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EXPERIMENTAL COMPARISON OF THE PERFORMANCE OF FOUR DIFFERENT DESIGNS OF FLAT-PLATE COLLECTORS

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Abstract

An experimental set-up was built to compare the efficiency of four different types of solar collectors. The first type consists of two parallel plates spaced 2.2 cm apart. The water is fed into the collector through one inch diameter tube, having a 1.6 cm wide and 65 cm long slot. The second type is also a two-parallel-plate type. The plates are 1.1 cm apart and the feeder is a one-inch diameter tube, having a slot which is 0.8 cm wide and 65 cm long. The third type is similar to the first one with the only difference that the tube feeder has 86 holes, 3-mm diameter each and separated successively by 1 cm. The fourth collector is one of the conventional type (tube type) which consists of 6 tubes, half inch standard threaded each. The distance between the center lines of the two tubes is 10 cm.

The comparison between the four types was made by two methods; i) the average efficiency methods recommended by NBS (National Bureau of Standards) ii) the system performance method based on thermosiphon action. The results of this study show that the collector, with 1.1 cm spacing between the plates gives the highest efficiency.

Nomenclature

A_c	Surface area of flat-plate collector, m^2.
C_p	Specific heat, $J.kg^{-1}.K^{-1}$
I_c	Total solar energy incident upon plane of the collector per unit time per unit area, W/m^2
$\dot{m}$	Mass flow rate, kg/s.
q_u	Useful heat output, W.
$T_{f,in}$	Temperature of the working fluid entering the collector, °C
$T_{f,out}$	Temperature of the working fluid leaving the collector, °C
t	Time, s.
η_c	Solar collector efficiency.

1 Introduction

Measurement of performance of solar collectors is an important step for the understanding of the systems used for space heating. Also comparing the performance curve is a good tool in selecting the suitable type of solar collector.

There are two basic methods for testing a collector: The instantaneous and calorimetric procedures [1]. For the instantaneous method it is only necessary to measure simultaneously the mass flow rate of the heat-transfer fluid flowing through the collector, its temperature difference, the collector inlet and outlet and insolation incident on the plane of the collector. The efficiency in this case can be given as [2,3].

$$\eta_c = \frac{q_u/A_c}{I_c} = \frac{\dot{m}\ cp\ (T_{f,out} - T_{f,in})}{I_c\ \ A_c} \qquad (1)$$

The calorimetric procedures employ a closed system in which the time rate of change of temperature of a constant thermal mass is measured and related to the incident solar energy through the relation:

$$\eta_c = \frac{\dot{m}\, c_p\ (\delta T/\delta t)}{I_c\, A_c} \tag{2}$$

The NBS [4] recommends that a series of tests should be conducted each of which determines the average efficiency for 15 minutes over a range of temperature difference between the average fluid temperature and the ambient air. The efficiency should then be calculated from the relationship

$$\eta_c = \frac{\int_0^t \dot{m}\ c_p\ (T_{f,out} - T_{f,in})dt}{A_c \int_o^t I_c\ dt} \tag{3}$$

Kreith [1] has introduced a thermal analysis of flat - plate collector-absorber plate. He concluded that, if the distance between the two tubes becomes zero (see Fig. 4.5, Ref [1]), the entire plate will be at the base temperature, and the fin efficiency approaches unity, the maximum portion of the radiant energy impinging on the fin becomes available for heating the fluid. This is the case when the collector consists of two parallel plates.

The author [5], has introduced a numerical solution of the natural convection problem, between two parallel plates. It was concluded that as the distance between the two plates increases the water flow rate increases while the average temperature decreases. In order to check if this is the case in two parallel plates collector, different types of collectors were designed, and selected to have different separation distance.

It is well known that the pressure drop plays an important role in the system performance, when the heating system works by thermosiphon. Also the uniformity of the flow is of importance, specially when the flow passes over a large surface area. To check which one of the above parameters is the most important, four different feeder types were selected.

