A NEW DESIGN OF SOLAR COLLECTOR USING MULTI-CORRUGATED CHANNELS

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ABSTRACT

The performance of a newly designed solar collector with multi-corrugated channels was investigated experimentally. Tests had been conducted outdoors under actual weather conditions. This paper presents a comparison between corrugated and straight channels for both forced and natural circulation conditions. The performance of the present corrugated channel under different operating conditions, was also investigated. The corrugated plate collector shows an improvement in the collector thermal performance (temperature rise and collector efficiencies) from 10% to 15% than the flat plate collector in the case of forced flow condition. For natural circulation flow condition, a little improvement in the heat transfer coefficient can be obtained. Consequently, a little reduction in the flow rate is noticed. The thermal and the exergitic efficiencies of the collector show an increase tendency with the increase of the working fluid volume flow rate.

Keywords: Heat transfer, Fluid flow, Solar energy, Thermal solar collector, Flat plate

INTRODUCTION

Testing of flat-plate solar collectors is usually performed under steady or transient conditions. Steady state methods are widely used, but they require that the ambient conditions be within certain limits. This condition may result in limiting the total time span available at the location for conducting the tests. To overcome these difficulties, transient test procedures under actual weather conditions have been used.

For collectors with liquid fluids, the most frequently used absorber design is the fin and tube construction and the rear used absorber design is the channel construction. With respect to manufacturing of absorbers, the fin and tube construction offers advantages. For example, absorbers of almost any total area, length and width may be fabricated by the use of one and same absorber fin. On the other hand, absorbers with channels over the whole area intrinsically show better thermal performance, as there are no heat losses caused by the fin.

Saito *et. al.* [1,2] derived the basic equations of a flat-plate finned-tube solar collector model, which describe the transient characteristics for periodic solar intensity variation. The fluid temperature distribution in a flat-plate finned-tube solar collector under the actual unsteady mode of operation was studied by Abdel-Azim *et. al.* [3]. A review of the literature on the test methods of flat plate solar collectors environmental conditions has been carried out by Amer *et. al.* [4]. The methods have been classified into six groups: simple, indoor, multi-node, multi-test, response function and unvalidated method. The results of different methods were compared with each other and with the steady-state values based on the ASHRAE 93-86 standard. The review reveals that test procedures based on multi-node models may not be implemented accurately in experimentation and Saunier's (multi-test) method yields parameters close to those obtained on the basis of the ASHRAE standard. A method to calculate the short-time dynamic behavior of solar collectors,

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working with varying fluid-flow rate, has been developed by Hilmer *et. al.* [5]. The extension of the method to finned-tube flat-plate collectors was demonstrated as well.

The information available on multi-channel solar collectors is surprisingly small in view of the many years of use of this geometry. Rommel and Moock [6] investigated analytically the collector efficiency for a narrow-channel absorber. They determined the temperature distribution on the absorber surface and in the fluid and used these results to calculate the efficiency factor. By comparing their absorber with tube and fin design, the results showed that the collector efficiency of narrow-channel absorbers may be higher.

To improve the performance of the solar collector, heat transfer devices can be employed to enhance the heat transfer through the already existing solar collector surfaces. The enhancement technique improves the connvective heat transfer and results in an increased rate of heat transfer per unit surface area. Various types of such devices have been employed and tested. The work by Emin *et. al.* [7] provides that an increase of 250 percent in the overall heat transfer enhancement can be obtained with a wall attached ring inserts in a pipe compared with an empty one. Heat transfer enhancement can also be accomplished through corrugated wall channels which recently found to have a very practical importance. The fluid flow in such geometry results in periodic changes of direction as it encounters the succession of peaks and valleys. A sinusoidal channels having constant period brought about an increase in the heat transfer with increasing the Reynlods number of the flow although the pressure drop in these channels remained almost constant close to straight channel results, [8]. Recently, Sano and Asako [9] stated that the behavior of the increase of the heat transfer coefficient is strongly related to turbulence intensity superimposed by the corrugation in near wall region.

In this paper, the performance of a newly designed solar collector with multi corrugated channels will be investigated experimentally. Tests have been conducted outdoors under actual weather conditions. The first part of this paper presents a comparison between this corrugated and straight channel for both forced and natural circulation conditions. Thus, the performance of the present corrugated channel under different operating conditions, is investigated

EXPERIMENTAL TEST RIG

In order to carry out the comparative study of the performance between the corrugated plate and flat plate collectors, an experimental test rig was designed. A schematic diagram of the collector-storage arrangement, measuring devices and the other control and piping systems are shown in Figure 1.

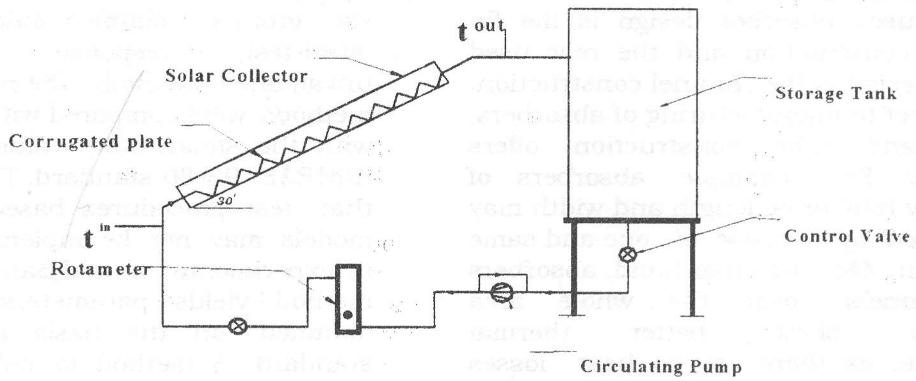

Figure 1 Schematic diagram of the Test Rig.

The collector is the part of the circuit which absorbs the solar radiation for heating the working fluid. The collector consists of an absorber plate, glass cover, insulation layer and the containing box. For this study, two different absorber plate collectors are used. The first one, is the normal type flat plate collector and the other one is the corrugated plate collector. The two collectors have the same dimension (1000 × 1900 mm) except that the new design has a corrugated channel absorber plate.

