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Experimental Evaluation of Internal Finned Storage Tank of an Integrated Solar Water Heater with Corrugated Absorber Plate for Domestic Usage

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Abstract:

Integrated storage solar water heaters (ICS-SWH) are among the simplest and lowest-cost technologies for collecting and storing heat in a single vessel. In the present work, the impact of adding fins within the corrugated storage tank, between the absorber's lower surface and the tank bottom, was experimentally investigated. To increase the heat transfer between the water and the ICS-SWH absorber, an insulated reflective cover was installed on the top of the ICS-SWH to reflect sunlight towards the absorber during the day. At night, it was used as a cover to insulate the glass. The thermal performance of the ICS-SWH was studied under load and without load. The results showed that the highest recorded temperature of the stored water was 67 °C. In contrast, the system's thermal efficiency was 78.5% and 89%, respectively. This result is higher than previous works. A comparison between the present tank (12 cm depth) and the previous work (14 cm) regarding stored water temperature was conducted. The comparison showed that a decrease in the depth of the storage tank by 2 cm led to a 25% increase in the temperature difference.

Keywords:

Solar water heater; Integrated; Internal fins; Thermal efficiency.

Highlights:

- The Integrated collector storage solar water heater was investigated experimentally.
- Integrating the storage tank with internal fins increased the thermal efficiency by 6%.
- The current ICS-SWH can heat 156 L of water to 62 °C.

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1.INTRODUCTION

The development of solar-powered systems became an urgent priority due to the demand for renewable energy as an alternative to fossil fuels. In this context, solar water heaters are among the rapidly developing technologies in the sustainable energy sector. Generally, the design of a solar water heater is based on three techniques: forced circulation, natural convection, and integrated collector-storage. When considering the compact, efficient, and multipurpose approach, the integrated collector-storage solar water heater (ICS-SWH) is the optimal choice, as it is simple in operation and design [1]. Compared to other designs, the systems are more feasible because they serve as both a heat storage and a solar collector in a single section [2]. The ICS-SWH system operates independently of grid electricity as it is deemed an isolated system due to its lack of moving parts. In addition, ICS-SWH can avoid freezing under various conditions because it has a large thermal mass in contact with the absorber surface. The ICS-SWH can reliably and consistently supply hot water for several years with minimal maintenance, such as periodic cleaning of the glazing surface. Mokhlif et al. [3] experimentally studied the performance of ICS-SWH coupled with reflectors. During the day, the reflectors captured more solar irradiance and directed it to the absorber, which had a corrugated surface to improve thermal performance. For night use, the reflector served as a cover, with its back side thermally insulated to reduce heat loss at the top boundary. The use of reflectors has increased the ICS-SWH's overall thermal efficiency by 13%. Salih et al. [4] experimentally investigated an ICS-SWH coupled with a reflector and PCM. They found that the reflector enhanced the overall thermal efficiency by 4%. Kumar et al. [5] reviewed recent work on solar water heaters integrated with reflectors. The geometric shape of the ICS-SWH with inclined cutting significantly affects its thermal performance, as reported by Ahmed [6], Al-jerjery, and Ahmed [7]. The inclined cutting hypothesis posits an increase in the absorber area-to-storage tank volume ratio. Compared to the conventional flat-plate type, the cylindrical ICS-SWH had similar performance. The rhombus shape exhibited an efficiency of 59%, higher than that of previous works. In the context of storage tank geometry, Kumar and Rosen [8] found that an extended tank of a conventional rectangular type enhances the efficiency by 5%. Another attempt to supply hot water for domestic use in Iraq during winter was performed by Bani et al. [9] using multistage ICS-SWH. A recent design of a solar water heater for domestic use was presented by Yassen et al. [10]. They indicated that in May, without water consumption, the highest daily efficiency was 54%, whereas in September, with consumption, the maximum daily efficiency increased to 55%. The problem of heat loss from the ICS-SWH during night hours has been addressed by adding an insulated plate with baffles parallel to the absorber plate, as performed by Faiman et al. [11] and Kaushik and Garg [12]. During the day, the water circulates in the storage tank via thermosiphon action, while the cold water above the insulated plate prevents circulation. Consequently, the warm water does not contact the cold absorber during nighttime. Hence, the hot water is continuously provided. The experimental method of testing solar heaters should follow standard procedures. The dynamic system testing method according to Standard ISO 9459-5 has been utilized by Messaouda et al. [13] to evaluate the performance of the new ICS-SWH under Tunisian climate conditions. A long-term performance study has been conducted across various climatic conditions based on a coupling model between DST data and a transient numerical technique. Based on the dynamic system evaluation, the total stored heat capacity was found to be 0.87 MJ/K. The useful collector surface area was 1.21 m², and the storage tank heat-loss coefficient was 10 W/K. This system covers 79.3% of the typical Tunisian family's daily consumption needs. Using a corrugated absorber is one of the important techniques adopted to improve the performance of the ICS-SWH. Enhancing the efficiency of ICS-SWH was numerically and experimentally investigated by Kumar and Prakash [14]. The enhancement was numerically and experimentally performed by vee-corrugating the absorber and vee-included angle optimization. For these conditions, the eight-corrugation model of ICS-SWH had higher efficiency than the five-corrugation model. The simulation model predicted that the optimum design had 18 corrugations, with a vee-involved angle of 28.78°. For winter conditions in Iraq, Yassen et al. [15] experimentally investigated the corrugated ICS-SWH performance. In cold-day conditions, the maximum stored water temperature was 59 °C. A comparison between single- and double-glazing cover was performed for corrugated ICS-SWH by Mokhlif et al. [16]. The authors found that the double-glazing cover reduced heat loss at a storage temperature of 11 °C compared with a single-glazing cover. In terms of average daily thermal efficiency, the double-glazing case showed a 4.6% increase over the single-glazing case, with an average of 69%. Phase change materials have been utilized to improve the performance of ICS-SWH. Smyth et al. [17] investigated various double-vessel ICS-SWH prototypes with a horizontal cylindrical configuration and a very low-pressure annular cavity. This development improved the cold-start daily collection efficiency to more than 55%. The ICS-SWH with PCM has been modified by Bilardo et al. [18, 19] to add heat pipes to the system. This system was designed and modeled to supply hot water for domestic use at a flow rate of 0.87 kg/min. This modification helped to produce a maximum storage temperature of around 79°C. Eleiwi et al. [20] investigated a solar water heater integrated with PCMs. They found that the thermal efficiency of the storage unit system was enhanced by 5%. To enhance the performance of solar water heaters, Taheri et al. [21] proposed a compact solar water heater (CSWH). For this CSWH, black-colored sand was used as an absorber with a porous structure, which allows water to penetrate it. This ICS-SWH exceeded 70% in daily efficiency, while the maximum storage temperature reached 52 °C. The thermal losses through the boundaries of the solar storage systems are considered a major drawback of operating during sun-off hours. This issue was addressed by Barone et al. [22] through developing a high-vacuum ICS-SWH to overcome the heat losses due to convection. This modification saved between 33% and 62% of energy. The incident area of solar collectors is deemed an important design parameter. In compact systems, reflectors have been used to increase solar radiation collection capacity without increasing the ICS-SWH area. This solar water-heating technique was designed by Harmim et al. [23] for integrating into the building façade using a parabolic reflector. This approach increased water temperature from 22 °C to 49 °C. In conclusion, the challenges of high cost and complexity should be optimized based on the chosen materials and design to achieve the high thermal properties of the ICS-SWH, as reviewed by Saint et al. [24]. Hence, the geometrical design of each part of the ICS-SWH may significantly affect thermal performance, which has motivated various approaches to developing this technology, as presented by Omer et al. [25], such as utilizing nanotechnology, solar cells, mirrors, and phase change materials (PCM). The main contribution of the present research is to enhance the thermal performance of an ICS-SWH with a thermosiphon. The proposed enhancement can be achieved by installing a longitudinal rectangular fin on the inner surface of the corrugated absorber to improve heat transfer between the stored water and the absorber, ensuring the absorber surface is in contact with the full depth of the stored water. The present work utilizes an insulated reflector. To validate the effect of adding fins, the performance of the present work will be compared with that of previous studies.

