Flat Plate based- Solar System with a tracking system

M. Abdunnabi[1], A. Abusalama [2], M. Algamil[3] , and M. Almontaser[4]

[1]Center for Solar Energy Research and Studies, Tajoura, Tripoli-Libya

[2]Mechanical Engineering, Tripoli University, Tripoli, Libya

[3]Mechanical Engineering Department, University of Subratha, Subratha, LIBYA

[4]Mechanical Engineering, Tripoli University, Tripoli, Libya

e-*mail:* [1]*m_abdunnabi@csers.ly;*

Abstract: Water heating in Libyan domestic sector represents over 29% of the total electrical consumption. There is a great potential of hot water usage in the industrial and other sectors. Solar energy can play vital role in providing hot water to the residential and industrial sectors. In this paper, numerical simulation and experimental investigation are undertaken to study the enhancement of thermosyphon solar water heater with flat plate collector system through design, manufacturing and implementation of a single axis tracking. The collector tracks the sun in a band angle equal to 70° from east to west with surface tilted angle of 45° from the horizontal. The design and manufacturing processes of the tracking system and assembling to the thermosyphon systems are presented. Numerical simulations are carried out using TRNSYS software where several cases of one axis and two axis tracking systems are simulated and presented in this paper. TRNSYS simulation results indicate that 38% extra energy can be harnessed in case of single-axis tracking system over stationary one. Experimental testing of designed tracking system are performed along with stationary identical system for several months, substantial amount of data are. The results show that the performance is enhanced by an average value of 21.17% over stationary one. This result is considered to be very reasonable compared with the theoretical one. The additional cost incurred due to the inclusion of the tracking system is estimated to be 20.4%.

منظومة تسخين شمسي بمجمع شمسي مسطح مع منظومة تتبع شمسي

محمد عبدالنبي[1]، علاء ابوسلامة[2]، المبروك الجميل[3]، محمد المنتصر[4]

[1]مركز بحوث ودراسات الطاقة الشمسية ـ طرابلس ـ ليبيا

[2]كلية الهندسة ـ جامعة طرابلس ـ طرابلس ـ ليبيا

³كلية الهندسة- جامعة صبراتة- صبراتة -ليبيا

⁴كلية الهندسة- جامعة طرابلس- طرابلس - ليبيا

ملخص: يمثل تسخين المياه في القطاع المنزلي بليبيا اكثر من 29 % من الطاقة الكهربائية الكلية المستهلكة. وهناك اتاحية كبيرة لاستخدامات المياه الساخنة في القطاع الصناعي والقطاعات الاخرى. الطاقة الشمسية يمكن ان تلعب دورا في توفير المياه الساخنة للقطاع المنزلي والصناعي. في هذه الورقة دراسة نظرية وعملية اجريت لمعرفة تعزيز السخان الشمسي بمجمع شمسي مسطح من خلال تصميم وتصنيع وتطبيق تتبع احادي المحور. المجمع الشمسي يتتبع الشمس في مدى 70 درجة من الشرق إلى الغرببزاوية ميل للمجمع الشمسي تعادل 45 درجة. المحاكاة اجريت باستخدام برنامج الترنزيس في حالة احادي وثنائي المحور. نتائج الترنزيس اظهرت ان 38 % زيادة في الطاقة يمكن تحقيقها في حالة التتبع احادي المحور عن حالة عدم التتبع. الاختبارات العملية للمنظومة الشمسية احادية تتبع الشمسي واخرى ثابته ممائلة لها. النتائج العملية بينت ان 21.17 % تحسن في الاداء للمنظومة المتتبعة عنها في المنظومة الثابته. وهذه النتيجة تعتبر مقبولة مقارنة بنتائج المحاكاة. التكلفة الاضافية نتيجة اضافة منظومة تتبع لحركة الشمس تقدر بحوالي 20.4 %.

Keywords: Thermosyphon; Solar water heating; Solar collector; Solar tracker; TRNSYS.