The absorber corrugated plate is formed from sheets of galvanized steel of 1.5 mm thickness. Each channel is corrugated at 15° tilt angle with horizontal plane, as shown in Figures 2 and 3, such that five channels are formed. Each channel has a rectangular cross section dimension of 100X12 mm and 1900 mm length. The distance between each channel (fin distance) is 1000 mm to compromise between the fin efficiency and the thermal efficiency of the collector.

The storage tank formed of double cylindrical tanks, the space between the inner and the outer tank is filled with glass wool insulation to form the insulation layer. The inner tank has dimensions of 530 mm diameter and 1000 mm height and is used as stratified storage tank for the loop. A water circulating pump is used to force the water through the circuit in the case of forced flow condition but for natural circulation condition the pump is by-passed from the circuit.

The discharge of the water flowing through the collector is measured by means of a Rotameter, which is placed between the storage tank and the collector inlet (down comer pipe). The flow rate is controlled by the control valve to the desired discharge. The local temperature through the circuit is measured by using (K-Type) thermocouples. And the total solar radiation is measured by using Pyranometer (photovoltaic).

The experiments are carried out outdoors, through an approximate complete solar hour of the day (9:00 to 20:00). The experiments are conducted under forced flow condition and also natural flow (thermosyphone effect) for each of corrugated plate collector and flat plate collector. For forced flow, the flow rate is varied from (0.25 L/min) to 1.5 (L/min). The ambient temperature and the total solar intensity incident on the collector is assumed to be approximately constant for all the experiments.

Figure 4 shows the variation of solar radiation through different days of July 1998, in which the experimental tests were performed. Through out all tests the solar radiation found to be approximately constant. The Appendix illustrates the date and the operating conditions for all the conducted tests.

PERFORMANCE CALCULATIONS

The experimental results obtained from the tests are analyzed to evaluate the performance of the solar collector as follows:

The total heat absorbed by the collector plate is calculated from the heat balance Equation 1 as :

$$\dot{Q}_c = \dot{m}cp(t_{co} - t_{ci}) \qquad (1)$$

The dynamic performance of the system is reflected through the instaneous collector thermal efficiency, and defined as the useful heat gained by the water divided by the total solar radiation incident on the collector [10 and 11]:

$$\eta_{th} = \frac{m_{cp}\ (t_{co} - t_{ci})}{I_o\ A_c} \qquad (2)$$

The primary energy utilization is given when using second law efficiency, based on the exergy of heat gained by the water, instead of the first law efficiency according to Equation 2. The useful exergy of heated water is expected to be very low compared with the primary exergy input to the collector. The exergy of heat absorbed by the water can be expressed as :

