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Paper

PAPER

AN EXPERIMENTAL STUDY OF A FLAT SOLAR WATER HEATING COLLECTOR FEATURING A REFLECTOR AND TWISTED CHANNELS

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Abstract

In this article, the authors present a pilot industrial version of a flat solar water heating collector. This collector is equipped with reflectors and twisted channel absorber tubes, and is integrated with paraffin as a phase change material (PCM). The authors also conducted an experimental study of the collector's energy efficiency. These studies took place in July and August 2025 at the "Alternative Energy Sources" training and scientific polygon of Karshi State Technical University, in conditions representative of the region's natural meteorological and climatic conditions. During these studies, changes in solar radiation, outdoor air temperature and water temperature at the collector outlet were measured, and the results were analysed. Data on solar radiation was recorded using the NASA POWER and GIDROMET databases, as well as measuring and control devices installed during the research. The results showed a consistent increase in water temperature with increasing solar radiation, which accelerated heat exchange processes significantly due to the reflectors and twisted channel tubes. Notably, despite the decrease in solar radiation after 16:00, the water temperature remained high for a period, indicating the release of heat accumulated by the paraffin-based FCM during the day.

Key words: flat solar water heating collector, solar energy, hot water, PCM, energy efficiency.

Introduction

When assessing the energy efficiency of a flat solar water heating collector (SWHC) with a reflector and a twisted channel, one of the main determining factors is the time-varying nature of solar radiation. The intensity of solar radiation directly affects the heat flux that falls on the absorber surface of

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the collector and significantly impacts the heat exchange processes that occur in the system, the degree to which the working fluid is heated, and the overall useful work coefficient. Therefore, to reliably assess the energy efficiency of an SWHC in real operating conditions, meteorological factors must be taken into account, particularly daily and seasonal fluctuations in solar radiation [1-3].

In practical conditions, the amount of solar radiation does not remain constant throughout the day. It is constantly changing due to factors such as atmospheric transparency, cloudiness, air temperature, humidity and the height of the sun above the horizon. These changes result in an uneven distribution of the energy flux incident on the collector surface, which directly affects the system's thermal efficiency and stable operation. For flat-plate collectors with reflector and twisted channel designs in particular, taking real-time incident radiation values into account enables the energy advantages of their design to be correctly assessed [4].

Methods and Materials

In this research, the energy efficiency of the solar collector was analysed based on real meteorological observations. During the experiments conducted in 2024–2025 at the "Alternative Energy Sources" educational and scientific polygon of the Karshi State Technical University (65.809266°E, 38.835851°N), the values of changes in solar radiation over time were recorded regularly. Figure 3.4 shows the daily dynamics of solar radiation, based on the experimental data obtained, and this was used as an input parameter when assessing the heat generation capacity and useful work coefficient of the solar collector [5-6].

Taking into account the laws of change in the intensity of solar radiation recorded in real conditions enabled the energy efficiency of the reflector and twisted channel flat-plate collector to be assessed more accurately, and its optimal operating modes to be justified.

The experimental research process was carried out on 17 August and 19 November 2025, and 10 May and 15 July 2025. These dates represent the characteristics of solar radiation in different seasons. Experiments were conducted in field conditions on these dates, and the results were obtained.

As can be seen, 14 May 2025 coincides with the spring season. There is a sharp increase in solar radiation, starting at 11:00, which reaches a maximum value (1100 W/m^2) between 13:00 and 14:00. This period ensures the efficient operation of the SC using PCM. 15 July 2025 corresponds to the summer period. Solar radiation exceeds 1200 W/m^2 and remains stable between 13:00 and 15:00. This is the day of the year when the highest solar radiation is recorded, providing an opportunity for the SC to produce the most thermal energy. On 17 August 2025, in the second half of the summer season, the amount of solar radiation was slightly lower (900–990 W/m^2), reaching a maximum between 12:30 and 14:00. Despite the high air temperature during this period, the intensity of solar radiation decreased slightly due to the sun's lower position in the sky. Since 19 October 2025 fell in autumn, the amount of solar radiation recorded was slightly lower (830 W/m^2), but it remained stable.

The variable nature of solar radiation is the main factor in determining the heat generation capacity of a flat solar water heating collector during the experiment. Since the amount of energy absorbed by the collector depends directly on the intensity and distribution of solar radiation over time, this factor influences the heat exchange processes in the system, the increase in temperature of the working fluid and the useful heat output. Therefore, when analysing the experimental results, it is important to take into account the daily fluctuations in radiation flux in order to make an objective assessment of the energy potential of the solar water heating collector in real operating conditions [7-8].

