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EXPERIMENTAL STUDY OF NATURALLY CIRCULATED HOT WATER SOLAR SYSTEM

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Abstract

An experimental study was carried-out to investigate the thermal performance of naturally circulated hot water solar systems. Each of the three systems considered, consists of a flat plate solar collector (of different type design), naturally circulated water loop, and a hot water storage tank. One system was tested at the city of Baghdad and the other two were tested at Basrah, Iraq. The effect of the differences in the environmental conditions and the collector type on the systems performance are presented for both without and with hot water extraction. These results may be useful for both designers and analysts of solar energy systems, particularly in Iraq.

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Nomenclature

A&B	Refer to different types of solar collectors used in the city of Basrah, see Fig. (1).
a'	Collector area (m^2)
C	Specific heat (kJ/ kg. C^o)
I	Solar Intensity (W/m^2)
m	Mass flow rate (kg/s)
η	Collector efficiency, defined as: $\eta = [m.C.(T_{w,o} - T_{w,i})/I.a']$

Subscripts

a	air
i	inlet
ins	instantaneous
m	mean
o	outlet
w	water

1. Introduction

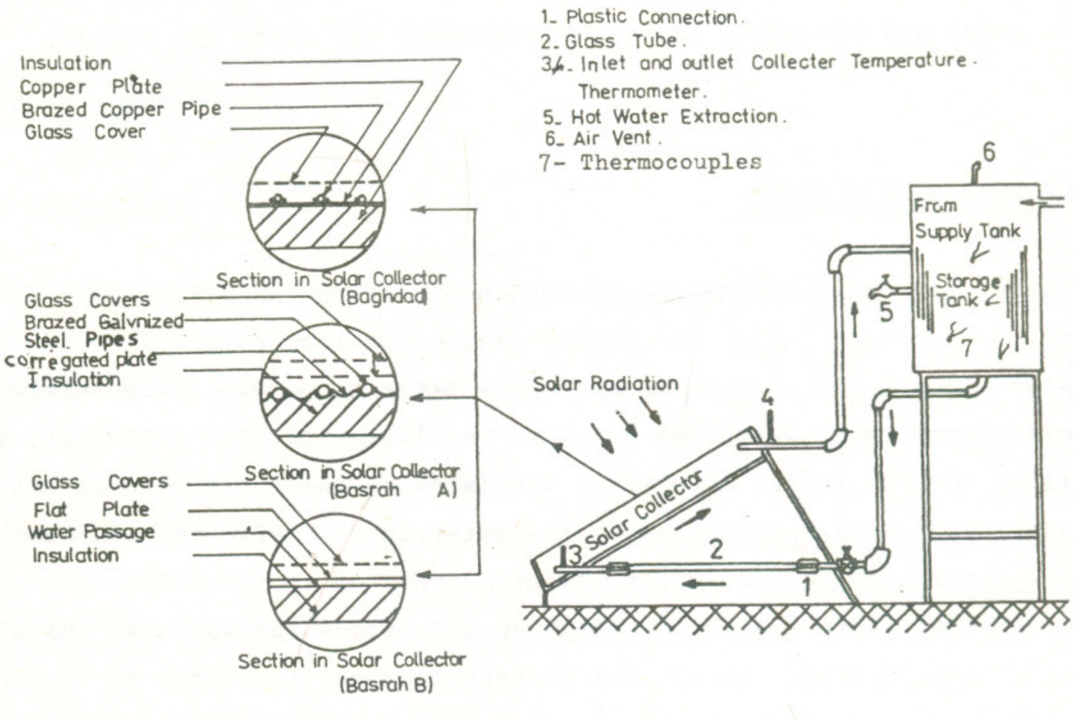
Solar energy utilization for water heating proved to be a good and reliable systems particularly for domestic uses. This fact is more significant in the areas which have a wide range of sunny hours as in Iraq (up to 4000 sunny hours/ year). Different studies have been carried-out to optimize solar collection parameters, systems performance, collected energy storage, ...etc. Inspite of such world wide researches, there is still a need to study the system performance under the local design and environmental consitions.