$$eq_c = \Delta h - T_a\ \Delta S \qquad (3)$$

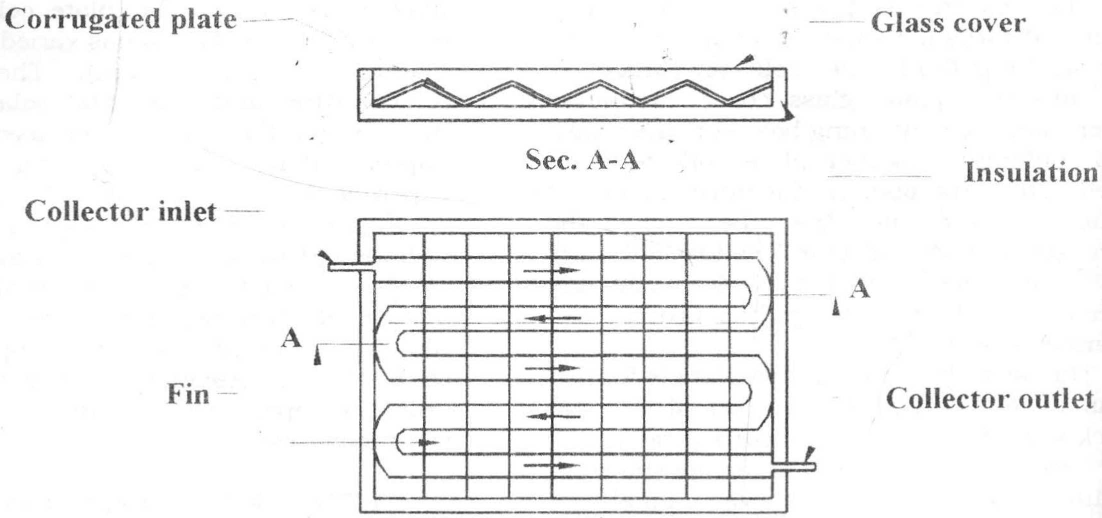

Figure 2 Corrugated plate

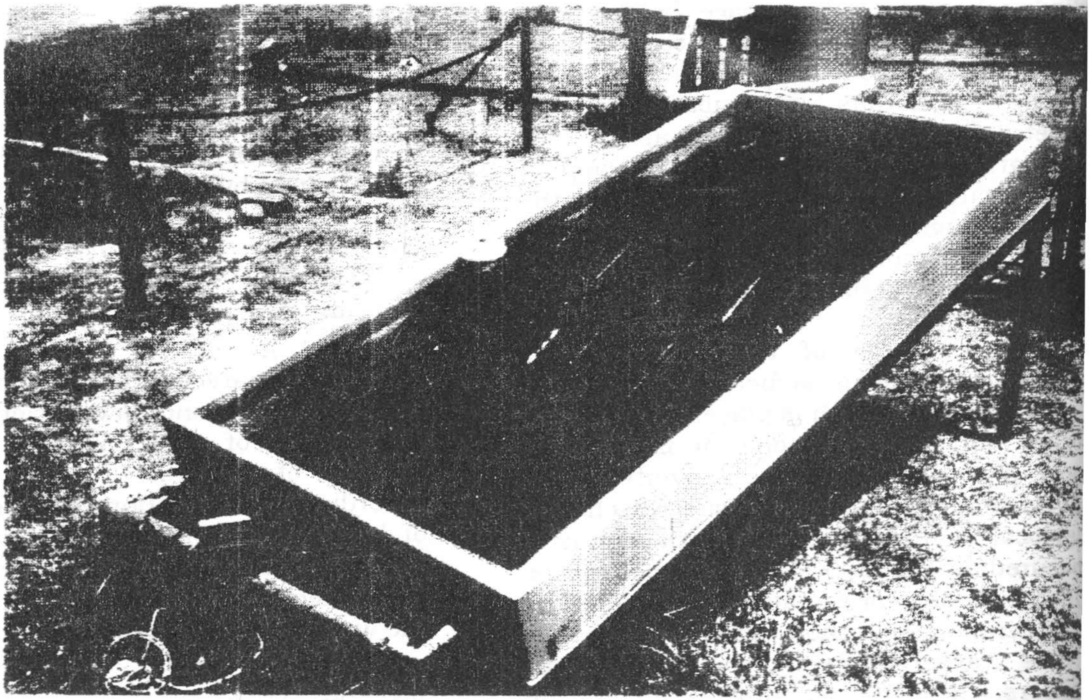

Figure 3 A photograph of the corrugated plate

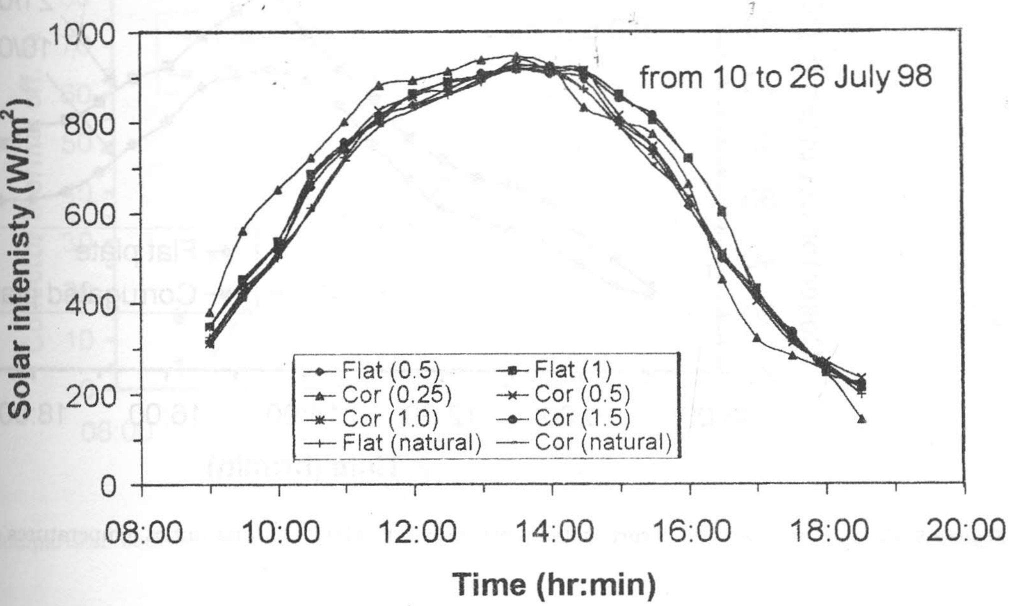

Figure 4 Variation of solar radiation through different days of the experiments

Where Δh is the enthalpy rise of water and ΔS is its entropy change. Thus, an expression for the exergitic efficiency of the system can be written as [12]

$$\eta_{ex} = \frac{\dot{m}\, eq_c}{A_c\, I_o\, \eta_{car}} = \frac{\dot{m}\, cp\left[(t_{co} - t_{ci}) - T_a \operatorname{Ln}\left(\frac{T_{co}}{T_{ci}}\right)\right]}{A_c\, I_o\, \eta_{car}} \qquad (4)$$

Where, η_{car} is the Carnot efficiency based on the ambient temperature (t_a) and the black body temperature, which gives the same I_o.

RESULTS AND DISCUSSION

The experimental results of this work can be classified into three parts, the first part, holds a comparison between the performance of the flat plate and the corrugated plate under forced flow condition. secondly, comparison between the performance of the flat plate and the corrugated plate under natural flow condition. Finally, the performance of the corrugated plate under different operating conditions is evaluated.

Forced Flow Condition

For the comparison between the performance of the corrugated and flat plate collectors, two experiments are conducted for different flow rates (0.5 L/min and 1 L/min). Figure 5 shows the variation of the collector outlet temperature at 0.5 L/min for each of the corrugated plate and the flat plate during the day. The outlet temperature of the corrugated plate collector found to be higher than the outlet temperature of the flat plate, this is due to the increase of the inside convective heat transfer coefficient of the corrugated channels than the flat channel. The increase of the heat transfer coefficient obtained from the corrugation of the channels increases the total heat absorbed by the plate, and consequently the outlet collector temperature of the water. Figure 6 shows the same variation as in Figure 5 but for 1 (L/min) flow rate, the same improvement of the heat transfer coefficient is cleared in the outlet collector temperature for the corrugated channels.

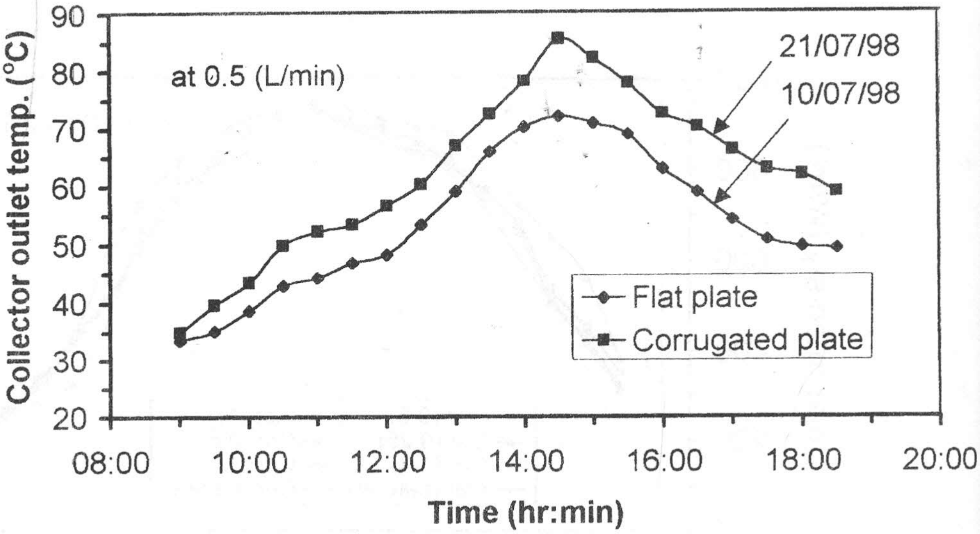

Figure 5 Comparison between corrugated plate and flat plate collector outlet temperatures at (0.5 L/min)

