twist ratio of 5.0 and 7.0 for experimental examination. The results show that the optimum enhancement of 188% is found by using twist ratio of 5.0.
[111]	Water	Clock wise and anti-clock wise Twisted tape.	$830 < Re < 1990$, TR = 3,4 and 5	The author used clock and anti-clock wise twisted tape as a HT device. The experimentation was done on three different twist ratios of 3,4 and 5. The outcomes show that the smallest TR of 3 is most efficient among others.
[112]	water	Oblique delta-winglet twisted tape	$3000 < Re < 27,000$, TR = 5 and 7, Depth of wing cut ratios = 0.11, 0.21 and 0.32)	The author performed study on oblique and delta-winglet twisted tape for ameliorate the thermal performance of system. The experiment outcomes show that the Oblique delta twisted tape enhance the system 1.05–1.13 times higher than the delta winglet.

Table 7

Some important discussion related to twisted tape turbulator used in solar water heater.

Author's	Geometry	Operating parameters	Conclusion
Jaisankar et al.	Helical and left–right twisted tape	Left-right twist 3 and Helix 3	Maximum HT rate attains at 375% with left–right twist 3
Anand and jaisankar	Twisted tape with rod	Full length twist, twist with rod and spacing length of 125, 250 and 500 mm	Maximum heat augmentation attain for full spacer is 2.48.
Puthilibai et al.	Aluminium twisted tape	The coiled aluminium strips with a height of 1500 mm, a breadth of 12 mm, and a TR of 2.5	The maximum outlet water temperature was raised to 71C by using twisted tape
Eiamsa-ard et al.	Peripherally-cut twisted tape	Constant TR of 3, Tape depth ratio of 0.11, 0.22 and 0.33, tape width ratio of 0.11, 0.22 and 0.33.	The overall efficiency of 1.29 is found for depth ratio of 0.33 and width ratio of 0.11.
Jaramillo et al.	Twisted tape.	TR = 1, 2, 3 and 4	The maximum thermal efficiency is found to be 0.65 for TR of 1.
Kumar and parsad	Twisted tape.	TR of 3,6,10 and 12.	The maximum thermal efficiency is found to be 70% for TR of 3.
Jaisankar et al.	Spacer and trailing edge of twisted tape.	TR of 3 and 5.	The HT rate is higher for TR of 3
Saravanan et al.	Square and V-cut twisted tape.	TR of 3,4 and 5	The TR of 3 gives the higher thermal efficiency and the maximum instantaneous efficiency is found to be 85%.

enhancer with different geometrical configuration with pitch ratio of 3 and 5 with varying spacer length of 100 mm, 200 mm and 300 mm. The maximum HT is found for lower twists' ratio of 3 with fill spacer length. Saravanan et al. [119] works on Square and V-cut twisted tape in SWHS.

There are different types of turbulator are used by different author for enhancing the performance of the system. The different turbulator shapes such as Conical turbulator [120], Wire coil-turbulator [121], Helical-screw tape [122], Circular ring turbulator [123], Helical-ribbed tube with double twisted tape [124], Vortex generators with propeller-type geometry [125], Helical-screw tape [126], Helical screw tape coupled with rib turbulators [127], Twisted tape turbulator [104,128], Delta-type hindrance promoter [9], Finned rod turbulator [129], Perforated tape [130], Rectangular cut tape [131] and Longitudinal vortex generator [132] are used between the year 2000–2023. Fig. 5 shows the comparative study on thermal performance of different SWHS loaded with heat enhancement materials.

Review work comparisons, trends, and a summarized report

Conclusion

Extensive research has been conducted on the performance of solar water heating systems, with the aim of improving existing technologies and creating new ones. The available literature provides a comprehensive evaluation of the developments in these fields. The following are the key findings from this research.