Solar heating water systems that utilize thermosyphon (natural circulation) flow to transfer solar energy from the collector to the hot water storage tank are widely used. These systems are simple, passive, and therefore they have relatively high reliability, maintianability, and minimum cost. There has been extensive work for the analysis of the performance of such systems [1 to 5]. Ahmed [6]., Khassaf [7], and Khassaf and Ahmed [8] studied the performance of a forced circulation solar water heaters in Baghdad and the effect of the number of collectors glass covers and the selective paint.

This investigation presents a continuation of these later studies, [6] to [8], and in particular the systems performance under different collector designs and different environmental conditions. Therefore, one naturally circulated system was tested at the city of Baghdad and other two were tested at the city of Basrah, Iraq. These two cities are 600 km apart and have different environmental conditions (Baghdad is sunny and dry while Basrah is sunny/cloudy, dusty and humid).

2. Experimental Setup

Figure (1) illustrates the present hot water solar system set-up. The system consists of a flat plate solar collector, naturally circulated water loop, and hot water storage - extraction tank. Three different collectors types were used as shown in Figure (1). The collectors were tilted towards south. A vertical insulated cylinder was used as the hot water storage/extraction tank. The water level inside the storage tank was controlled by a water float connected to the inlet cold water connection (from the supply tank) an extraction tap was also installed below the storage tank. The storage tank was connected to the solar collector through a naturally circulated loop. Extracted water flow rate was measured using scalled container and stop watch. The circulated water temperatures at collector inlet and outlet were measured using mercury thermometers. The average storage tank water temperature was measured by four thermocouples installed at different locations and levels inside the tank so that water stratification temperature differences is taken into account. For other thermocouples were used to measure the inner surface temperatures of both cover and absorber plates. The accuracy of these measurements are within 0.5°C, flow rates accuracy are within 4%. Table (1) summarizes the main differences between the system used in Baghdad and the two systems used in Basrah (see also Figure (1)).



Figure(1) Naturally Circulated Solar System.

Table (1) The Main Features of The Three Studied Systems, See Also Figure (1)

component	Baghdad	Basrah (A)	Basrah (B)
Absorber	Flat plate, copper sheet of 50cm x 50 cm, with five copper tubes (9.5mm diameter)brazed on the sheet,figure(1-a).	corregated galvanized iron plate of 100 cm x 100 cm, with seven galvanized tubes (12mm diameter) brazed on the sheet and 15 cm apart, see figure (1-b).	Tow iron flat plates of 100cmx100cm were welded and separated by 5 mm through which water flows. No. tubes are used, see figure (1-c)
Glass Cover	Single window glass cover of 4 mm thickness and 2.5 cm above the absorber	single and also double window glass cover of 4 mm thickness, 2.5 cm above the absorber and 2.5 cm sperating the glass covers	Single window glass cover of 4 mm thickness and 2.5 cm above the absorber.
Tilt Angle From horizontal	30 degrees	27 degrees	27 degrees
Hot water storage tank capacity	13 liters	40 liters	40 liters
Temperature Measurement storage absorber cover	 average of (3) thermocouples average of (2) thermocouples average of (2) thermocouples	 average of (4) thermocouples average of (6) thermocouples average of (4) thermocouples	 average of (4) thermocouples average of (6) thermocouples average of (4) thermocouples
Connecting loop pipes	12.5 mm inner diameter	13.7mm inner diameter	18.7 mm inner diameter

3. Results and Discussion

3.1 No Load Tests

Solar heating systems usually operates under such no load conditions, for working families, most of the day sunny hours. Therefore the tests will give a prelimenary results on the way the systems act under no hot water extraction. Figure (2) presents a selected systems temperatures during the day hours. Figure (2-a) shows the average storage hot water temperature for a sunny and partially cloudy days in Baghdad, as well as the supply water temperature. From this figure one can notice; (i) the average storage hot water temperature is initially higher than the supply water temperature due to the previous day solar energy storage, (ii) the supply water temperature continiously increases up to a maximum value (just after miday) after which it drops agian. The