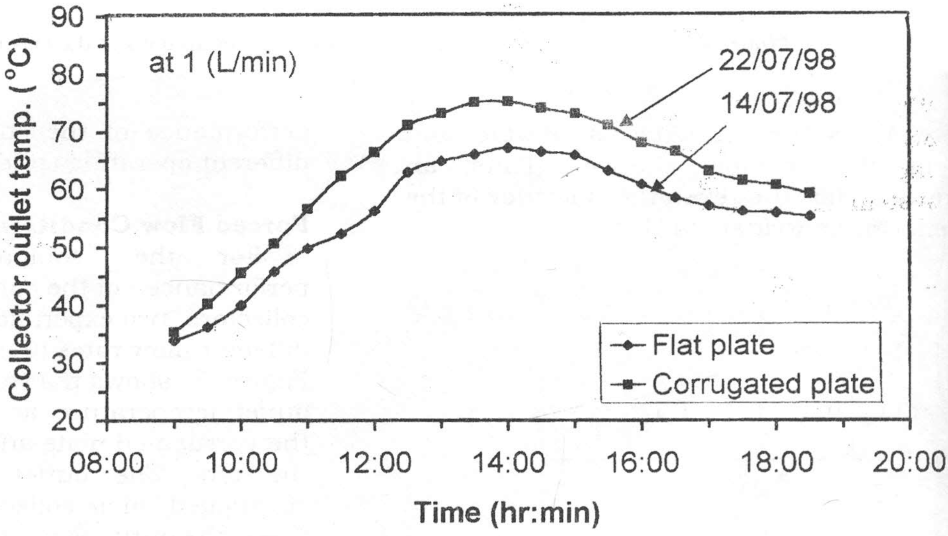

Figure 6 Comparison between corrugated plate and flat plate collector outlet temperatures at (1 L/min)

Figures 7 and 8 illustrate a comparison between the variation of the collector thermal efficiency for both corrugated plate and flat plate collectors at different flow rates (0.5 and 1 L/min) the thermal efficiency of the corrugated plate is higher than that of the flat plate, this is due to the improvement of heat transfer coefficient inside the corrugated channel which increases the absorbed heat from the plate and increases the thermal efficiency of the corrugated plate.

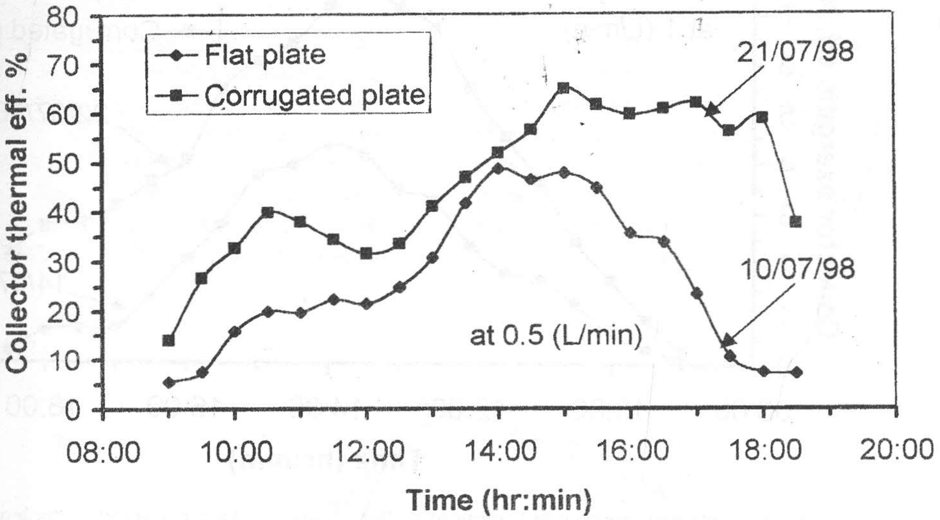

Figure 7 Comparison between corrugated plate and flat plate collector thermal efficiency at (0.5 L/min)

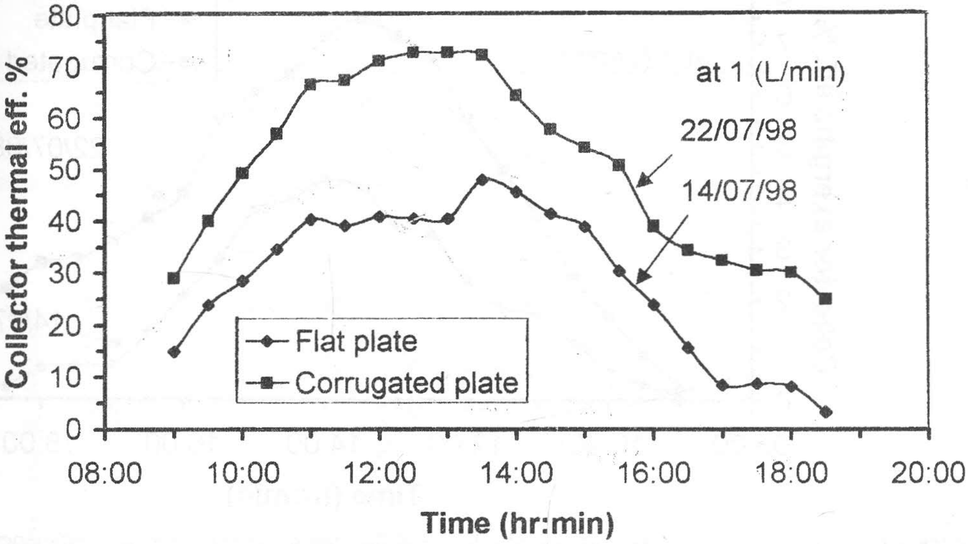

Figure 8 Comparison between corrugated plate and flat plate collector thermal efficiency at (1 L/min)

Figures 9 and 10 show respectively the same comparison as in Figures 6 and 7 but for the exergitic efficiency. The exergitic efficiency depends on both the collector thermal efficiency, and the collector outlet temperature. The increase of the collector thermal efficiency and the outlet water temperature cause the increase of the exergitic efficiency for the corrugated plate. The corrugated plate collector shows an improvement in the collector thermal performance from 10% to 15% than that for the flat plate collector.

