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EXPERIMENTAL COMPARISON OF THERMAL PERFORMANCE BETWEEN V-CORRUGATED AND FLAT PLATE SOLAR COLLECTORS

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Abstract- In this study, the performance of flat plate (FP) and V-corrugated plate (VCP) solar water collectors (SWCs) with double glassed have been evaluated experimentally for purposes of comparison. VCP and FP absorber plates have been well-designed and constructed individually to prevent heat losses. The surface area of each solar collector (SC) is 1.5 m^2. The absorber plates are made from copper with water tubes of 12.75 mm diameter fixed above the absorber plate in multi U-shaped along with the absorber plate. The study was achieved in winter 2022 (beginning in January and ending in March) utilizing Mosul's solar irradiation in Iraq, in clear sky circumstances, for about 7 hours through the day. Both collectors were manufactured and investigated in winter (January to March) under the same water flowrate is 0.0165 kg/s and under the same weather conditions. The most sun irradiation was reported in March, with the peak occurring between 12 and 1 p.m. The results showed that average values of experimental efficiencies for three months (January, February, and March) for VCP and FP collectors at mid-day hours are equal to 50% and 44%, respectively. Also, the mean absolute percentage error (MAPE) of experimental efficiencies between FP and VCP collectors and other works in the literature review was 8.8% and 7%, respectively. The current research offers a valuable tool for calculating the efficiency of solar water collectors (SWCs) in Mosul, Iraq.

Keywords: Efficiency; Flat Plate; Double Glazed; Solar Water Heater; V-Corrugated Plate.

1. INTRODUCTION

The world's reliance on conventional fuel resources is high, posing increased environmental risks to humans, animals, and plants. Several research studies have shown that utilizing fossil fuels negatively impacts environmental circumstances. Several nations, like Iraq, rely heavily on fossil fuels and spend a significant quantity of this fuel to generate power [1]. Solar energy may be utilized as one of the cleanest energy supplies to lessen dependency on fossil fuels. Solar energy has tremendous potential for turning the sun's energy into electricity; hence, researchers have focused increasing emphasis on evaluating the performance of various solar system types.

There are many applications of SC for heating water, air conditioning systems, refrigeration of vapour absorption and space heating. As a result of their numerous uses, a designer continues to determine the thermal performance of FPSC. The SWC is a kind of heat exchanger which converts solar radiation to thermal energy. The SC varies from more traditional heat exchangers in various ways. The latter often perform a fluid-to-fluid transfer with maximum heat transfer rates and radiation as a minor issue [2].

Some profile shape optimization and performance, namely, rectangular and trapezoidal profiles with a local thickness step change, were studied by Kundu [3]. The results showed that rectangle profiles with a local thickness step change absorber plate shape outperform conventional shapes due to improved performance and fewer manufacturing challenges. The performance calculation of FP Collector with elliptical, circular, triangular and square cross-sectional area absorber tubes has been conducted by Norton [4]. The result showed that the FP collector efficiencies were 15-19% and 9-12% for triangular and elliptical shapes, respectively. Mahboub and Moummi [5] examined the top heat transfer of a 60° V-corrugated SC with single glazing. The glass temperature values and the heat coefficient loss were compared with the results obtained by iterative energy equations under various operating situations.

Chong, et al. [6] presented the optical, experimental, and cost evaluation of the V-trough SWH system. The visual performance of the V-trough type and the total efficiency of SWH has shown promising results in practice. The data obtained showed that the prototype had a visual performance of 70.54% and a temperature of 85.9 °C. Bakari, et al. [7] examined the effect of glass material thickness on the FP performance collectors. Glaze transmittance, reflectance, and absorptance impact SC performance, resulting in significant heat system losses. The findings revealed that variations in glass thickness cause variations in SC efficiency. For example, a collector of a 4 mm thick glass had the best thermal effectiveness at 35.4%, vs 27.8% with a collector of a 6 mm glass thickness. Manikandan and Sivaraman [8] examined a double-glazed solar FP water heater with multiple plate geometries, namely FP, square pulse, and V-grooved for varied geometries and flowrates are (0.0041, 0.0083, and 0.0125 kg/s). Double-glazed FPs have a higher thermal efficiency than square pulse and V-grooved plates.