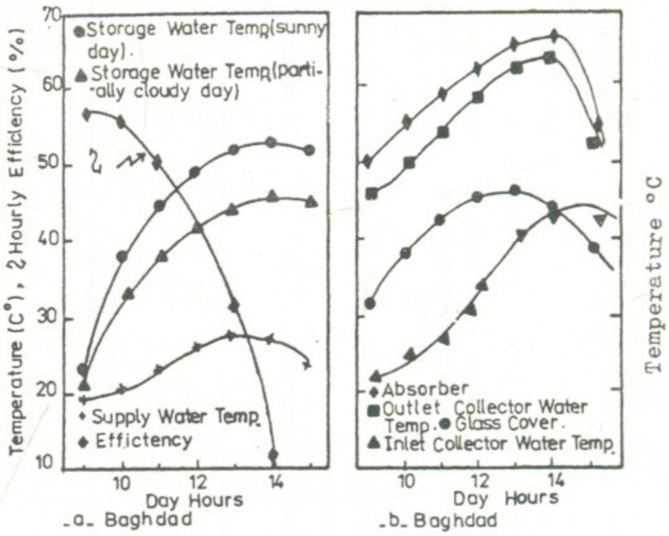


Figure (2) Solar System Temperature During Day Hours
(may 1986)

increase in the supply water temperature is expected since the supply water tank is subjected to some solar heating, (iii) for both sunny and partially cloudy days, solar heating is significant although the average storage water temperature is higher (by about 30%) for sunny day than its value for partially cloudy day, (iv) the maximum average storage water temperature is attained by 2.00 P.M. after which the temperature starts to drop again due to the presence of the collector shadow. Figure (2-b) shows the collector inlet and outlet temperatures and the absorber and cover inner plates temperatures during a sunny day hours. All temperatures increase during the day and reach a maximum value by about 2.00 P.M. The difference between the collector inlet and outlet temperatures is almost constant up to 2.00 P.M. after which the outlet temperature drops back while inlet temperature remains unchanged untill the two temperatures become equal. Both absorber and cover plates temperatures follow the same trend. Similar results were obtained for the systems tested at the city of Basrah.

Figure (3) shows a comparison between the effect of some design or operating parameters on the system performance at the city of Basrah. Figure (3.a) shows a comparison between the temperature results obtained at winter (Februrary) and spring (may) seasons. The maximum storage water temperature is higher in spring due to both higher supply water and higher absorber temperatures. Neverthless, it is also obvious that it is possible to obtain higher storage to supply water temperature difference in winter than spring. This is mainly due to (i) the collector relative smaller energy losses and (ii) the expected higher absorber to water temperature difference. The effect of dusty cover (not cleaned for 14 days) is shown in Figure (3-b) where the storage water temperature is shown to be reduced by 20 %. Figure (3-b) shows the hourly collector efficiency for clean and dusty covers. The

Table (3) Summary of results for variable load conditions

City (system)	Environmental conditions (month)	Load (rate of hot water Extraction) L/hr	Maximum storage hot water temp. °C	Time of Maximum storage water temp. temp. AM	Maximum initial to storage water temp. difference °C
Baghdad	Sunny day (may)	0.0	52.5	14	29.0
Baghdad	Sunny day (may)	1.0	45.0	13	15
Baghdad	Sunny day (may)	3.0	43.0	13	15
Baghdad	Sunny day (may)	5.0	50.0	15	25
Basrah (A)	Sunny day (may)	0.0	46	14.5	22
Basrah (A)	Sunny day (may)	10	26	13.5	14.5
Basrah (A)	Sunny day (may)	20	26	13.5	16.5
Basrah (A)	Sunny day (may)	25	21.5	13.5	8.5
Basrah (A)	Sunny day (may)	30	19.5	13.5	8.5

negative effect of dirty cover emphasises the importance of continious cover cleaning requirments (at least every 7 days). A comparison between two different types of collectors is shown in Figure (3-c), see also Figure (1). Collector type B is more effective than type A due to better heat transfer. Table (2) presents a summary of some important results obtained that could give a picture on the performance of the three tested systems. From the table one can realize that (i) the collected energy per unit area is higher at Baghdad mainly due to better environmental conditions, (ii) the collected energy in Baghdad is 50 % higher for sunny day than for partially cloudy day, (iii) the collected energy at Basrah in winter is higher than in spring.