1. INTRODUCTION

Libya is blessed with high solar insolation due to its location in the Sunbelt region that characterized with the highest solar insolation in the globe. The daily average of solar radiation on a horizontal plane is 7.1 kWh/m2/day in the coastal region, and 8.1 kWh/m2/day in the southern region, with an average sun duration of more than 3500 hours yearly [1,2].

As well known, domestic solar water heaters can be found today in the market as active or passive systems. Thermosyphon systems are the most common systems used worldwide in domestic appliances, where the demand for the hot water is not too insistence. However, in cold areas and homes with weak roofs and when the demand for hot water in insistence, thermosyphon systems are not the best option. Forced circulation systems are the most appropriate systems for large applications and in areas with sub-zero temperatures. Thermosyphon systems normally consist of a number of solar collectors (flat plate- vacuum tubes) connected to thermal storage tank through connecting pipes, with other essential components; expansion tank, safety and pressure relief valves [3].

The solar collectors of thermosyphon systems are always fitted stationary towards the equator with a tilt angle depends on the latitude and the hot water consumption. Enhancing the performance of thermosyphon systems have been studied by many

researchers [4-13]. Only one case study that dealt with implementation of tracking system was present in literature. Michaelides et al. [14] conducted a simulation study using the TRNSYS simulation program to investigate the performance of tracking and non-tracking thermosyphon solar water heaters at two locations. The results of the simulations indicate that the traditional thermosyphon solar water heater with fixed collector surface is the most cost-effective configuration as compared to single-axis tracking and seasonal tracking. For Nicosia, the best performance is obtained with the single axis mode, which results in a yearly solar fraction of 87.6% as compared to 81.6% with the seasonal mode and 79.7% with the fixed surface mode, while the corresponding figures for Athens are 81.4%, 76.2% and 74.4%, respectively. The payback time of this mode, however, is 10±1 years as compared to 5 years with the fixed collector surface tracking mode. Saed et al [15] designed a thermosyphon system with small sized parabolic trough collectors. The system is tested under local climatic conditions under the test procedure outlined in the ISO9459-2, and the experimental results showed that the maximum outlet temperature of withdrawn hot water at the end of the day was 73.4 °C for a daily solar insolation of 27.67 MJ/m² and diffuse ratio less than 18% (clear sky). The minimum hot water withdrawn temperature was 37 °C with daily solar insolation of 12.82 MJ/m² and diffuse ratio over 61%. The system performance is compared with other similar

systems with different collection technologies, and the compassion showed a competitive performance.

Literature reveals that most of the studies were focused on the existing solar tracking technologies and their impact on the performance of PV modules. In any solar system, the amount of extracted (thermal or electrical) energy depends on the solar collector orientation. For photovoltaic (PV) systems and solar tubular collectors, which are typically fixed southward with a tilt angle equal to latitude ±10°, the energy output changes throughout the day with the maximum output at the solar noon. Their performance could be improved by allowing them to track the sun, i.e. to keep them oriented toward the sun throughout the day. Some studies have

shown that the performance of these systems could increase by 20-50% using a tracking system [16].

The present study aims at designing and manufacturing sun tracking system for thermosyphon solar water heater. The performance of the new thermosyphon system will be compared experimentally with similar non-tracking thermosyphon system.