F. Jamadi [9] demonstrated the PTC, exchangers, and two reservoirs, all of which are utilized to store heated water for later use. So the author attempted to maximize the effectiveness of the PTC via varying the oil flow rates; when raising oil flowrate, collector's efficiency improves; this fact is consistent with the findings from other researchers' investigations. Fan, et al. [10] demonstrated a novel multi-channel V-corrugated absorber for the fluid FP collector. The absorber is constructed with triangular channels made of aluminum and directly produced to optimize sun absorption, minimize heat conduction thermal resistance, and lower pressure drop. Harun [11] investigated the rise in water temperature due to SWH collector plate change.

The method used in this experiment modified the shape of a plate of FP collector from quadrangle-folded (A) to triangle-folded (B). The results demonstrate that FP collector A is less efficient than FP collector B. Abdullah [12] Studied three different models of air heaters to know their thermal performance. The first model is FP without cans, the second model is FP with cans, and the third model is FP with staggered arrangement cans. Results of this work showed that the maximum efficiency of the SAHs was about 73.4% for staggered heaters at flow rate of 0.05 kg/s. Fan, et al. [13] showed that a FP using V-corrugated absorbent (VFPC) might enhance steady-state thermal and optical efficiency by close at 15.8% and 10.7%, respectively. Furthermore, the results show that the Quasi-Dynamic Test Model (DHTM), followed by the TFM (Transfer Function Model) and coefficients of the dynamic test model (QDTM), can forecast the thermal simple terms characteristics of VFPC correctly.

Sakhaei and Valipour [14] carried out an experimental investigation to investigate the impact of pitch length and corrugated riser roughness height on heat transfer in an FPSC. The findings showed that the FPSC had a maximum efficiency of 61.59% (P/D_H=0.3 and e/D_H=0.15). Darici and Kilic [15] studied two solar air heaters' performance at three distinct air mass flowrates of (0.022, 0.033, and 0.044 kg/s). The first air heater was made with a trapezoidal corrugated panel, while the second air heater was made with a flat absorber panel. Their findings demonstrate that of 0.022 kg/s air flowrates, the highest temperature increase in trapezoidal corrugated plate air collectors is 9 °C higher than in FP solar air collectors. Alkhafaji, et al. [16] performed experimental and computational research to show the influence of various plate geometry (smooth plate and VCP) on the performance of the FPSC. Their results indicated that the discrepancy between experimental and computational data is 8.12% for the average temperature of water in a tank. In comparison, the working liquid temperature at the riser pipe is about 8.36%, and the performance of the VCP model is higher than that of the conventional model.

M. El Badaoui and A. Touzani [17] demonstrated the CanSol SC work by recovering soda cans and then describing the ingredients utilized and estimating the SC's effectiveness. Their findings revealed that the performance and exit temperature have been tested throughout November 2020, with satisfactory results ranging around 31.1 °C and 35.1 °C when tried to compare towards the autumn through Khouribga, which recorded an ordinary temperature 25 °C and an efficiency ranging between 40.85% and 70.01%.

Jiang, et al. [18] used a V-corrugated FPSC with an automated movable cover plate (MCP). A comparison experiment was conducted to investigate the impacts of MCP arrangement on overheating performance and loss of heat. The FPCs combined with the new MCP performed admirably in terms of decreasing heat loss and limiting overheating. Liu, et al. [19] developed an indoor collector experimental setup. They demonstrated collector tilt angle, solar irradiation, glass thickness, and flowrate on corrugated FPC thermal performance. Their results showed 4 mm best glass thickness, 1.5 °C best temperature differential and 89% best thermal efficiency. In addition, The findings indicated that the highest efficiencies are 89%, 86% and 73% when the flowrates are 0.15 kg/s, 0.13 kg/s, and 0.1 kg/s, respectively, and the related radiation energies are 670 W/m^2, 850 W/m^2, and 1000 W/m^2, respectively. Sharma, et al. [20] achieved an experimental investigation based on the collector absorber plate design adjustment. They evaluated circular absorber efficiency and the Contact of absorber tube trapezoidal surfaces. They found that trapezoidal absorber surfaces outperformed circular and plate absorber surfaces. Yehualashet, et al. [21] sought to experimentally and numerically examine a novel developed corrugated plate solar collector with a chevron absorber surface. The computational and experimental findings indicated that the sinusoidal corrugation increases bond conductance, resulting in a higher outlet temperature and a smaller plate-to-fluid temperature differential, increasing collector efficiency.