The "instantaneous method", presented by Krider and Kreith [9] is used to compare the three types of collectors used. Figure (4) shows the instantaneous collector efficiency for the three types, refer also to Figure (1). The flat plate collector (Basrah B) has the highest instantaneous efficiency. In addition, the collector with corregated absorber (Basrah A) has higher efficiency when double glass cover is used than with single glass cover. The results of Kassaf [7] are shown for comparison.

3.2 Variable Load Tests

Different tests were carried-out for the three systems under variable loads (i.e. different rates of hot water extraction, from the hot water storage tank). Figure (5) shows samples of these tests results. From this figure, it is obvious that the value of the storage water temperature with load is less than its value with no load. Cold water temperature (make-up) is the reason behined this finding. Figure (5-a) indicates that in spring, the system is capable of providing storage

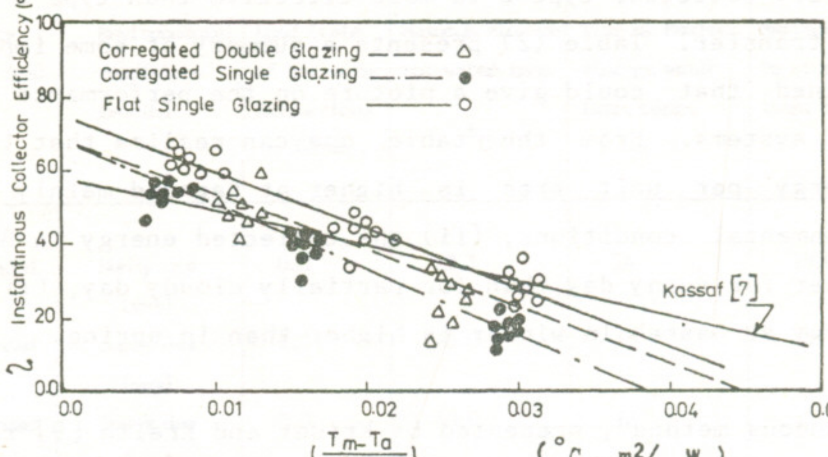


Figure (4) Measured Efficiency of The Solar Collector

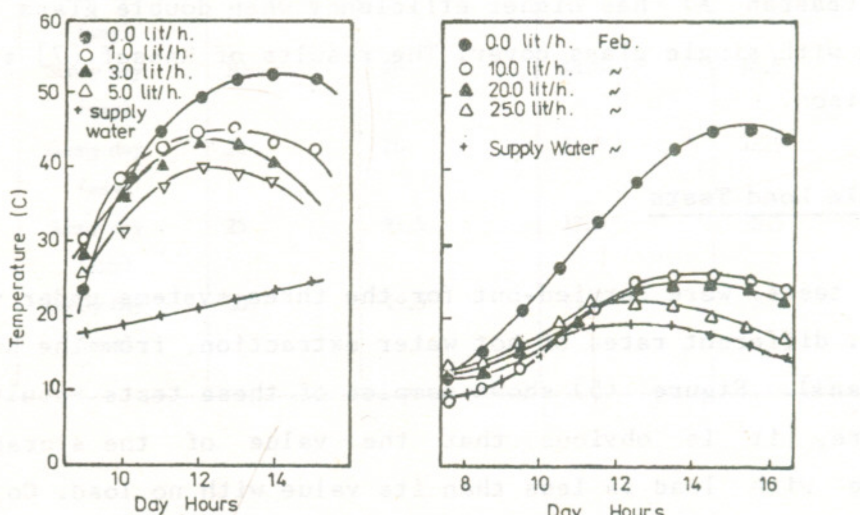


Figure (5) Effect of Different Rate of Extraction on Storage Tank Temperature.