2. THERMOSYPHON SYSTEMS

As shown in Figure 1 thermosyphon systems rely on the natural convection of warm water rising to circulate water through the collectors and to the storage tank. These systems usually designed in a stationary mode with fixed tilt angle and orientation.
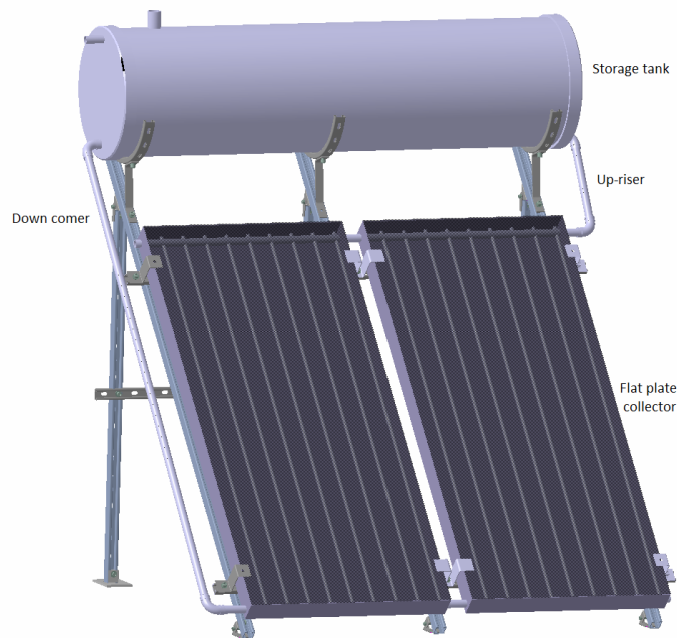

Figure (1). Thermosyphon solar water heating system

3. TYPES OF SUN TRACKERS

Taking into consideration of all the reviewed sun-tracking methods, sun trackers can be grouped into one-axis and two-axis tracking devices.

Figure 2 illustrates all the available types of sun trackers in the world. For one-axis sun tracker, the tracking system drives the collector about an axis of rotation until the sun central ray and the aperture normal are coplanar. [16]
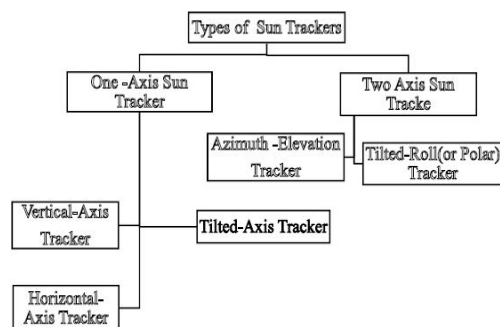
Figure (2). Types of sun trackers

4. TRACKING SYSTEM DESIGN

4.1 Design Requirements

The proposed solar tracking system should satisfy certain technical requirements specific to intended application, as follows:

- Simplicity of movement (motor, sensors), to diminish the cost and to increase the viability.

- Minimum energy consumption, for the maximization of global efficiency of the installation and optimum performance-cost ratio.

- Reliability in operation, under different perturbation conditions (wind, dust, rain, high temperature variations).

- The designed angular movement of the collector from east to west is 70°.

4.2 Design Options

In this work two options of control tracking system were examined, they are:

Option I (tracking based on sensing). The main design idea of the solar-tracking system is to sense the sun light by using two light dependent resistors (LDRs). Each LDR is fixed inside a hollow cylindrical tube. The LDR, controlling the angle of azimuth, are positioned East-West direction.

Option II: (Tracking based on timing). This option is based on the accurate calculation of the sun position and timing. A precise timing program is used for moving the collector from east to west, then control program reset to original point. This option is more reliable and achievable and therefore is chosen to be implemented in this study.

4.3 Tracker Components

The tracker is composed of mechanical frame to house the collector, set of lubricated roller bearing for minimizing friction and power consumption of super jack and motor, storage tank mounting frame are shown in Figure 3 (A), while Figure 3 (B) presented tracking frame assembly.
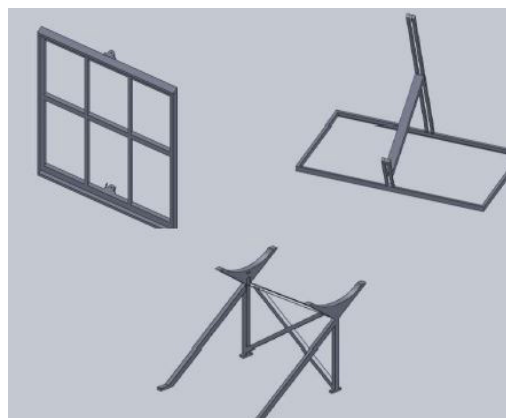