The aim of the present work is to investigate and compare between the conventional solar collector (tube type), which is highly used in the Middle East area, and the two parallel plates as well as the effect of different feeder types on the system performance, when the system works by thermosiphon.

2. The Experimental Set-Up

A schematic diagram for the test apparatus is shown in Fig. 1. It consists of four flat-plate collectors (the figure shows only one of them). Each collector has a separate storage tank, and a selector key to measure the required temperature. All collectors are connected such that the flow of hot water from the collectors into the storage tank will be by natural convection, which is called thermosiphon system [6]. In such systems, under no conditions should piping smaller than half inch national pipe thread (NPT) be used. The flow rate through a thermosiphon system is about 40 liters.m^{-2}. hr^{-1} in bright sun [1].

The four types of solar colletors under investigation can be

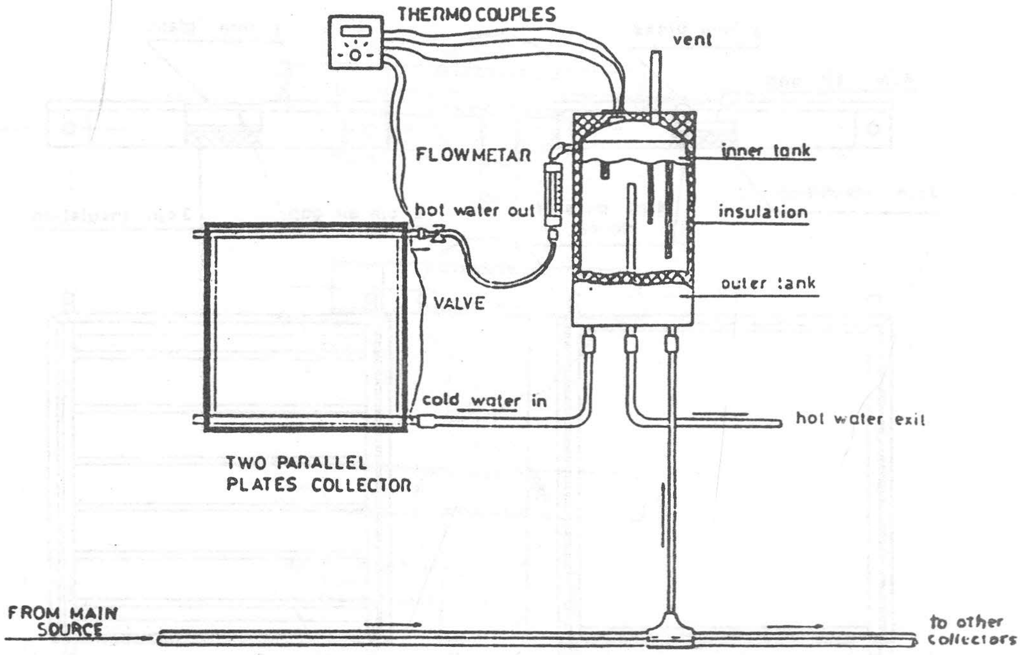

Figure 1. Schematic diagram of test apparatus

described as follows:

1. The first type consists of two parallel plates, spaced 2.2 cm apart(Fig. 2.a). The feeder type is one slot, 1.6 cm wide, 65 cm long on one inch NPT diameter tube.

2. The parallel plates in the second collector are separated by 1.1 cm. The feeder is one inch NPT diameter, having one slot 0.8 cm wide, and 65 cm long.

3. The third collector is again a two-parallel-plate type, where the plates are separated by 2.2 cm. The feeder is a one inch NPT diameter, and has 68 holes, 3-mm diameter each, and are 1 cm apart from each other. The feeder types are shown in Fig. 3.