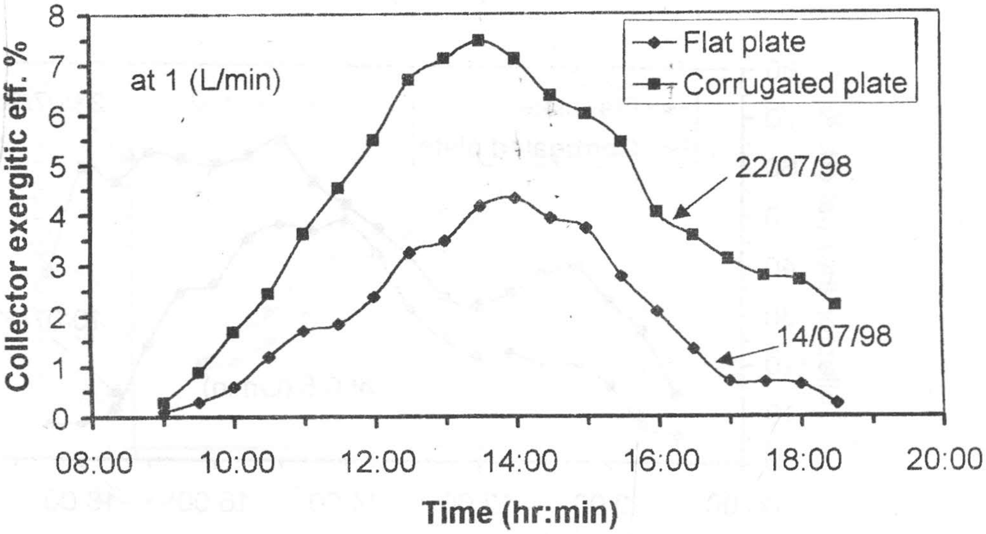

Figure 9 Comparison between corrugated plate and flat plate collector exergitic efficiency at (0.5 L/min)

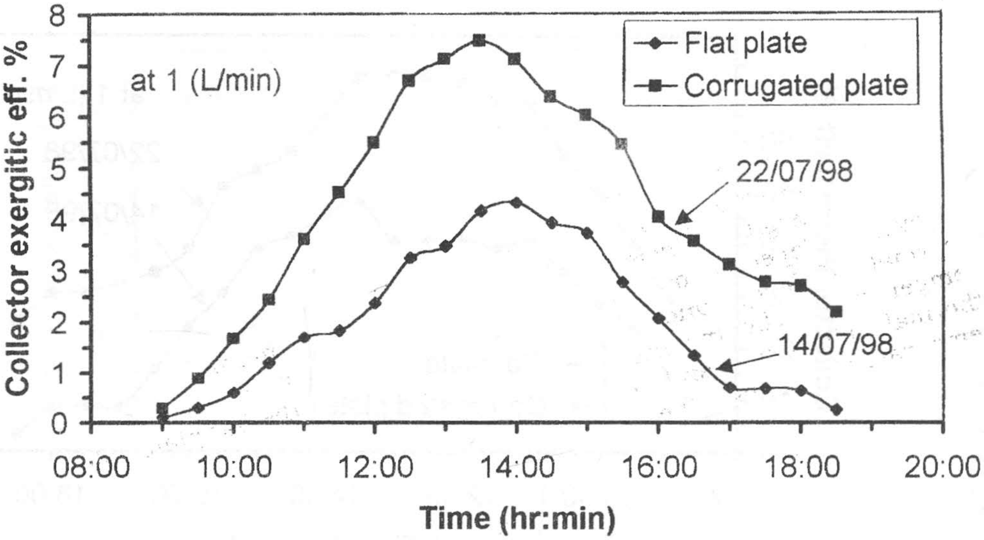

Figure 10 Comparison between corrugated plate and flat plate collector exergitic efficiency at (1 L/min)

Natural Flow Condition

In this case, the flow through the circuit depends on the thermosyphon effect which means natural circulation of the water, which depends on many parameters such as the temperature rise inside the collector (Driving force) and the friction through the circuit (resisting force).

Figure 11 shows the comparison between the collector outlet temperature for both of the corrugated and the flat plate collectors during the day. There is a very slightly effect for the corrugation on the outlet temperature. So, a little improvement in the heat transfer coefficient can be obtained. This seems to be due to the low flow rate resulting from the natural circulation through the corrugated channels.

Figure 12 shows the variation of the flow rate in (L/min) for both of the corrugated and flat plate collectors, normally for flat plate the flow rate increases when the temperature rise between the inlet and the outlet increase. From Figure 12 it can also be seen that the maximum volume flow rate can be reached around (0.6 L/min) for this case, then decreases again with the decrease of the temperature rise through the collector. However in the case of corrugated plate, the flow rate is lower than the flat plate and the maximum flow rate obtained is (about 0.48 L/min). It means that, with the corrugated plate a little reduction in the flow rate is noticed, this is caused mainly due to the increase of the friction resistance through the corrugated channels which is consequently decreases the thermosyphon effect. The variation of the Reynold's number, (Re = 25 to 330), for both cases are shown in Figure 13, the same behavior as in Figure 12 for volume flow rate is obtained.