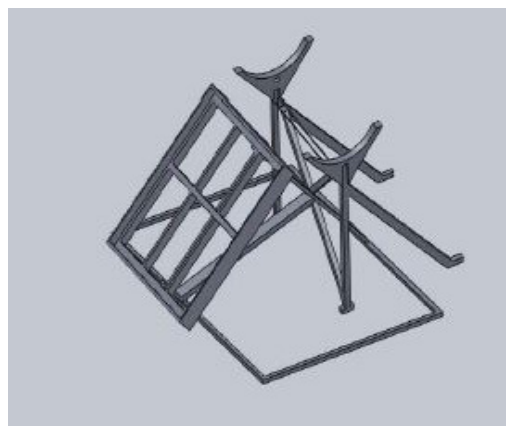**Figure (3A). tracker mechanical structure**

Figure (3 B) Tracking frame assembly

Electrical control unit that controls the motor and the mechanical structure consists of controlling board "Arduino Uno", Relay, Voltage regulation (convertor), pif board, and wiring. The components and assembled control unit are shown in Figures 4 (A) and 4 (B) respectively.
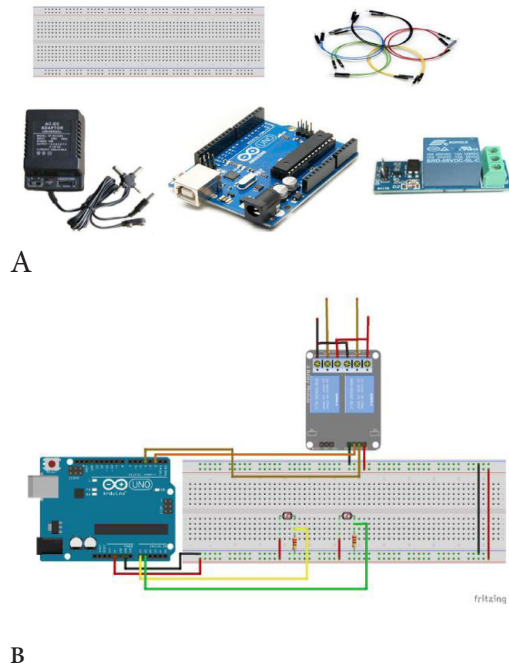

A

B

Figure (4) Tracker control unit components and assembly

4.4 TRACKER CODE

The driving potential for the tracker is the devised logarithm that instruct the whole system what to do. C++ program is written and interfaced with the control unit. The program is built based on the theoretical calculation of the hypothetical sun movement with respect to earth as shown in Figure 5. Figure 6 illustrates the overall tracking system.

The program start rotating the tracker from east with incremental movement at every 4 minutes at the end of day tracker reaches west (sun set) it stays for about 9 hours until dawn and then reset itself to east and so on .
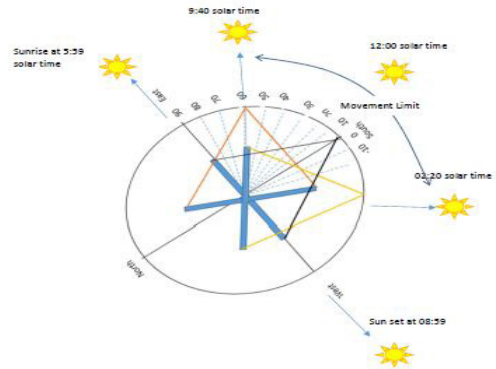

Figure (5) Theoretical bases of tracker code

Figure (6) Overall tracker and thermosyphon system.

5. EXPERIMENTAL WORK

The experimental work is carried-out at the Center for Solar Energy Research and Studies (CSERS), Tajoura. It is located in the east of Tripoli at longitude 13° 438' and latitude 32° 815'. The center has very advanced solar energy laboratories that can be utilized for testing and development of solar energy related projects.

5.1 SYSTEM DISCRIPTION

For the purpose of comparison two identical thermosyphon systems from Dimas Company (THERMO 200.1.20) were used, one is equipped with designed tracking system and the other is stationary.