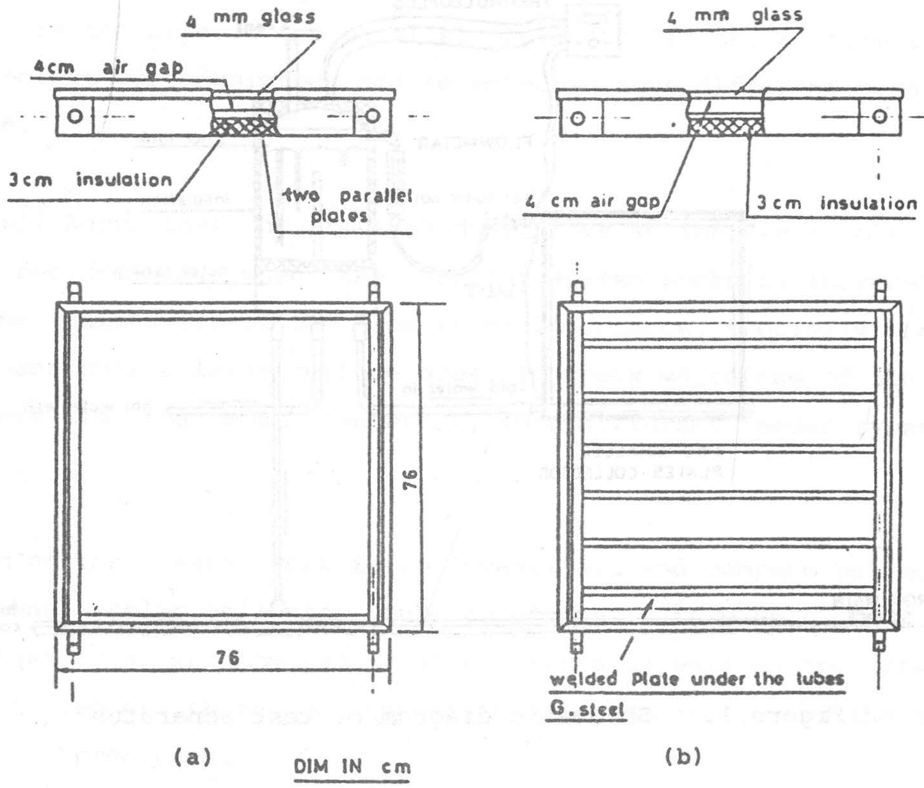

Figure 2. a. Configuration of two-parallelplate collector.

b. Configuration of tube collector

4. The fourth collector is one of the conventional type (tube type), which consists of 6, half inch NPT tubes, welded from both ends with two tubes, one inch NPT diameter each. The distance between the center lines of each two tubes is 10 cm.

The reasons behind the selection of the above mentioned types are:

1. To study the difference between the two parallel plates collector and the tube type.

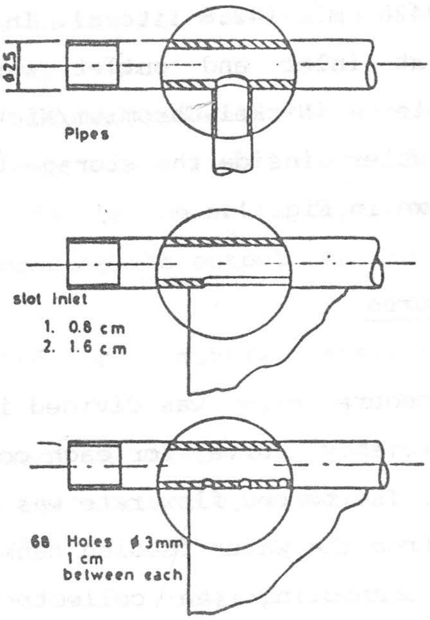

Figure 3. Types of feeders.

2. To study the effect of feeder type (types 1 and 3 have been chosen).

3. To study the effect of the plate separation (Types 1 and 2 have been chosen).

All collectors were chosen to have the same surface area 76x76 cm^2. The only reason for this is to fabricate two collectors from one commerically available metal sheet (1m x 2m).