2. METHODOLOGY

2.1. Apparatus

The schematic representation of the proposed ICS-SWH is shown in Fig. 1. The main components of the setup were an insulated box, a storage tank, a single-glazing cover, and a reflector. The upper side of the storage tank served as the absorber, with a triangular corrugated shape that increased the heat transfer surface area. Eight longitudinal fins were vertically welded inside the storage tank, as shown in Fig. 2, to enhance the heat transfer by convection between the absorber and the stored water. To increase solar radiation absorption, the corrugated outer surface of the storage tank was painted using matte black. The lateral walls and the base of the storage tank were thermally insulated with thick glass wool to reduce heat loss to the external environment. Moreover, the corrugated upper tank roof was exposed to an air gap, confined by the corrugated absorber and the single glass cover. One reflector was used to enhance the intensity of solar radiation incident on the collector during daytime. The reflector was hinged on one side to adjust the inclination angle and cover the ICS-SWH during sun-off hours. The back face of the reflector was thermally insulated with a 2 cm layer of cork to reduce the heat dissipation from the ICS-SWH top surface to the surrounding air during the night. The entire ICS-SWH was tilted at 40° from the horizon and faced south. Depending on the location of the tests presented by Yassen et al. [15]. The detailed physical specifications of the present ICS-SWH are listed in Table 1.

2.2. Measurements

This work focuses on measuring the thermal performance of the ICS-SWH under load and no-load conditions. The no-load case represents closing the inlet and outlet valves after filling the tank (closed system) and heating the water in the solar heater tank to determine the system's efficiency and the maximum temperature reached in the tank during the day. The load condition represents heating the water until solar noon. The water temperature reached approximately the highest value at that time. Then, the valves were opened to allow the hot water to flow from above and the cold water to enter from below, where its temperature continued to rise as it flowed upward due to density differences. The hot water flow rate was measured manually by collecting the outlet water in a beaker over a specified time. The temperature at various locations was measured by a calibrated type-K thermocouple probe (Chromel-Alumel), measuring temperature in the range (50 to 1000 °C) with accuracy ±0.1 °C. A Type K thermocouple was used to measure the water temperature at the inlet, outlet, and three positions within the storage tank. The environmental temperature was measured, and the sixth thermocouple position was determined. All of the thermocouples were connected to a data logger type Applent AT4808. Solar irradiance was measured with an accuracy of ±3% using a solar digital meter (Daystar DS-05A). Figure 3 shows the test setup and the measurement positions for temperature and solar irradiance.

2.3. Testing Conditions and Procedures

A set of regular-experimental trials was conducted to evaluate the thermal performance of the proposed ICS-SWH. The experiments were performed at Tikrit University in Iraq (34040′ N and 43039′ E). The test dates were selected for February 28th and March 29th, 2024. Instantaneous hourly measurements were adopted for solar irradiance, wind speed, and water temperature variation. The site for the experiments was selected to be free of obstacles that might block solar radiation incident on the ICS-SWH collector, as shown in Fig. 4.