Each system consists of one flat plate solar collector type (Energy+Evo 20) with aperture area of 1.89 m2, storage tank with capacity of 190 liters, connecting pipes, expansion tank, and pressure relief valves. The working fluid used throughout the experiment is pure water. General view of the systems is shown in Figure 7. The reason behind the choice of this thermosyphon system is the unique design of down comer and up-riser of the system resulting in easy mounting of tracking system.

5.2 TEST ARRANGMENTS

For the purpose of evaluating the thermal performance of natural circulation of solar water heaters according to the international standard ISO 9459-2, a set of parameters are measured: ambient air temperature; inlet cold water temperature from the source; outlet hot water temperature to the user (load); tilted solar radiation; diffuse horizontal solar radiation and water flow rate. The data-logger is connected with four water temperature sen sors, two tilted solar radiation sensor, and two flow meter sensor. The diffuse radiation is taken from the main weather station located very near to the experiment test rig. Test arrangements used are depicted in Figure 8. For full details about the instruments refer to ref [17].

Figure (7). Photo of tested systems

6. RESULTS

In this section, the results obtained by modeling thermosyphon tracking system in TRNSYS simulation program, and the experimental results are compared. Detailed discussion of the experimental work are also presented.
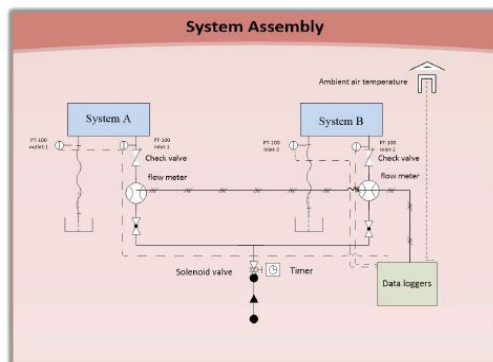

Figure (8). Test arrangement

6.1 TRNSYS Results

The simulation is conducted to illustrate the maximum benefits of using tracking system for thermosyphon SWHs. TRNSYS simulation program is used to simulate thermosyphon solar water heaters with the same specification of the system considered in this study for an open loop type whereas in experiment it was closed loop type. This is done as current TRNSYS version is not capable of handling closed loop thermosyphon SWH systems [18].

6.1.1 SIMULATED SYSTEM

The Thermosyphon SWH system implemented in TRNSYS is shown in Figure 9. The typical metrological year of Tripoli provided by TRNSYS is used and the typical hot water load pattern of Libyan family is considered [19]. The daily amount of hot water withdrawal is considered as 200 liters (one tank size) at temperature of 45 °C. Several TRNSYS runs were performed for different system configurations.

6.1.2. Simulation Results

The simulation program is run for three thermosyphon SWH cases: stationary, one-axis, and two-axis tracking. The amount of thermal energy obtained from solar energy in the three cases are shown in Figure 10. It is very clear from the figure

that, more energy is obtained from tracking system than stationary one, and there is small difference between one-axis and two-axis systems. This could be attributed to the fact that this technology is non-concentrating and therefore no need for accurate tracking to the sun rays.
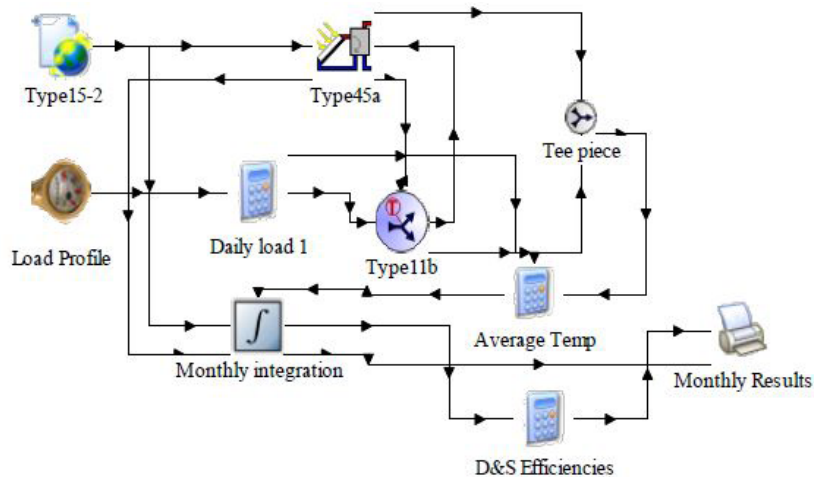