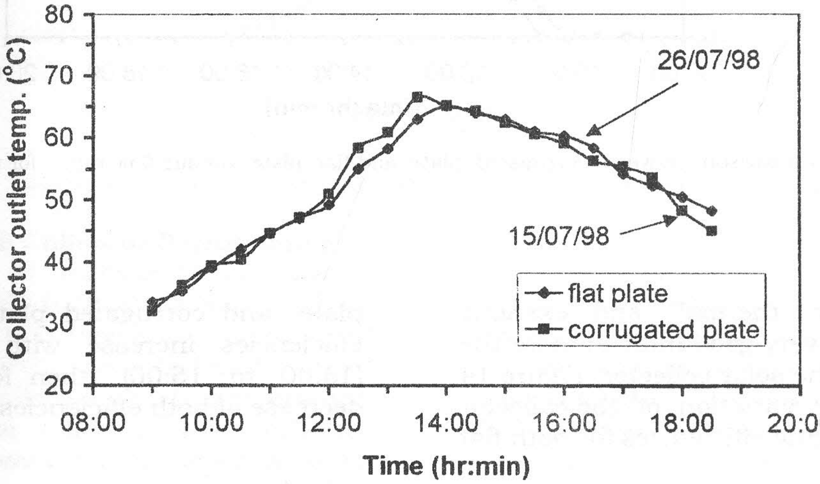

Figure 11 Comparison between corrugated plate and flat plate collector outlet temperature for natural flow.

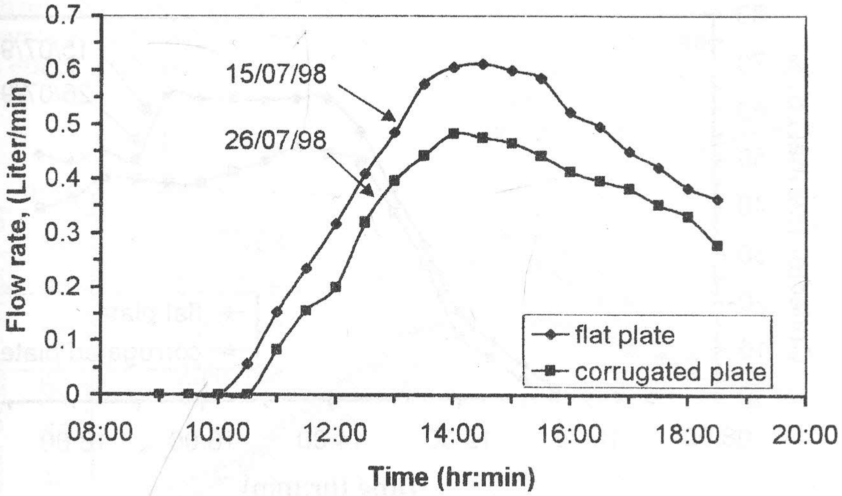

Figure12 Comparison between corrugated plate and flat plate volume flow rate for natural flow.

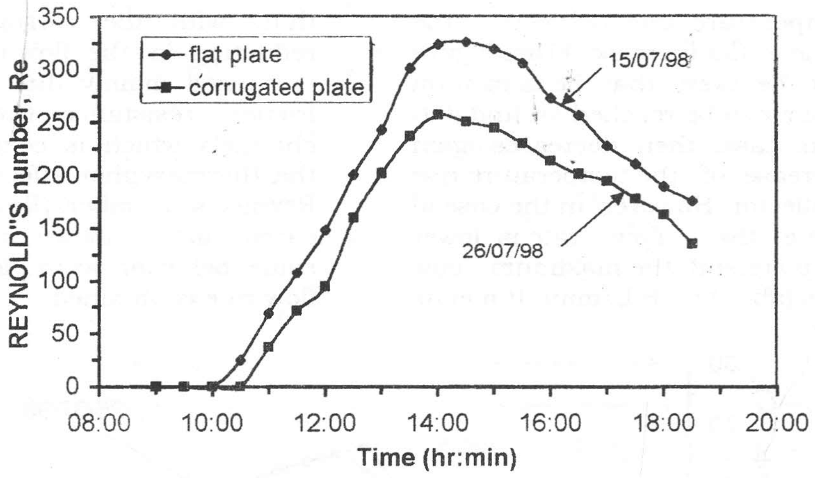

Figure13 Comparison between corrugated plate and flat plate volume flow rate for natural flow.

The collector thermal and exergitic efficiencies are a very good indication for the performance of the solar collector. Figure 14 and 15 show the variation of the collector thermal and exergitic efficiencies for both flat plate and corrugated plate collectors. The efficiencies increase with the time up to (13:00 to 15:00) then followed by slight decrease of both efficiencies.

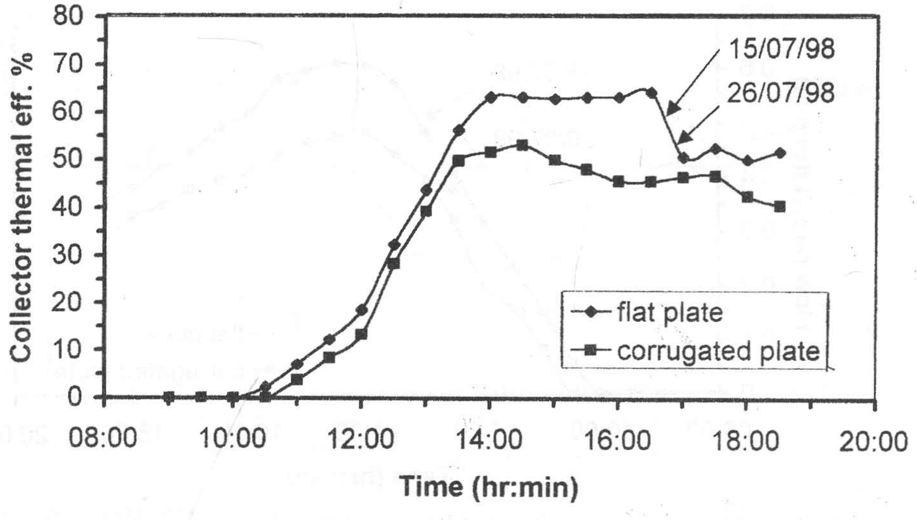

Figure14 Comparison between corrugated plate and flat plate collector thermal efficiency for natural flow.