The storage tanks were fabricated from galvanized steel. The outer container is 0.7 mm thickness, while that of the inner one is 2 mm. The inner tank has a diameter of 33 cm and height of 50 cm, and a total volume of 0.0428 m^3 (42.8 liters). In each collector, the fluid temperatures at inlet and outlet were measured using a K-type thermocouple (Nickel-Chromium/Nickel-Aluminium). The temperature of the water inside the storage tanks were measured at three locations as shown in Fig. 1.

3. Experimental Procedures

The experimental procedure here was divided into two parts. In the first part, the efficiency curve for each collector using NBS [4] method was carried out. The forced flow rate was obtained from a fixed pressure head coming from the water feeding tank. Figure 1 shows this case when the hose connecting the collector and storage tank is isolated. In the second part, thermosiphon behaviour was considered to investigate the temperature rise in the storage tank.

3.1 Part 1; Efficiency Curve

Before starting the test, all the collectors were set-up to work by the thermosiphon action for one day, this is in order to get a reasonable temperature difference between the inlet water temperature for the collector and the ambient ones. The following procedures were conducted:

1. The hose connected between the collector and the storage tank was properly isolated.

2. The valve was adjusted to get a constant flow rate (m).

3. The input and output temperature for the collector ($T_{f,in}$ and $T_{f,out}$, respectively) were recorded each minute.

4. The total insolation was recorded using a solarimeter, supplied by ISI company, Italy, Model TD 208b. This meter has the extra facility of instantaneously measuring the insolation and integrating it over the time to provide the total input energy ($\int_0^t I_c \, dt$). It is to be noted that the solarimeter has been calibrated by comparing its output reading with a pyranometer.

5. Step 3 was repeated for 15 minutes, every one minute.

6. The data obtained in steps 2,3, and 4 were substituted into equation (3) to calculate the average efficiency over 15 minutes.

7. The average efficiency obtained in step 6 is only a point on the efficiency curve. Therefore, in order to obtain the complete efficiency curve, the mass flow rate was changed and the above procedure from step 2 to step 6 was repeated.

It is to be pointed out that the efficiency curve for any flat-plate collector is affected by the incidence angle (as the incidence angle increases, the efficiency decreases). In the present experiment we do not have the facility for continuous tracking, therefore, it is assumed that there is a symmetry in terms of the incidence angle for the same period of time before and afternoon time. For example if the local noon is at 12 , the experiments performed at 11 AM, and the one at 1 PM are considered to have the same incidence angle.

3.2 Part 2; Performnce Curve Based on Thermosiphon System Behavior

Procedure

1. To make sure that the temperature inside the four storage tanks are identical, the system was drained and refilled before conducting this test.

2. The temperature of each storage tank and the total sun insolation were recorded instantaneously.

3. Step 2 was repeated every 15 minutes for at least 3 hours.

4. The average tank temperatures were plotted versus time for the four tanks over a period of 3 hours.

It is convenient here to mention that it was very difficult to have the same initial temperature inside the four storage tanks, therefore in the comparison it is better to consider the rise in temperature T, rather than the temperature itself.

4. Results and Discussion

The results of efficiency curves for the different collectors types, teken at different days but almost at the same time (average time 3 PM) are plotted in in Fig. 4. A least-square method was used to fit the experimental data. The resulting equations are written on the top of the figure, from which it is clear that the two parallel plates collector, spaced 1.1 cm, gives the best efficiency. However, of the figure is that, it does not give a higher range of temperature difference between the water inlet to the collector and the ambient temperature.

While carrying out the efficiency measurements, the inlet water temperature was noticed to decrease rapidly when the flow rate was high. This was one of the sources of errors in evaluating the collector efficiency. Another source of error was the accuracy of measuring the flow rate, which was slightly varying during the test.