This paper evaluates the performance of the SWH system working with two different SC types. The first collector was set up with an FP type, while the second was with a VCP type. The two collectors are working at constant mass flow rates and same weather conditions. The study was carried out in winter 2022 for months (January, February, and March) Using Mosul, Iraq's solar irradiation during clear sky conditions for about 7 hours throughout the day.

The Inlet water, atmospheric air, outlet water, glass cover, and mean plate temperatures versus daylight hours were measured on January 10, February 12, and March 16 for the VCP collector and FP collector, respectively. These days have been selected according to weather conditions that are nice and free of dust and clouds. Solar irradiation values were measured every hour between 9 am and 4 pm. In addition, the thermal efficiency of FP and VCP is evaluated and validated with other data available in the literature.

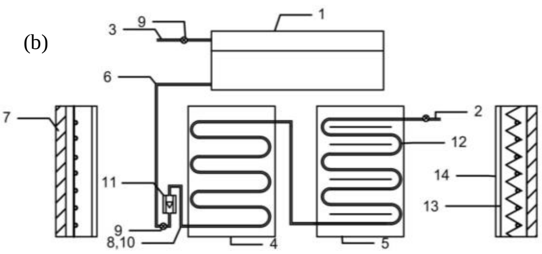
2. METHODOLOGY

2.1. Experimental Test Rig

The FP and VCP collectors under clear sky conditions have been evaluated experimentally for comparison under the same flow rate and weather conditions. Both collectors were manufactured and investigated in winter (January to March) in Mosul city in Iraq under the same flowrate of water 0.0165 kg/s and simultaneously for three months from 9.00 am to 4.00 pm.

Moreover, both collectors have the same dimensions with a 1.5 m^2 surface area; at the beginning, Two collectors were directed southward. Therefore, the SWH performance under the clear sky condition has been investigated experimentally.

The SWH system consists of 60 liters, a well-insulated tank, plastic tubes, one gate valve, and two collectors. The experimental setup, as well as the schematic representation of the SWH and collector components, are depicted in Figure 1. The SWH system dimensions are indicated in Table 1.



1 Collecting water tank
2 Pipe to exit the water to load
3 water Supply pipe
4 Flat plate collector
5 V-corrugated plate collector
6 The withdrawal tube from the tank
7 Glass wool insulation
8 point of the inlet pipe
9 Gate valve
10 Data logger
11 Rotameter
12 U-shaped tubes
13 Inner glass cover
14 Outer glass cover

Figure 1. Experimental test rig photograph and schematic diagram (a) Photograph, (b) Schematic diagram

Each collector consists of a plastic frame of 10 cm thickness, a black painted copper sheet of 2 mm thickness, 5 cm glass wool insulation thickness distributed along the bottom and edges of collectors, and two layers of glass covers of 3 mm thickness were used to reduce the thermal losses. In addition, seven pass water tubes were painted black to prevent the reflection of solar radiation and ensure high absorption and no thermal energy loss.

Table 1. Dimensions of solar collector

Parameter	Dimension
Collector surface area, A_c	1.5 m^2
The slope angle of the collector	48°
Collectors disposition	South
Space between glass cover and plate	5 cm
Distance between glass covers	2 cm
Number of glass covers	2
Glass cover thickness	3 mm
Thickness of insulation	5 cm
Tube material	Copper
Plate material	Copper
Plate thickness	2 mm
Diameter of tube	12.75 mm
Glass Emittance	0.88

The SWH system was installed on the roof of the solar energy lab building at Northern Technical University is located in Mosul, Iraq (longitude 43.12° E, latitude 36.34° N, latitude 228m). It was pointed due south (zero surface azimuth angle) and tilted by 48^o from horizontal. The absorber plates for both collectors were made from copper of 2 mm thickness. The water tubes of 12.75 mm diameters are fixed above the absorber plate by welding for both collectors. Finally, the horizontal V-grooved plate with 60° tilt angles and water tubes were joined together.