2.4. Uncertainty Analysis

It is important to assess the reliability of results and measurements by performing an uncertainty analysis. The experimental error has been calculated based on the bias error (B) and precision limit (P) principles, as described by Figliola and Beasley [26]. Table 2 tabulates the uncertainty rates of the considered parameters in the present work. The error in the solar radiation analysis was about 0.1. The device's accuracy was 3%. The uncertainty was as high as 7%. This uncertainty is due to the device being used for several years, which has increased the error percentage. The average uncertainty of the stored water temperature and ambient temperature was about 0.075. The uncertainty is acceptable and is consistent with that reported by Mokhlif et al. [3] and Mokhlif et al. [16].

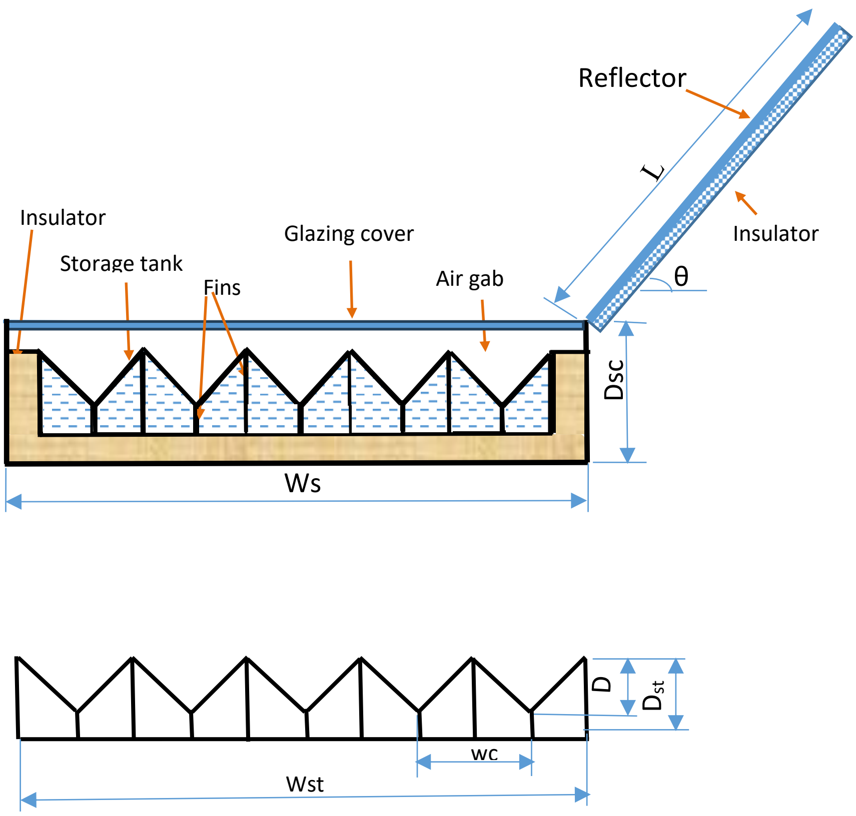

Fig. 1 The Physical Configuration of the ICS-SWH Attached with a Reflector-Insulator Cover.

Fig. 2 Fins Inside the Storage Tank.

Table 1 Solar Water Heater Design Parameters.

Part	Design element	Specifications
Collector	Length (*Lsc*)	1.1 m
	Width (Wsc)	1.3 m
	Depth (Dsc)	0.24 m
	Inclination angle (β)	40 °
	Aperture area (*A*)	1.2 m²
Reflector	Material	Glass mirror
	Number	1
	Length (L_R)	1 m
	Back insulation thickness	2 cm
	Insulation type	cork
Storage tank	Material	Galvanized steel gage 2 mm
	Thermal conductivity	50.2 W/(m·K)
	Paint	Black
	Absorber type	non-selective
	Absorber emissivity (ε_p)	0.9
	Capacity	96×10^{-3} m³
	Corrugation depth (*Dc*)	0.12 m
	Corrugation width (*Wc*)	0.24 m
	Storage tank depth (*Dst*)	0.14 m
	Storage tank width (*Wst*)	1.2 m
	Storage tank length (*L*)	1 m
	Fins material	Galvanized steel gage 2 mm
	Fins height	14 cm and 2 cm
	Fins length	90 cm
Transparent cover	Material	Glass
	Number	Single layer
	Thickness	4 mm
	Glazing space (S_{dg})	5 cm
Insulation	Material	Glass wool
	Thermal conductivity	0.0343 W/m k
	Thickness	0.05 m