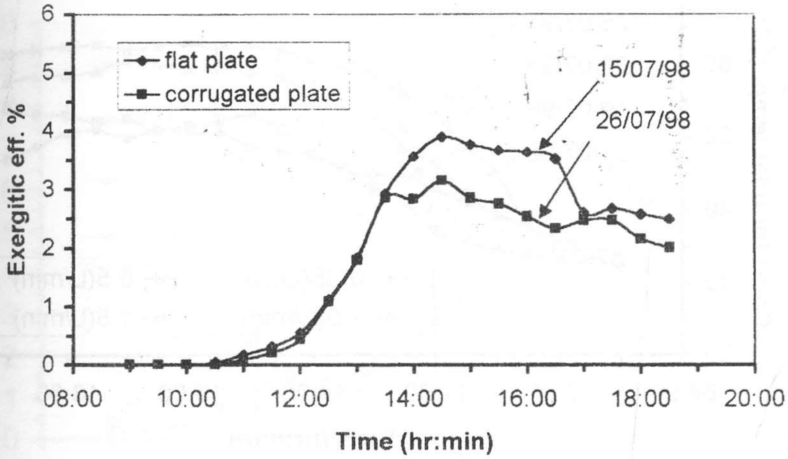

Figure 15 Comparison between corrugated plate and flat plate exergitic efficeincy for natural flow.

Corrugated Plate Collector Performance

This section of study gives the dynamic performance of the corrugated plate collector for different volume flow rate. The collector performance such as, collector outlet temperature, collector inlet temperature, collector thermal efficiency and collector exergitic efficiency mainly depends on the volume flow rate through the collector. The increase of the flow rate decreases the temperatures through the system but increases the system efficiency, the next figures show this effect in details.

Figure 16 shows the effect of the flow rate on the collector outlet temperature, the increase of the mass flow rate decreases the outlet temperature from the collector. This is due to the decrease of the absorber temperature at high flow rate. The effect of the flow rate on the collector inlet temperature, is mainly equal to the effect of the flow rate on the temperature distribution inside the storage tank. The increase of the flow rate causes the increase of the stratification of the storage tank and increases the temperature at the bottom of the tank, which is equal to the collector inlet temperature as shown in Figure 17, if no heat loss through piping.

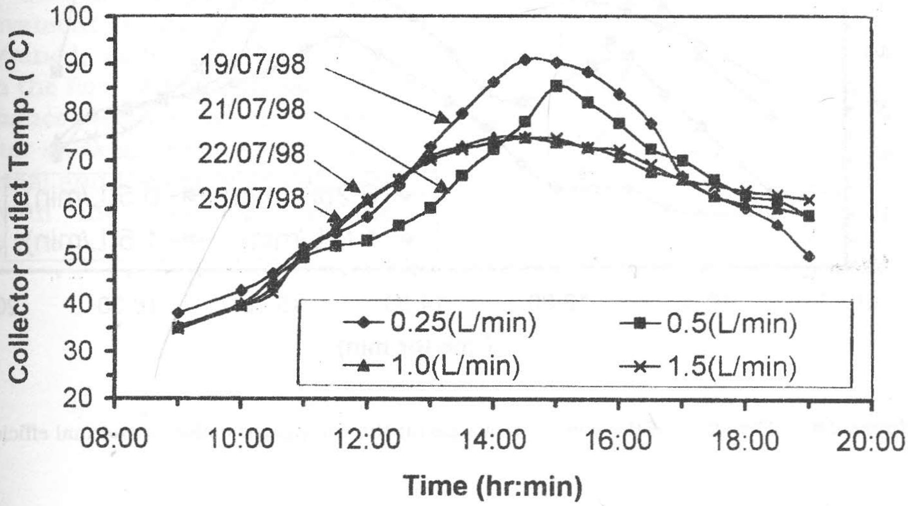

Figure 16 The effect of the volume flow rate on the corrugated collector outlet temperature

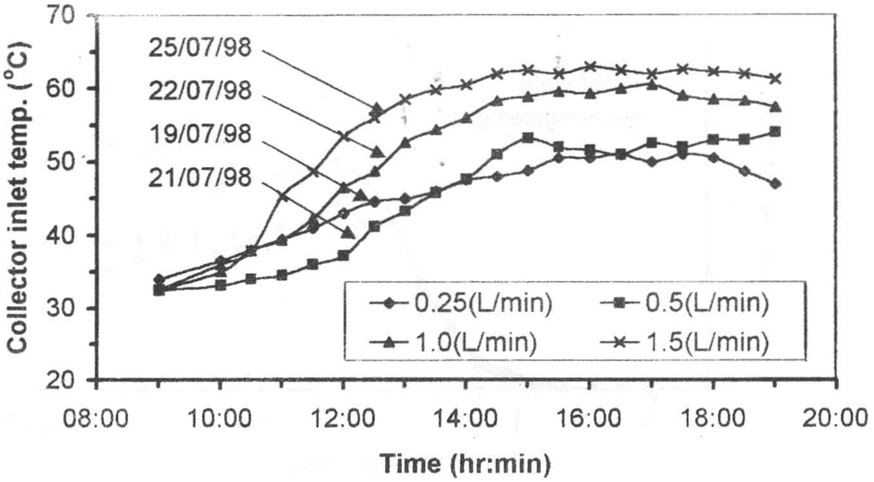

Figure 17 The effect of the volume flow rate on the corrugated collector inlet temperature

As mentioned before, the collector thermal efficiency increases when the flow rate increases as illustrated in Figure 18 and also the corrugation effect increases. The increase of the flow rate increases the heat transfer coefficient, due the increase of the turbulence intensity inside the channels. It causes tendency to increase the heat transfer coefficient inside the channel and in turn increases the quantity of the heat absorbed from the plate. The increase of the thermal efficiency, as well as, the increase of the improvement of the collector temperature gives an increase of the exergitic efficiency of the collector, this is described in Figure 19.