The dates of the study were selected to be representative of typical days, which enabled a comparative analysis of the collector's operational efficiency in different meteorological conditions, i.e. clear, partly cloudy, and variable atmospheric conditions. This approach is important for determining the influence of external environmental factors on the heat exchange processes of the reflector and twisted channel solar water heating collector and for assessing the device's stability and adaptability. The solar radiation data used in this study were obtained from the NASA POWER Data Access Viewer and the databases of the Uzbekistan Hydrometeorological Service. To increase the reliability of information received from external sources, real-time measurements were also recorded using high-sensitivity solar radiation sensors installed at the "Alternative Energy Sources" training and scientific polygon of Karshi State Technical University. The instrumental measurements obtained were compared with satellite and meteorological station data, and their mutual compatibility was verified.

Cross-verifying data from different sources significantly increased the accuracy and reliability of the experimental studies, enabling errors in estimating the heat generation capacity of a flat-plate solar collector with a reflector and a twisted channel to be minimized [9-10].

The flat solar water heating collector with a reflector and twisted channels, as proposed in the research work, is designed using modern, energy-efficient technologies to ensure maximum capture, storage and transfer of solar energy.

The experimental design of the SWHC comprises a flat collector with a reflector and twisted channels. The SWHC s main element is a flat collector in which several functional layers and materials work together to facilitate complex heat exchange processes. The development of this system into an industrial prototype is carried out in the following sequence.

Figure 1 presents the experimental design of a flat solar water heating collector with a reflector and twisted channels.

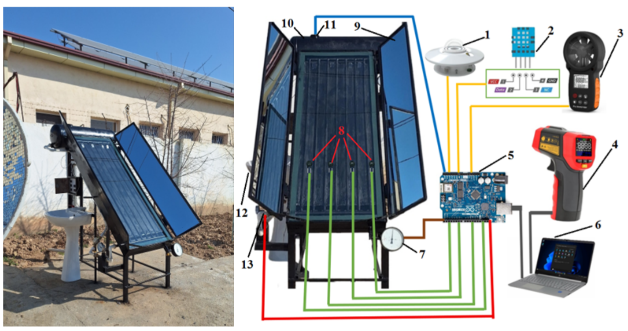

Figure 1. Pilot-industrial model of a flat-plate solar water heating collector. here, 1-pyranometer, 2-thermometer, 3-anenometer, 4-infrared pyrometer, 5-Arduino (for transferring and storing all results to a computer), 6-computer, 7-barometer, 8-thermocouples, 9-flat reflectors, 10-water storage tank, 11-cold water inlet pipe, 12-consumer, 13-water outlet pipe.

This flat-plate solar water heating collector is innovative because its design is based on a complex combination of several technological solutions that increase efficiency. Notably, it optimally combines flat reflectors for additional focusing and concentration of solar radiation, twisted copper tubes for intensive heat exchange, a special stainless steel channel filled with paraffin for heat energy accumulation, and high-performance insulation materials to sharply reduce heat loss. The collective effect of these design solutions significantly increases the collector's overall thermal efficiency, the stability of the outlet temperature, and its energy storage capacity.

Using flat reflectors improves the angle at which sunlight hits the absorber surface, increasing the useful part of the radiant flux. Conversely, copper pipes with twisted channels lead to the formation of secondary vortices in the flow. This increases the heat transfer coefficient by disrupting the boundary layer and intensifying the mixing of the fluid. The stainless channel containing paraffin (a heat accumulator based on a phase change material) ensures the system's thermal stability by accumulating excess heat during the day and gradually releasing it when solar radiation decreases. The highly efficient insulation layer reduces heat loss through the collector body and increases the proportion of useful energy obtained.

This innovative combination has resulted in the creation of the SWHC, which is extremely convenient and promising for use in rural areas with an insufficient centralised energy supply, in social facilities such as schools, kindergartens, polyclinics and recreation centres, and in devices operating independently of the network (off-grid). Its structural simplicity, the possibility of local production, low operating costs and environmental friendliness allow it to be used effectively for hot water supply, low-temperature technological processes and seasonal heating systems.

Additionally, the modular structure of the SWHC allows it to be designed in different power ranges and adapted to the climatic conditions of a particular region. This makes it a practically attractive energy source for not only domestic facilities, but also small and medium-sized industrial ones.

Results and Discussions

The results of the experimental study are presented in Figures 1–3 below.

Figure 1 shows how solar radiation intensity,

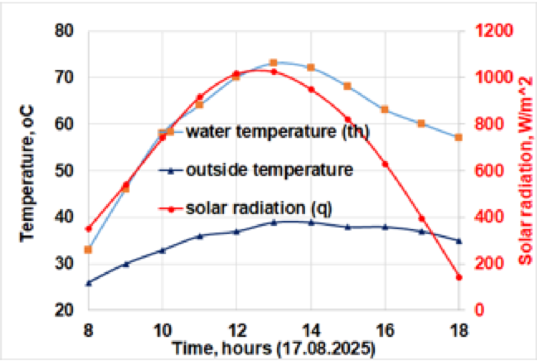

Figure 1. Results of the pilot study on 17 August 2025.