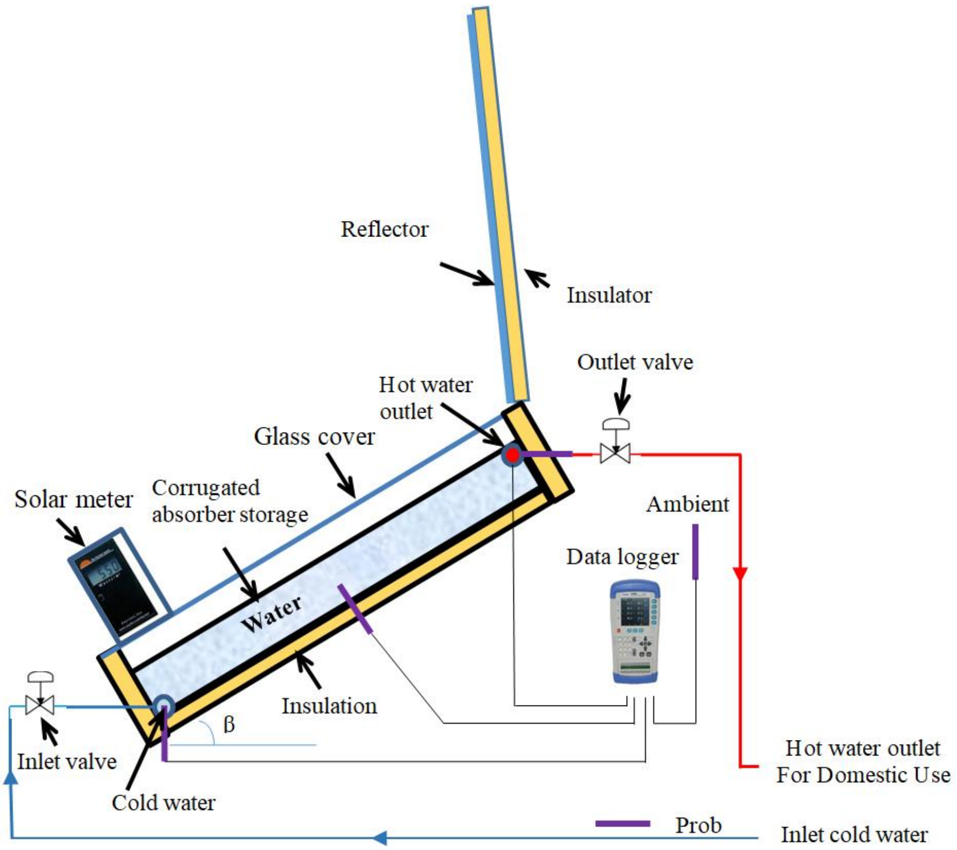

Fig. 3 Schematic Diagram of the Experimental Setup.

Fig. 4 The Test Rig of the Present ICS-SWH.

Table 2 The Measured Parameters Uncertainty.

Parameter	I (W/m²)	T_{wa} (°C)	T_{out} (°C)	T_a (°C)
U_x	74.87	3.72	3.86	1.824
$\frac{U_x}{x}$	± 0.10	±0.0759	±0.0758	±0.0732

2.5.Mathematical Background

The heat input to the ICS-SWH during day hours can be obtained as follows:

$$Q_{in} = \int_0^t IA\,dt \qquad (1)$$

The useful heat gain, also known as the output heat, is the energy added to the water stored in the tank. In practice, not all of the solar irradiance incident on the collector is converted into useful heat gain. The output heat is less than the input heat due to various types of heat loss, such as reflected irradiance from the glass cover and that absorbed by it. Experimentally, the output heat is determined by calculating the difference in water heat content between the outlet and inlet of the storage tank as follows:

$$Q_{out} = m^{\circ}\, C_w\,(T_{out} - T_{in}) \quad (2)$$

The heat stored in the ICS-SWH after sunset is given by:

$$Q_{stor} = mC_w\left(\frac{dT}{dt}\right) \quad (3)$$

The ICS-SWH average daily thermal efficiency with load can be expressed as:

$$\eta_{wl} = \frac{Q_{stor}+Q_{out}}{Q_{in}} \quad (4)$$

Equations (1) to (4) are combined to determine the mean daily thermal efficiency of the system with load as follows [27, 28]:

$$\eta_{wl} = \frac{m^{\circ} C_w(T_{out}-T_{in})}{IA} \quad (5)$$

The useful heat amount generated in the ICS-SWH is expressed by the numerator of Eq. (5), while the denominator in Eq. (5) represents the solar energy reaching the glass cover. For the no-load operating mode, the daily efficiency is computed as follows:

$$\eta_{wol} = \frac{Q_{stor}}{Q_{in}} = \frac{m_w C_w(T_{wf}-T_{a-1})}{\int_0^t IAdt} \quad (6)$$

3.RESULTS AND DISCUSSION

3.1.No-Load Test Results for the ICS-SWH Water Temperature

The thermal performance of the ICS-SWH water heater in no-load operation mode can be discussed by presenting the water temperature inside the storage tank. The experiment was conducted on a clear, sunny day on February 28th, 2024, using a reflector. Figure 5 shows the behavior of the water storage temperature under the relevant meteorological conditions, i.e., solar radiation and ambient temperature. It can be observed that the water temperature inside the thermal tank was at its lowest at the beginning of the test at 07:00, due to the lowest values of both solar radiation and environmental temperature. Then, it increased slightly with solar radiation and environmental temperature until 10:00. After that, the water temperature rapidly increased as direct and reflected radiation from the reflector plate toward the absorber plate increased, approaching the peak time. The maximum environment temperature was 15 °C at 14:00, while the minimum value was 8 °C at 07:00. The peak solar radiation value was about 1250 W/m² in the afternoon. The water temperature inside the storage tank reached a maximum of 67 °C at 14:00. It increased by 37 °C from 7:00 to 14:00. The water temperature followed the ambient conditions, influenced by direct solar radiation reflected from the reflectors. The heat is transferred from the absorber to the stored water. After that, the temperature of the stored water started to decrease to 58 °C at 18:00, as heat was transferred from the water to the absorber plate and then lost to the environment through the glass cover.