The experiment was done in winter of 2022 (February, January, and March). as stated by ASHRAE guidelines, the ideal collector tilt angles of these three months are close to 56°, 49°, and 39°, respectively [22]. As a result, to avoid frame construction complications and optimize sun radiation, its SC has been tilted in the flat direction by an optimum angle of 48°, reflecting the average algebraic angle of such months.

2.2. Experimental Procedures

This study evaluates the performance of FP and VCP solar water collectors with double glassed experimentally. VCP and FP absorber plates have been well-designed and constructed individually to prevent heat losses. This system works by natural water circulation between the water tank and the SC, so the distance between the tank and the upper edge of the SC does not exceed 50 cm. Therefore, the force of gravity circulates the water between the tank and the SC. A 60-litre cylindrical water tank was made of plastic and well-insulated to decrease heat loss and keep the water's temperature inside the tank during running hours.

The two collectors are connected in series such that, as the cold water flowing through the tubes of first SC (flat plate type) acquires heat and thus, its density is reduced. So the buoyant force drives the water to the highest point in the collector and leaves from the collector's upper side. Hot water that leaves the first collector enters through a completely isolated tube to the second collector (V-corrugated type) through a vent at the bottom of the second collector. The water acquires more heat through a V-type plate arranged in horizontal grooves and then drained to atmosphere.

The tubes were welded with grooves to exchange heat between them. The system includes a gate valve to control the water flow rate entering the collectors. A flowmeter type (uxcell 2-18 LPM Water Flow Panel Mount) was used to measure the flow rate of water entering the first collector, as shown in Figure 2a. In addition, a 16-channel Data logger type (8002-16A) was used to monitor the temperature at various sites, which are arranged as follows:

One channel was placed to monitor the temperature of ambient air, and the second channel was installed on the surface of the glass to measure the temperature of the cover. The third channel is fixed in the mid of the absorbent plate to read the mean plate temperature. In addition, two channels are installed as follows: One at the collector entrance to read inlet cold water temperature and the other at the collector outlet to read the exit hot water temperature, and thus the difference in temperatures between the inlet and exit water can be measured. The Data logger picture is shown in Figure 2b.

(a)

(b)

(c)

Figure 2. Measurement devices
(a) Flowmeter, (b) Data Logger, (c) Solar irradiance meter

The experimental work was conducted through winter (January to March) from 9.00 am to 4.00 pm. Glass, air, absorber plate, inlet and outlet water, and temperatures were measured every 30 minutes. Furthermore, solar radiation measurement was taken between 9:00 am and 4:00 pm every hour using a solar meter shown in Figure 2c (Seaward Solar survey 100 irradiance Meter) with an accuracy of 1 W/m^2.

3. THERMAL EFFICIENCY CALCULATION

The experimental useful heat gain of solar water collector may be evaluated as follows [23]:

$$Q_{\exp} = \dot{m} \times c_p \left(T_{out} - T_{in} \right) \tag{1}$$

The water mass flow rate can be calculated as:

$$\dot{m} = \rho \times V \times A_t \tag{2}$$

The water tubes' cross-sectional area can be estimated depending on tube diameter as follows:

$$A_t = \frac{\pi}{4} d^2 \tag{3}$$

The useful of heat gain to incident energy has been defined as the experimental thermal collector efficiency and expressed as follows [8]:

$$\eta_{\exp} = \frac{Q_{\exp}}{A_c \times I} \tag{4}$$

where, A_c is collector surface area m^2 and I is solar irradiation (W/m^2).

4. UNCERTAINTY ANALYSIS

The experimental uncertainty ω_η has been utilized to create a more precise calculation for thermal efficiency [23]. $\eta = f\left(I, T_i, T_a\right)$, so:

$$\omega_\eta = \left\{ \left(\frac{\partial \eta}{\partial I} \omega_I \right)^2 + \left(\frac{\partial \eta}{\partial T_i} \omega_{T_i} \right)^2 + \left(\frac{\partial \eta}{\partial T_a} \omega_{T_a} \right)^2 \right\}^{0.5} \tag{5}$$

where, ω_{T_i} and ω_{T_a} are temperatures uncertain ω_I is solar meter uncertainty. If $\omega_{T_i} = \omega_{T_a} = \pm 1\ ^{\circ}\mathrm{C}$, $\omega_I = \pm 1\ \mathrm{W/m^2}$.