1. Previous studies have focused primarily on the effect of the hindrance promoter on system performance, neglecting other critical factors such as coating, insulation, and PCM impact. This study aims

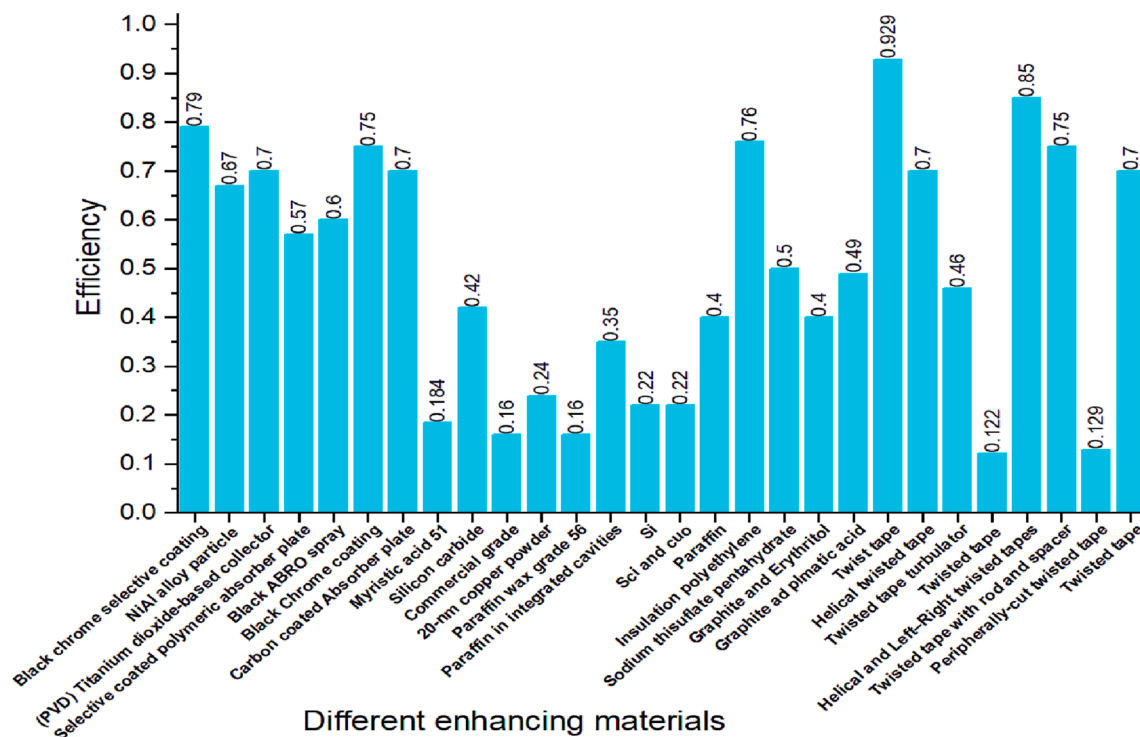


Fig. 5. Comparative study on thermal performance of different SWHS loaded with heat enhancement materials.

to account for these additional factors in evaluating system performance.

- Thermal energy storage systems could potentially replace current SWHS by providing a simpler and more affordable solution. Of the available options, latent heat thermal energy systems are a practical choice for storing solar heat energy and have exhibited promising commercial viability. However, more research is required to explore this field further.
- Twisted tape has been shown to improve heat transfer in solar collectors more effectively than conventional plain tube collectors. It is commonly utilized as a passive technique for boosting heat transfer in solar water heating systems, although its use is somewhat limited in this field. Twisted tape has also been utilized in heat exchangers for various purposes.

CRedit authorship contribution statement

Rohit Khargotra: Methodology, Formal analysis, Conceptualization, Writing – original draft. **Tabish Alam:** Writing – review & editing. **Kyaw Thu:** Writing – review & editing. **Kovács András:** Writing – review & editing. **Tauseef Uddin Siddiqui:** Writing – review & editing. **Tej Singh:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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