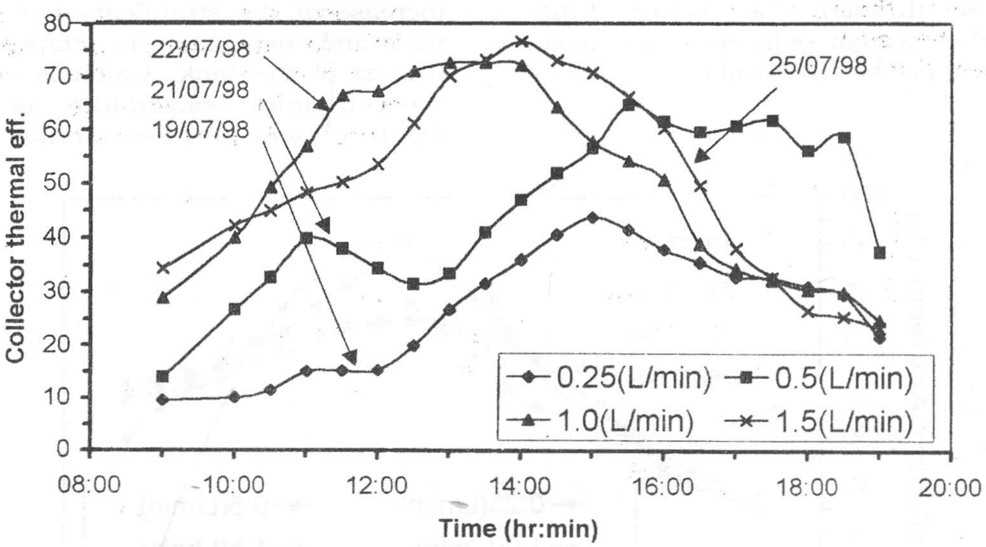

Figure 18 The effect of the volume flow rate on the corrugated collector thermal efficiency

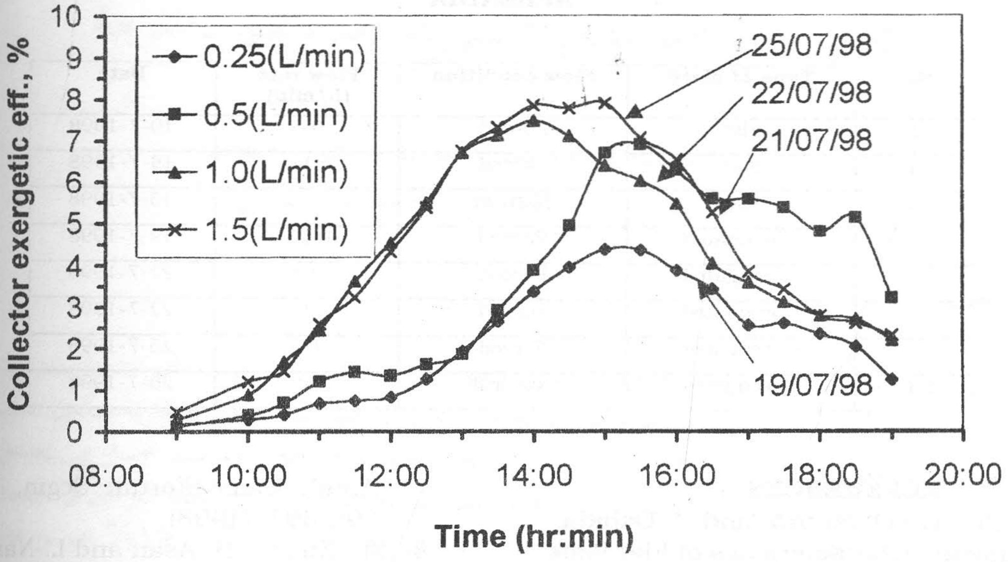

Figure 19 The effect of the volume flow rate on the corrugated collector exergitic efficiency

CONCLUSION

The performance of a newly designed solar collector with multi corrugated channel is investigated experimentally. From this paper, it is concluded that :

- The corrugated plate collector shows an improvement in the collector thermal performance (temperature rise and collector efficiencies) from 10% to 15% than the flat plate collector in the case of forced flow condition.
- For natural flow circulation condition, a little improvement in the heat transfer can be obtained, consequently, a little reduction in the flow rate is noticed.
- The performance tests of the corrugated plate collector show an increase tendency of the thermal and the exergitic collector efficiency with the increase of the volume flow rate.

NOMENCLATURE

A_c	collector area, mm^2
cp	water specific heat, J/(kg K)
d_h	channel hydraulic diameter, mm
eq_c	exergy of absorbed heat, J/kg
I_o	total solar radiation, W/m^2
M	mass flow rate, kg/s
Q_c	heat absorbed rate, W
T_a	ambient temperature, K
t_{ci}	collector inlet temperature, ^oC
t_{co}	collector outlet temperature, ^oC
u	water velocity through the channel, m/s
η_{car}	Carnot efficiency
η_{ex}	collector exegitic efficiency
η_{th}	collector thermal efficiency
ν	water kinematic viscosity, m^2/s
Δh	enthalpy difference, J/kg
ΔS	entropy difference, J/(kg K)
Re	Reynold's Number, (u $d_{h/\nu}$)

APPENDIX

No.	Type of plate	Flow condition	Flow rate (L/min)	Date
1	Flat	Forced	0.5	10-7-1998
2	Flat	Forced	1	14-7-1998
3	Flat	Natural	-	15-7-1998
4	Corrugated	Forced	0.25	19-7-1998
5	Corrugated	Forced	0.5	21-7-1998
6	Corrugated	Forced	1	22-7-1998
7	Corrugated	Forced	1.5	25-7-1998
8	Corrugated	Natural	-	26-7-1998

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تصميم جديد لمجمع سطحى شمسى بإستخدام القنوات المعرجة

نبيل المنشاوى و كمال مراد و أيمن محمد
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ملخص البحث

تصمم معظم المجمعات الشمسيه السطحية بأسلوب الأنابيب و الزعانف أو بأسلوب القنوات المستقيمة. فى هذا البحث تم تعديل أسلوب القنوات المستقيمة بتصميم قنوات معرجة. تمت الأختبارات العملية للمقارنة بين معدلات الأداء للمجمعات التى تعمل بأسلوب القنوات المستقيمة و الأخرى التى تعمل بقنوات معرجه و ذلك خارج المعمل فى وجود الظروف الطبيعية للتشغيل. فى الجزء الأول و الثانى من التجارب تمت مقارنة معدلات الأداء لكلا النوعين فى حالتى التدفق الجبرى والتدفق الحر. و قد أعطى التصميم الجديد معدلات أداء تزداد فى حدود من ١٠% إلى ١٥% عن معدلات أداء القنوات المستقيمه. أما الجزء الثالث فقد تناول أختبار معدلات الأداء للتصميم الجديد عند تدفقات متغيره. وقد وجد أن زيادة معدلات التدفق للسائل الوسيط تؤدى إلى زيادة الكفاءه الحراريه للمجمع.