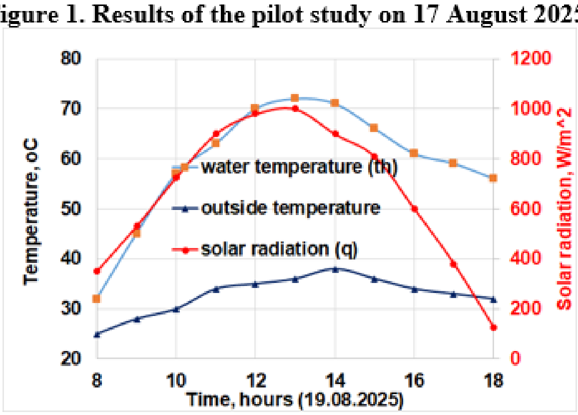

Figure 2. Results of the pilot study on 19 August 2025.

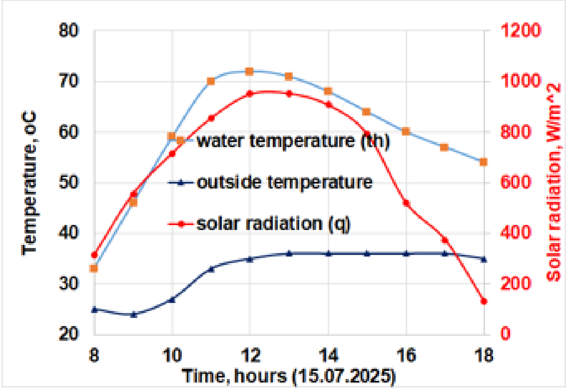

Figure 3. Results of the pilot study on 15 July 2025.

outdoor air temperature and water temperature at the collector outlet changed over time during the experiment conducted on 14 August 2025. As can be seen from the graph, solar radiation increased rapidly between 08:00 and 13:00, approaching its maximum value. As a result of the increased energy flux falling on the SC absorber surface during this period, the water temperature increased almost linearly. This indicates that heat exchange processes are active in the SC and that heat transfer through the twisted channel pipes is effective.

Closer to noon (approximately between 12:00 and 14:00), solar radiation reaches its maximum value and the water temperature also peaks. During this period, the collector's heat generation capacity is at its maximum, as is the amount of useful radiation falling on the absorber due to the reflectors. The outside air temperature changes relatively slowly and remains much lower than the water temperature, confirming the collector's heat-generating capacity.

After 14:00, solar radiation gradually decreases. However, as can be seen from the graph, despite a significant decrease in solar radiation after 16:00, there is no sharp drop in the water temperature; rather, it remains stable for a period of time, even remaining at a relatively high level. This is due to the effect of the phase change material (PCM) integrated into the collector structure – paraffin – acting as a heat accumulator.

During periods of high solar radiation, the paraffin melts and accumulates excess heat energy in the form of latent heat. After 16:00, as solar radiation decreases, the paraffin begins to solidify and gradually releases the previously accumulated heat. Consequently, the thermal regime inside the collector stabilises, maintaining a relatively high water temperature even in conditions of reduced solar radiation.

The experimental results showed that the absorber surface temperature was high, indicating that the PCM had stabilised the outlet water temperature. Despite the relatively low solar radiation during the October experiment, the outlet hot water temperature from the SWHC remained above 65-70°C, indicating the technology's suitability for stable seasonal operation. The system equipped with the PCM module efficiently supplied hot water throughout the day by increasing the rate of heat flow and storing energy.

Conclusions

This research study examined the energy efficiency of a flat solar water heating collector with a reflector and a twisted channel under real meteorological conditions. Experiments were conducted at the "Alternative Energy Sources" training and scientific polygon of Karshi State Technical University from 2025. Changes in solar radiation over time and the dynamics of changes in outdoor air and water temperatures at the collector outlet were analysed.

The results showed that an increase in solar radiation intensity consistently increased the water temperature, confirming the effectiveness of increasing the radiation flux using reflectors and accelerating heat exchange processes due to the twisted copper pipes in the channel. It was observed that the collector reached its maximum heat generation capacity at noon.

A significant finding was that, despite a substantial decrease in solar radiation after 16:00, there was no sharp decline in water temperature, which remained high for some time. This demonstrates the efficient operation of the paraffin-based phase change material integrated into the collector. The latent heat accumulated by the paraffin during the day's high radiation period was released in the evening, increasing the collector's thermal inertia and extending the heat generation process.

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