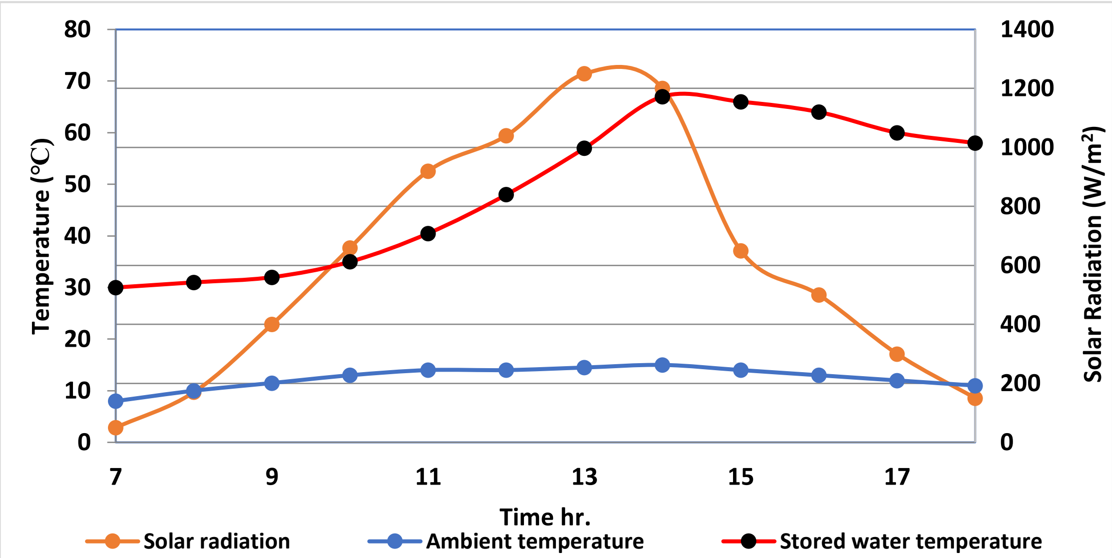

Fig. 5 Variation of Stored Water Temperature with Time for No-Load Test.

3.2.Load Test Results for the ICS-SWH Water Temperature

The load test demonstrates the ICS-SWH's potential to provide hot water for domestic use. This test was performed by allowing water to flow from the tank's outlet. The proposed domestic load for the test was 0.0033 l/s (12 l/h). The experiments were performed on the ICS-SWH coupled with a single reflector. The stored water temperature and metrological conditions, i.e., ambient temperature and solar radiation, were measured on March 29th, 2024, as presented in Fig. 6. On that day, the solar radiation recorded a maximum rate of 1200 W/m² at 13:00, while the ambient temperature rose from 16 °C at 08:00 am to 31 °C at 13:00. From the solar radiation measurements, an ideal experimental condition of clear skies was observed during the test hours. The temperature of the water outlet from the tank was measured from 13:00, when the water inlet and outlet valves were opened, until 18:00, when the outlet water temperature began to rise, reaching its highest value at 16:00, i.e., 67 °C. In comparison, it was 30 °C at the inlet, despite opening the valves, draining hot water, and entering cold water from the lower opening, and decreasing solar radiation with ambient temperature, as a result of the continued heat gain and the rise in the temperature of the water to high levels during the first hours of the test, i.e., thermal energy stored in the water. This condition persisted until 16:00. Then, the water temperature significantly decreased due to a rapid reduction in solar radiation and environmental temperature, and to increased thermal losses, especially from the upper glass cover. The amount of water supplied during the test was 60 liters, with an average temperature of 62 °C and a temperature difference between the outlet and the inlet of 37 °C. After the test was completed, the amount of hot water remaining in the tank was 96 liters at 54 °C. In conclusion, the ICS-SWH water heater provided 156 liters of hot water, which is enough for domestic use during the winter season.

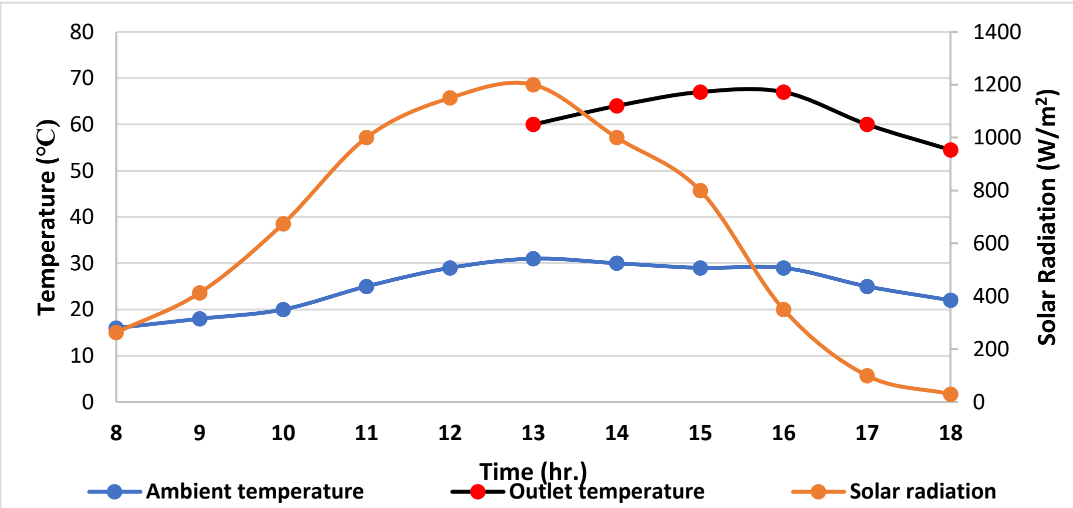

Fig. 6 The Performance of the ICS-SWH with Time for Load Test.