5. RESULTS AND DISCUSSION

In this work, the performance of FPSC and VCP collectors was investigated under a constant mass flow rate and evaluated under the same working conditions. Furthermore, a comparison between experimental efficiencies has been made. Finally, both collectors' efficiency is evaluated and validated with other data available in the literature.

Figure 3 shows the distribution of solar irradiation along the selected days and hours (January, February, and March). These days have been chosen according to weather conditions that are nice and free of dust and clouds. Solar irradiation values were measured between 9 am and 4 pm every hour. The maximum solar intensity was recorded at 1 pm, Figure 3. Because the sun's height in Mosul city is greater in March than in January and February, the greatest solar irradiation values were measured in March, as illustrated in same figure. Solar irradiation generally starts with small values at sunrise hours, then increases as the time is close to mid-day hour, and then decreases [3].

The Inlet water, atmospheric air, outlet water, glass cover, and mean plate temperatures versus daylight hours on March 16 for the VCP collector and FP collector, respectively, indicated in Figure 4. It can be seen that the VCP collector has a higher outlet water temperature than the FP collector because the VCP surface area is larger than the FP type. So the V-grooved plate temperature is greater than the FP collector for the same weather condition and water mass flow rate.

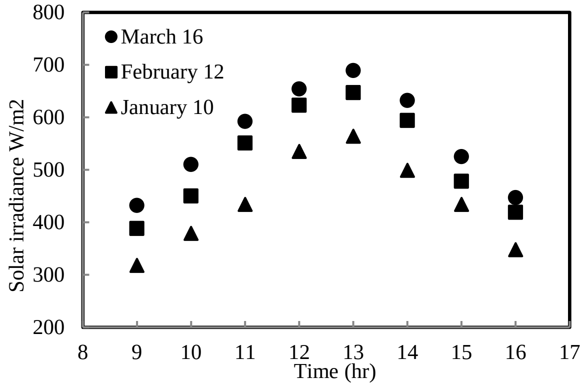


Figure 3. Solar irradiation versus day hours for three days (January 10, February 12, and March 16)

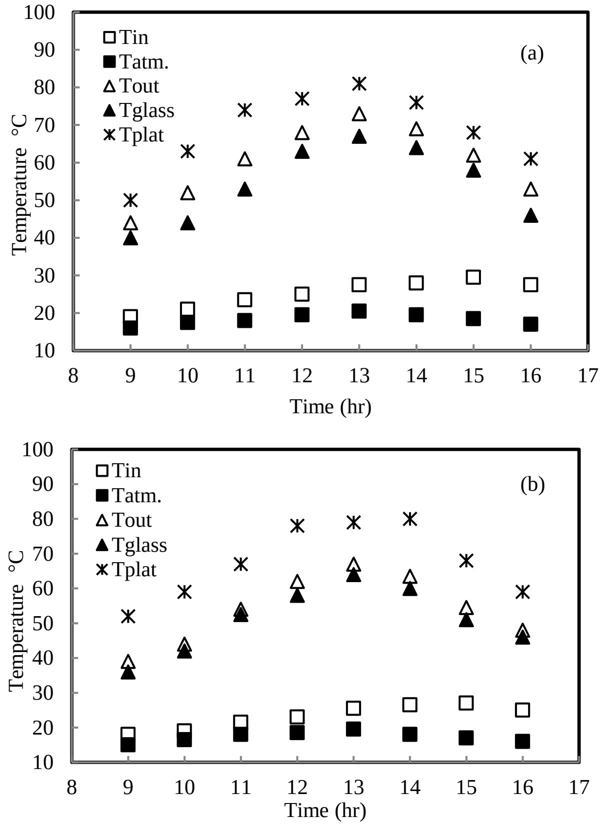


Figure 4. Inlet, atmospheric, outlet, glass, and plate temperatures versus day hours on March 16
(a) V-corrugated plate collector, (b) Flat plate collector

Figure 5 shows the temperature difference versus daylight hours on (January 10, February 12, and March 16) for VCP and FP collectors. It is clear that the VCP has a higher temperature difference than FP for all months, and the temperature differences reach maximum values at 1 pm. Furthermore, the highest difference occurs on March 16, when the sun is higher in the sky than in January and February.