water temperature as high as 45 C°, when the initial water supply temperature is between 23°C to 30 °C. On the other hand, the system in winter is capable of providing hot storage water at about 27 °C when the initial water temperature is between 8 °C to 13°C. The maximum storage temperature decreases as load increases. Exceptions may occure due to unexpected environmental conditions. The maximum storage temperature is attained at or near noon time. It should be remembered that the relatively high rate of hot water extraction, as compared to the storage tank size, may be a reason behined the low storage water temperatures attained. Table (3) presents additional results obtained under variable load tests.

4. Conclusion

The thermal performance of naturally circulated solar system (for water heating) has been investigated experimentally. Three systems were tested, one at Baghdad and the other two at Basrah, Iraq. The effect of environmental conditions as well as collector type on the system performance were studied for operating conditions and different rates of hot water extraction. The results can be summarized as follows:

1. The solar system temperatures, including the storage hot water, increase during the day hours up to a maximum value (at about 2.000 P.M. for no load, and, at 12.00 noon under variable loads conditions) after which they drop again due to the presence of collector shadow, and higher radiative and convective losses.
2. Although the systems are capable of providing high storage hot water temperature at spring (up to 55 °C), the results show that the temperature difference between the hot water (storage) and the cold water supply (make-up) is higher at winter than at spring.
3. Flat plate (box type) collector has the highest collector

Table 2. Summary of results obtained for No load conditions

system	Environmental condition (month)	Storage tank size liter	Maximum initial to storage water temp. diff. °C	Collected Energy per unit area kJ/m^2
Baghdad	Sunny(may)	13	29.0	6443
Baghdad	Partially cloudy (may)	13	19.0	4149
Basrah(A)	Sunny (may)	40	22.0	3696
Baarah(A)	Sunny (Feb.)	40	34.0	5712
Basrah(A)	Partially cloudy (may)	40	20.5	3464
Baasrah(B)	Sunny (Feb.)	40	28.5	4788

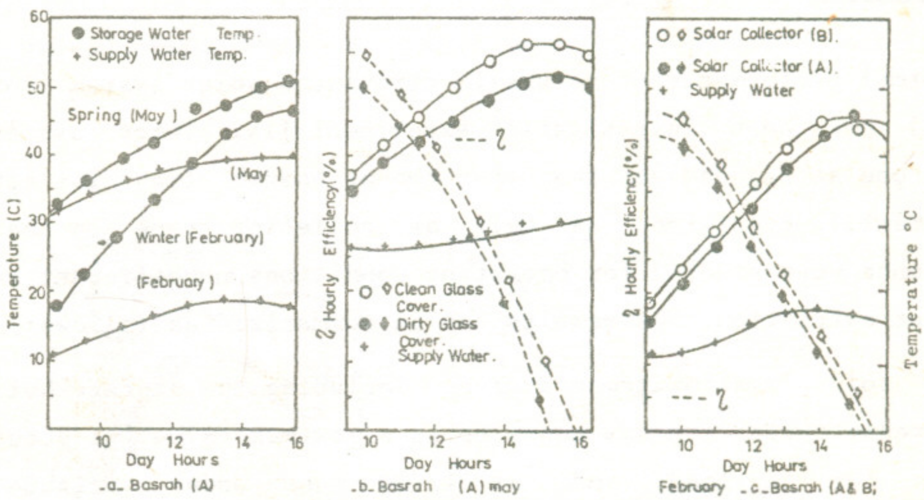


Figure (3) Solar System, Temperature and Collector Hourly Efficiency During Day Hours for Basrah.

efficiency. Double glass cover collector are more effective than single glass cover collectors. In addition, the dusty covers (not cleaned for 14 days)were found to reduce the attained storage water temperature by 20 %.

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