3.3.Daily Thermal Efficiency

Figure 7 shows the thermal efficiency of the ICS-SWH. The thermal efficiency is defined as the ratio of the input heat (solar energy incident on the glass cover) to the output heat (useful heat stored and used). Therefore, it is important to study these energies to understand the performance of the ICS-SWH, as reflected in daily thermal efficiency. In both no-load and load testing modes, it shows the differences between the output and input heats, as well as the stored heat in the ICS-SWH tank. In general, the input energies have higher rates than those entering the system due to thermal losses through the boundaries to the surroundings. In no-load operation, it was observed that during the day, the amount of heat entering the ISWH from solar radiation was 16.58 MJ, while the heat stored in the tank was 9.8 MJ. On the other hand, the amount of heat entering the ISWH from solar radiation was 29.58 MJ over the course of the day. On the other hand, the heat value at the water flow rate exiting the ICS-SWH was 9.16 MJ during load testing. While at the end of the day, the heat stored in the tank was 14.04 MJ.

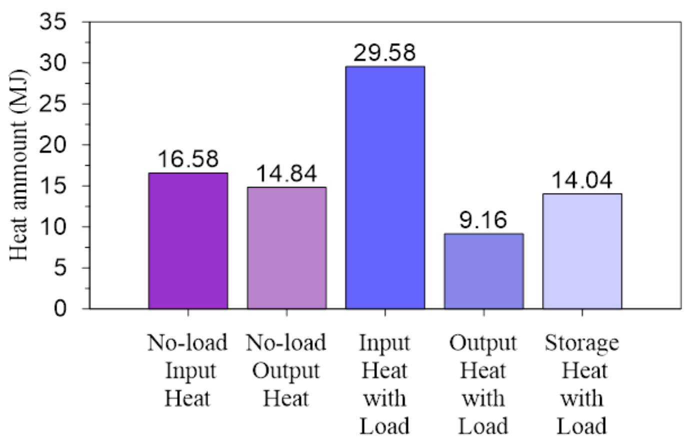

Fig. 7 The Input and Output Energies for No-Load and with Load Operation Modes of the ICS-SWH.

3.4.Results Validation

In the same context, the daily thermal efficiency of the ICS-SWH provides an overall, comprehensive insight into thermal performance. Figure 8 shows the daily thermal efficiency rates of the present ICS-SWH and previous works for the no-load operation mode. Taheri et al. [2] investigated the ICS-SWH of a flat-plate storage tank with a depth of 0.17 m, a capacity of 138 liters, and a double-glazing cover. They found that the overall daily no-load thermal efficiency was 76%. Mokhlif et al. [25] investigated an ICS-SWH with a corrugated storage tank, a double-glazing cover, and two reflectors insulated from the back. They found that the overall daily no-load thermal efficiency was 83%. However, the present design, with eight longitudinal fins and a regular distribution within the storage tank, increased the contact surface area between the water and the absorber, thereby enhancing heat exchange. Also, the temperature distribution along the fins was uniform, and the heat transferred through the fins reached the depth of the stored water. As a result, efficiency increased to about 89% despite using a single reflector. Despite using a single glass cover, this approach allowed more solar radiation to reach the absorber surface than the double glass cover. For the reasons mentioned above, the present ICS-SWH system is more efficient than previous systems.

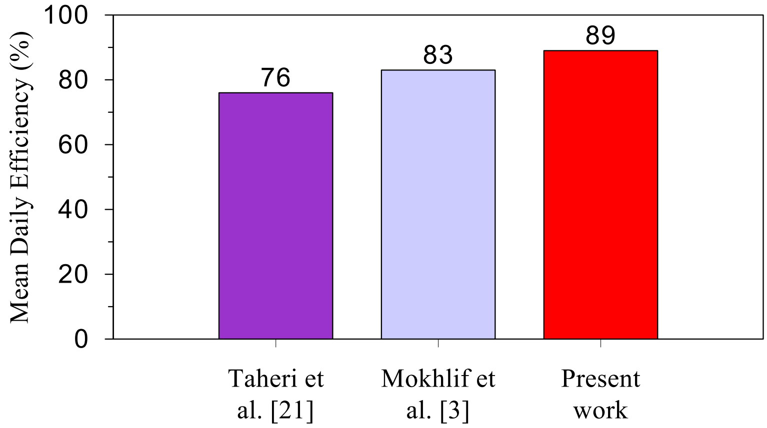

Fig. 8 The Daily Thermal Efficiency of the ICS-SWH for No-Load Operation Mode.

In terms of work with load, the performance of the present ICS-SWH was compared with previous works of Mokhlif et al. [15], Mokhlif et al. [25], and Yassen et al. [10], as shown in Fig. 9. For the present work, the overall daily thermal efficiency was 78.5 %. Obviously, it can be observed that the thermal efficiency for the present ICS-SWH was greater than that for the published works, attributed to firstly the effect of high solar intensity reflected from the reflector, secondly single glazing permit more solar irradiance to be penetrated compared to double glazing, and thirdly internal longitudinal fins inside the storage tank increased the rate of the heat transfer between the water and the absorber. During day hours, the presence of the thermal insulator (glass wool) fixed to the thermal tank contributed to reducing thermal losses through convection from all sides due to its low thermal conductivity, while the movement insulated reflective surface covers the top of ICS-SWH, enhances the reflection solar radiation on the absorption plate, that increased the temperature of stored water during the day and reduces thermal losses after closing at night; thus increase the system's thermal efficiency.