The comparison between the average values of experimental efficiencies of both FP and VCP in (January, February, and March) was illustrated in Figure 6.

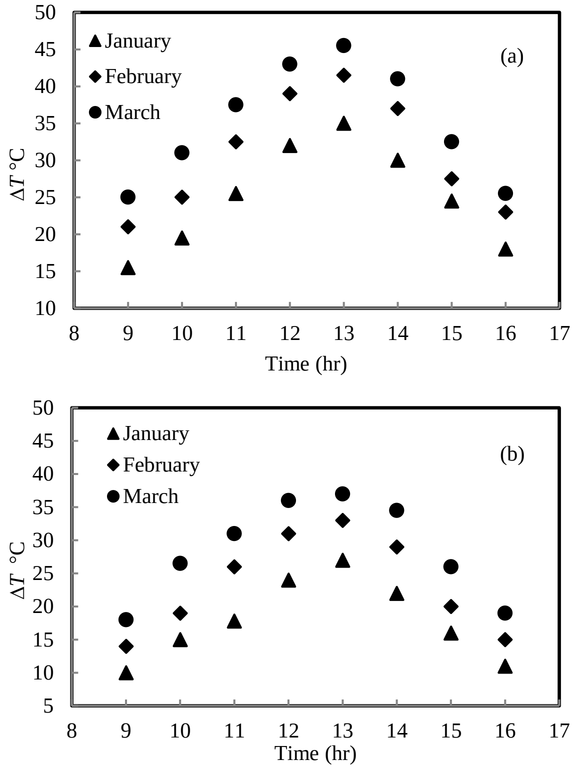


Figure 5. Temperature difference versus day hours for three months (January 10, February 12, and March 16)
(a) V-corrugated plate collector, (b) flat plate collector

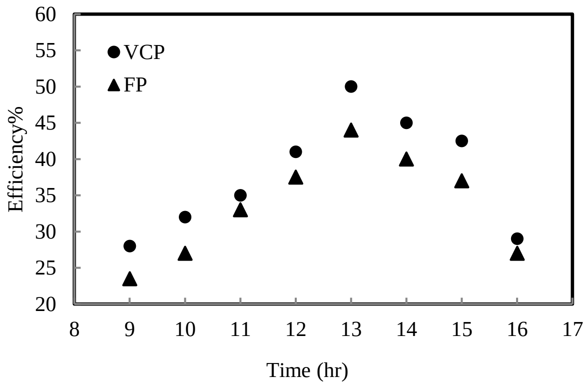


Figure 6. Experimental efficiencies versus day hours for three months (January 10, February 12, and March 16) for both VCP and FP collectors

It can be noted that the VCP thermal efficiency is higher than that for FP because the first one has a larger surface area than the second type. So the V-grooved plate can absorb more radiation than FP, which increases the thermal energy acquisition under the same water rate of 0.0165 kg/s. It shows that the experimental efficiency for VCP increases during the sunrise and reaches the maximum value (50%), while the efficiency for FP does not exceed (44%) at 1 pm.

Figure 7 shows the comparison between (FP) and (VCP) experimental efficiencies of the present work and that presented in Selvakumar and Somasundaram work [24]. It can be seen that there is a good agreement for all daylight hours, and these efficiencies have a similar trend of increasing gradually as the solar intensity reaches maximum value after one hour from the mid-day. It was observed that the VCP has the highest values of efficiencies compared to the FP due to the ability of the V-corrugated surface area to absorb more solar irradiation. The mean absolute percentage error (MAPE) between the results presented FP collector and FP in Selvakumar and Somasundaram work [24] was 8.8% and the (MAPE) between VCP of present work with that of the VCP of Selvakumar and Somasundaram work [24] was VCP was 7%.