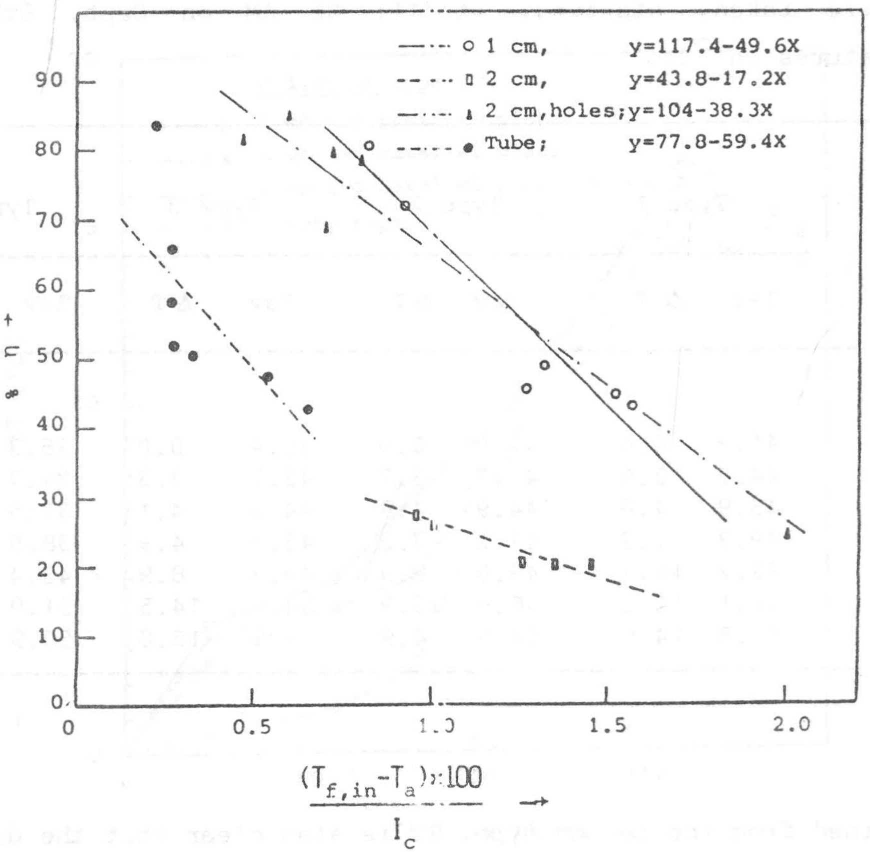

Figure 4. Experimental results for collector efficiency

For the above reasons, the reliability of measured efficiency is not quite good. This leads to the necessity of carrying out the second test.

The results of the experiment explained in part 2, taken in a clear-sky weather (September 6, 1988) are tabulated in table 1 and plotted in figure (5). It is clear from the figure that the highest increase of temperature (the average temperature of the storage tank at any time minus the average temperature for that tank at starting time Δ T)

Table 1. Experimental results for the four types of collectors. The data were taken, starting, at 11: 06 AM on Sept. 6th, 1988. (Temperatures in $^{\circ}$C).

Time	Type 1		Type 2		Type 3		Type 4	
minutes	Tav	ΔT	Tav	ΔT	Tav	ΔT	Tav	ΔT
00	41.9	0.0	40.0	0.0	40.4	0.0	36.3	0.0
23	44.5	2.6	43.7	3.7	43.7	3.3	36.7	0.4
60	45.9	4.0	44.9	4.9	44.5	4.1	37.5	1.2
81	49.2	7.3	47.2	7.2	45.3	4.9	38.5	2.2
113	52.2	10.3	49.9	9.9	49.3	8.9	45.4	9.1
159	58.1	16.2	56.9	16.9	54.9	14.5	51.9	15.6
193	56.8	14.9	54.9	14.9	54.2	13.8	50.9	14.6

is obtained from the second type. It is also clear that the difference in ΔT between the second and the first collector is slightly small while the difference in ΔT between the second and the third one is noticeable. This means that the effect of separation distance for the two parallel plates collectors is not significant, while the effect of feeder type is very important. The reason behind that is during thermosiphon action, the driving force is of buoyancy type, which is very small. Therefore, the feeder must be chosen such that it gives the minimum pressure losses. It is noted that, the rise in temperature for collector having less separation distance, is higher than that for the collector which has greater separation distance. This is in agreement with the conclusion obtained by Ref. [5].