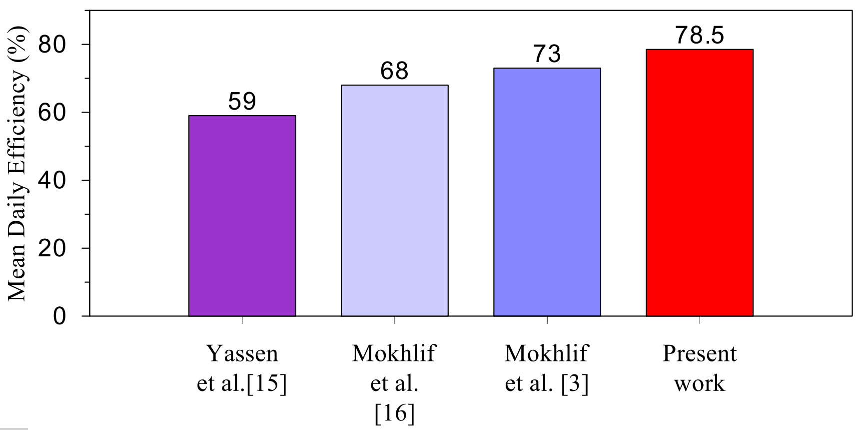

Fig. 9 The Daily Thermal Efficiency of the ICS-SWH with Load Operation Mode.

3.4.The effect of Storage Tank Depth

Figure 10 shows that the storage tank's depth affected the temperature rise of the stored water. For a 12 cm-thickness storage tank, the temperature difference was about 44 °C. However, for the thickness of 14 cm, the temperature difference was 35°C. In other words, a 2 cm decrease in the depth of the storage tank increased the temperature difference by 25%. The temperature difference for a thickness of 12 cm was higher than for a depth of 14 cm. Therefore, to achieve a high water temperature, a depth of 12 cm is used. To obtain a high volume of water, it is preferable to use a storage tank with a depth of 14 cm.

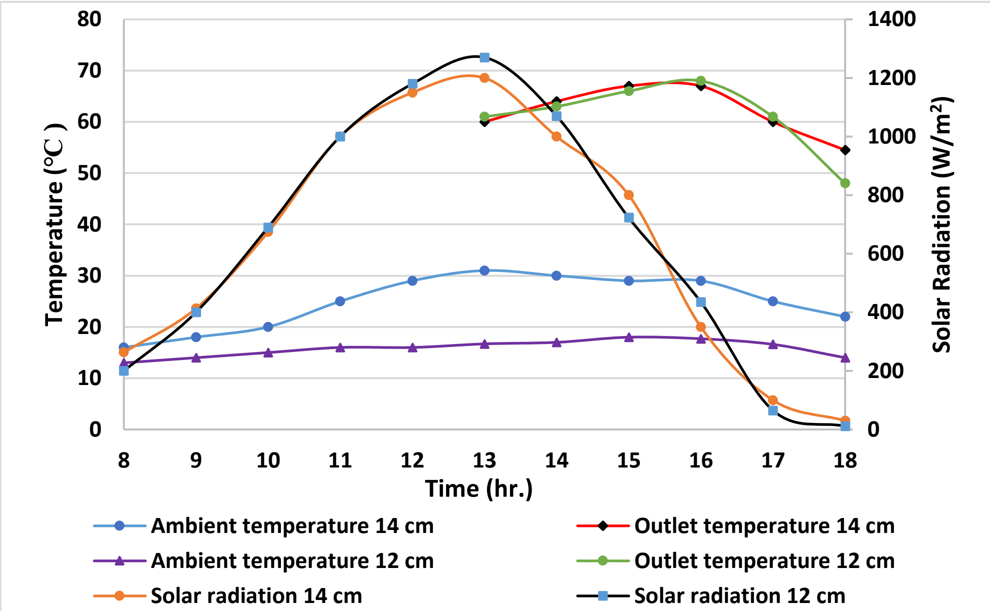

Fig. 10 The Effect of the Tank Depth in Terms of Outlet Temperature for Load Mode Operation, 14 cm for the present work and 12 cm for the previous work by Mokhlif et al. [3].

4.CONCLUSIONS

In the present work, ICS-SWH integrated with an internal fin and a reflector was investigated. Depending on the results from the present work, the following points can be deduced:

1) Adding internal fins and reflectors enhanced the ICS-SWH's performance during the day, while the insulated reflector cover reduced losses after sunset. The percentage of enhancement was 6% in terms of overall thermal efficiency.
2) A 2 cm decrease in tank depth increased the temperature difference in the solar water heater by 25%.
3) It is observed that 156 L of water at 62 °C can be heated using the present ICS-SWH, which is convenient for domestic use during winter. The 12 cm-deep tank is preferred over the 14 cm-deep tank to achieve a higher hot-water temperature.

In the future, it is recommended to investigate the present work using simulation software, such as Ansys Fluent. Also, it is recommended to adjust the internal fins' shape to achieve the optimal shape. Furthermore, the system can be enhanced using storage material, such as paraffin wax, inside the storage tank.

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REFERENCES

[1] Rao YA, Somwanshi A. **A Comprehensive Review on Integrated Collector-Storage Solar Water Heaters.** *Materials Today: Proceedings* 2022; **63**: 15-26.

[2] Kalogirou S. **Design, Construction, Performance Evaluation and Economic Analysis of an Integrated Collector Storage System.** *Renewable Energy* 1997; **12**(2): 179-192.

[3] Mokhlif ND, Eleiwi MA, Yassen TA. **Experimental Evaluation of a Solar Water Heater Integrated with a Corrugated Absorber Plate and Insulated Flat Reflectors.** *AIMS Energy* 2023; **11**(3): 522-539.

[4] Saleh HF, Eleiwi MA, Mokhlif ND. **Improving the Performance of a Home Solar Water Heater System Using Porous Materials and Reflectors.** *Tikrit Journal of Engineering Sciences* 2024; **31**(2): 244-254.

[5] Kumar Y, Verma M, Ghritlahre HK, Verma P. **Recent Developments in the Thermal Performance of Flat Plate Solar Water Heaters with Reflectors-A Review.** *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 2022; **44**(4): 9448-9475.