Finally, it was observed that VCP has the highest thermal efficiency values than FP under similar weather conditions. This thermal efficiency trend agrees with the results obtained by [25], and the differences may be due to the location and solar intensity.

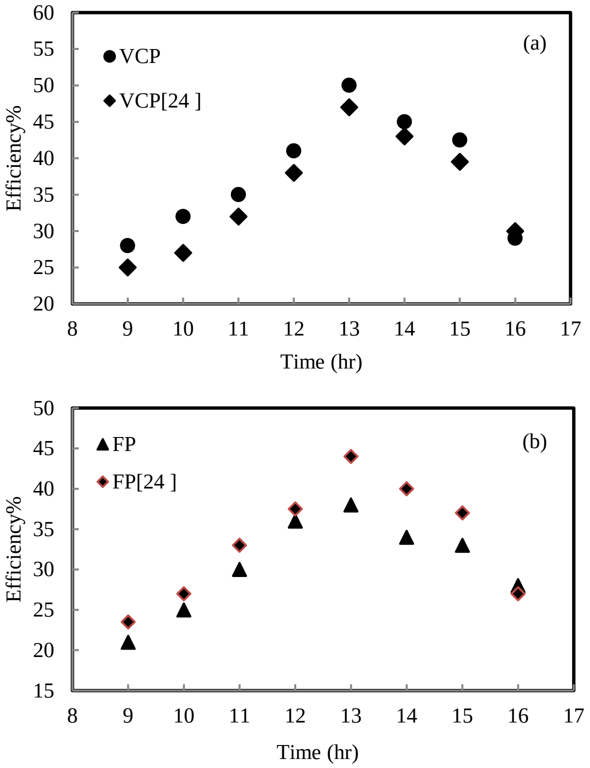


Figure 7. Comparison between experimental efficiency of the present work and data presented by Selvakumar and Somasundaram [24] (a) V-corrugated plate collector, (b) Flat plate collector

6. CONCLUSIONS

The thermal efficiency of V-corrugated and FP collectors has been investigated experimentally. This study is performed under Iraq climatic conditions for a constant water flow rate for water heating for domestic applications. It was concluded that:

1. A significant difference exists for solar radiation data that has been noticed in March and January related to the sun's height over the city sky being higher in March than those in January and February. Solar radiation peaked in March around 1 pm.
2. The thermal efficiency gradually increases against the sunrise hours until the maximum value at 1 pm for both V-corrugated and FP solar collectors under the same flow rate (0.0165 kg/s) and same weather conditions.
3. The plate surface area for VCP collector is larger than FP surface area, then VCP can absorb more radiation than FP collector.
4. The average values of experimental efficiencies (for three months in this study) were found to be equal to (50%) and (44%) for the VCP type and FP type, respectively.
5. The results of the present work and those presented in [24] have a good agreement for all daylight hours, such that the mean absolute percentage error (MAPE) of experimental efficiencies of FP and VCP collectors between the present work and those presented in the literature [24] was 8.8% and 7%, respectively.

NOMENCLATURES

1. Acronyms

DHTM	Dynamic Heat Transfer Model
FP	Flat plate
FPSWH	Flat plate solar water heater
FPSC	Flat plate solar collector
MCP	Movable cover plate
MAPE	Mean absolute percentage error
QDTM	Quasi-Dynamic Test Model
SWHs	Solar water heaters
SWCs	Solar water collectors
SC	Solar collector
TFM	Transfer Function Model
VCP	V- corrugate plate
VFPC	V-corrugated flat-plate solar collector
a	Ambient
c	Collector
Exp	Experimental
In	Inlet
Out	Outlet
t	Tube

2. Symbols / Parameters

A (m^2): Area
c_p (J/kg.K): Specific heat
d (m): Water tube diameter
$\dot{m}$ (kg/s): Mass flow rate
I (W/m^2): Solar irradiance
V (m/s): Air velocity
T (K): Temperature
η: Efficiency
ρ (kg/m^3): Air density
ω: Experimental uncertainty

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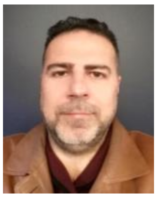

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