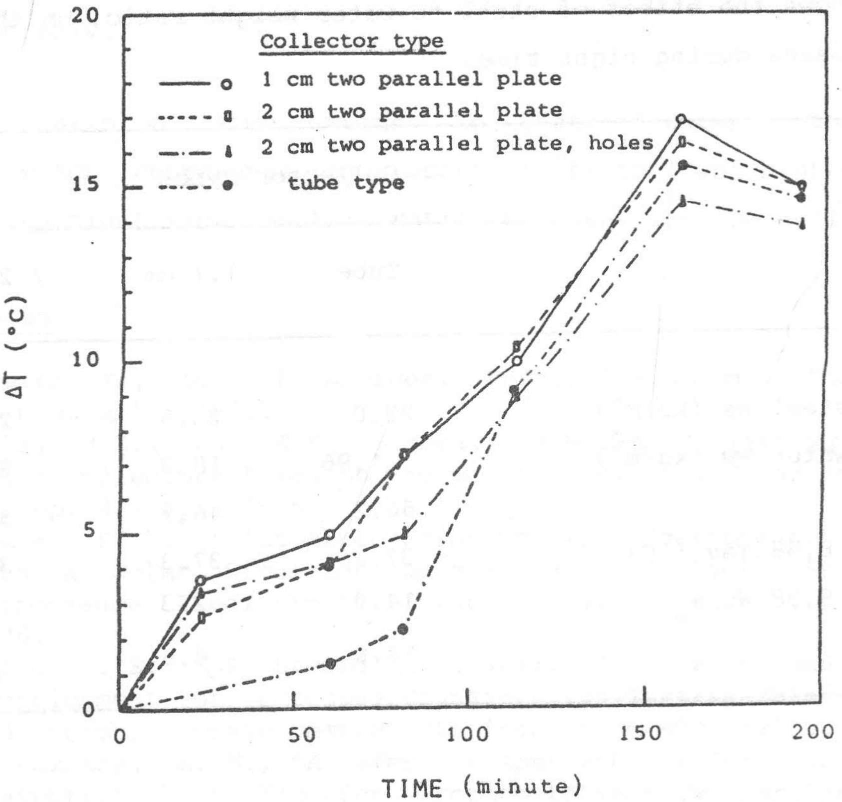

Figure 5. History of temperature rise for collectors in thermosiphon action.

For the tube type it is noticed that the rate of increase of temperature is higher than the other collector's at noon time, which means that the tube collector is affected by the incidence angle. Also it is noticed that the losses from tube collector is maximum during the night time. Typical values for temperature measurement are tabulated in table 2. The author believes that the ratio of the weight of collector (empty) to the weight of water inside the collector plays an important role for that phenomenon. Since the heat capacity (specific heat) of steel is lower than that of water, therefore, the steel works as a heat source during the day time (that is why the tube

Table 2. Shows the effect of steel to water weight ratio, on the losses during night time.

	Collector types		
	Tube	1.1 cm	2.2 cm
Weight of steel Ws (kg/m^2)	28.0	23.5	23.6
Weight of water Ww (kg/m^2)	1.96	10.0	20.0
Tav (°C)	50.2	46.2	36.1
7 PM. Sep. 8,88 Tav (°C)	37.2	37.3	35.1
8 AM, Sep. 9,88 Ws/W_w	14.0	2.3	1.18
T (°C)	13.0	8.9	1.0

type temperature increases rapidly), and as a heat sink during the night time (that is why the tube type temperature decreases too much during night).

5. Conclusions

1. The two parallel plate collectors with a separation distance about 1 cm, give the best efficiency.

2. The selection of feeder types has a great influence when the system works with thermosiphon. The best feeder is the one which has minimum pressure losses.

3. The tube type is good only when its load is in need during the day time only.

4. The ratio of steel weight to that of water content inside a collector represents an important factor which affects losses during night time. As this ratio increases the losses increase.

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