[6] Ahmed OK. **Experimental and Numerical Investigation of Cylindrical Storage Collector (Case Study).** *Case Studies in Thermal Engineering* 2017; **10**: 362-369.

[7] Al-jerjery AS, Ahmed OK. **Experimental Investigation of Thermal Performance for Novel Integrated Collector Storage.** *NTU Journal of Renewable Energy* 2024; **7**(1): 22-33.

[8] Kumar R, Rosen MA. **Integrated Collector-Storage Solar Water Heater with Extended Storage Unit.** *Applied Thermal Engineering* 2011; **31**(2-3): 348-354.

[9] Bani Yaseen A, Al-Hyari L, Almahmoud O, Hammad M. **Performance of a New Solar Water Heater Design with Natural Circulation.** *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 2020; **46**(1): 10694-10709.

[10] Yassen TA, Waes MM, Ahmed OK, Tahseen TA, Baharom M. **Performance Investigation on an Integrated Multi-Stage Cylindrical-Tank Solar Water Heater.** *AIP Conference Proceedings* 2018; **2035**(1): 040003.

[11] Faiman D, Hazan H, Laufer I. **Reducing the Heat Loss at Night from Solar Water Heaters of the Integrated Collector–Storage Variety.** *Solar Energy* 2001; **71**(2): 87-93.

[12] Kaushik S, Kumar R, Garg H. **Effect of Baffle Plate on the Performance of a Triangular Built-in-Storage Solar Water Heater.** *Energy Conversion and Management* 1995; **36**(5): 337-342.

[13] Messaouda A, Hamdi M, Hazami M, Guizani AA. **Dynamic Testing of a New Integrated Collector Storage Solar Water Heater (ICSSWH) According to Standard ISO 9459-5: Use of a Numerical Approach for Long-Term Prediction in Different Climatic Conditions.** *Environmental Progress & Sustainable Energy* 2024; **43**(1): 214-254.

[14] Kumar A, Prakash O. **Performance Analysis and Experimental Validation of a Vee-Corrugated Absorber Integrated Collector Storage Solar Water Heater.** *Heat Transfer* 2023; **52**(2): 1920-1946.

[15] Yassen TA, Mokhlif ND, Eleiwi MA. **Performance Investigation of an Integrated Solar Water Heater with Corrugated Absorber Surface for Domestic Use.** *Renewable Energy* 2019; **138**: 852-860.

[16] Mokhlif ND, Eleiwi MA, Yassen TA. **Experimental Investigation of a Double Glazing Integrated Solar Water Heater with Corrugated Absorber Surface.** *Materials Today: Proceedings* 2021; **42**: 2742-2748.

[17] Smyth M, Mondol JD, Muhumuza R, Pugsley A, Zacharopoulos A, McLarnon D, Palombo A. **Experimental Characterisation of Different Hermetically Sealed Horizontal, Cylindrical Double Vessel Integrated Collector Storage Solar Water Heating (ICSSWH) Prototypes.** *Solar Energy* 2020; **206**: 695-707.

[18] Bilardo M, Fraisse G, Pailha M, Fabrizio E. **Modelling and Performance Analysis of a New Concept of Integral Collector Storage (ICS) with Phase Change Material.** *Solar Energy* 2019; **183**: 425-440.

[19] Bilardo M, Fraisse G, Pailha M, Fabrizio E. **Design and Experimental Analysis of an Integral Collector Storage (ICS) prototype for DHW production.** *Applied Energy* 2020; **259**: 114104.

[20] Eleiwi MA, Mokhlif ND, Saleh HF. **Improving the Performance of the Thermal Energy Storage of the Solar Water Heater by Using Porous Medium and Phase Change Material.** *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 2023; **45**(1): 2013-2026.

[21] Taheri Y, Ziapour BM, Alimardani K. **Study of an Efficient Compact Solar Water Heater.** *Energy Conversion and Management* 2013; **70**: 187-193.

[22] Barone G, Buonomano A, Palmieri V, Palombo A. **A Prototypal High-Vacuum Integrated Collector Storage Solar Water Heater: Experimentation, Design, and Optimization Through a New In-House 3D Dynamic Simulation Model.** *Energy* 2022; **238**: 122065.

[23] Harmim A, Boukar M, Amar M, Haida A. **Simulation and Experimentation of an Integrated Collector Storage Solar Water Heater Designed for Integration into Building Facade.** *Energy* 2019; **166**: 59-71.

[24] Saint RM, Garnier C, Pomponi F, Currie J. **Thermal Performance Through Heat Retention in Integrated Collector-Storage Solar Water Heaters: A Review.** *Energies* 2018; **11**(6): 1615.

[25] Ahmed OK, Algburi S, Daouda RW, Shubat HN, Aziz EF. **The Various Designs of Storage Solar Collectors: A Review.** *International Journal of Renewable Energy Development* 2023; **12**(1): 166-185.

[26] Figliola RS, Beasley DE. **Theory and Design for Mechanical Measurements.** *Measurement Science and Technology* 2001; **12**(10): 1743-1743.

[27] Kumar R, Rosen MA. **Thermal Performance of Integrated Collector Storage Solar Water Heater with Corrugated Absorber Surface.** *Applied Thermal Engineering* 2010; **30**(13): 1764-1768.

[28] Dheyab HS, Al-Jethelah M, Ibrahim TK, Chtourou S, Baccar M. **Closed Solar Air Heater System Integrated with PCM (RT42 and RT50) in a Thermal Storage-Finned Heat Exchanger Unit.** *Tikrit Journal of Engineering Sciences* 2023; **30**(3): 27-37.