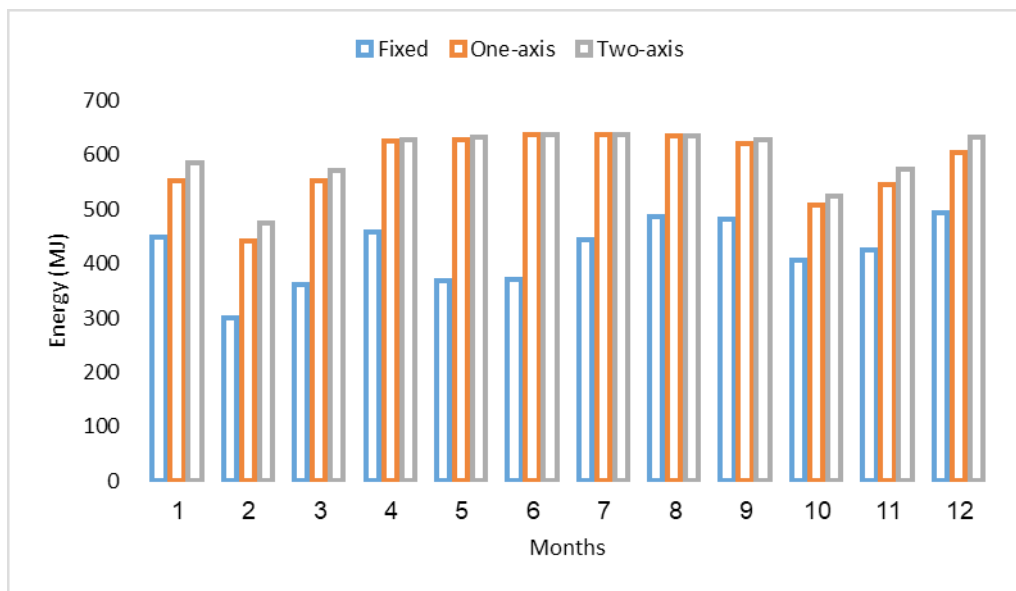**Figure (9) Simulated thermosyphon using TRNSYS**

Figure (10). Useful solar energy of fixed and tracking SWH systems

Table 1 shows the annual energy obtained from the sun for the three cases, it is clear that 38% extra energy can be harnessed for the single-axis tracking system over stationary one. The system solar fraction is increased from 68% for stationary system to 92% for the one-axis tracking system.

Table 1. TRNSYS –based annual output data for fixed and tracking SWH systems

	Tuser (°C)	SF	Efficiency	Useful energy (MJ)	Net Solar energy gain(MJ)	Solar insolation (MJ)	Energy differ.
Fixed	44.0	0.687	0.326	7335.94	5041310	7726.64	
one-axis tracking	44.74	0.924	0.340	7568.91	6990973	10284.98	0.387
Two-axis racking	44.83	0.944	0.333	7594.91	7166281	10766.66	0.422

6.1.3. Increasing collector area of fixed system

In this section an attempts is made to find out the equivalent collector area that gives the same performance of one-axis tracking system using TRNSYS program. The collector gross area is 2.0 m2 and the aperture area is 1.83 m2. Several simulation runs were conducted at different collector aperture areas as shown in Figure 11. The results show that the aperture area required for stationary system to get the same performance of one-axis tracking system is 3.3 m2. The increase of area is over 80% of original aperture area (almost double the original area) is needed to get the performance (92.4% solar fraction). This is could be attributed to the fact that not only the major effect of increasing the amount of solar radiation, but the influence of optical properties due to the normal incidence (incidence angle modifier) has the great effect on the performance.
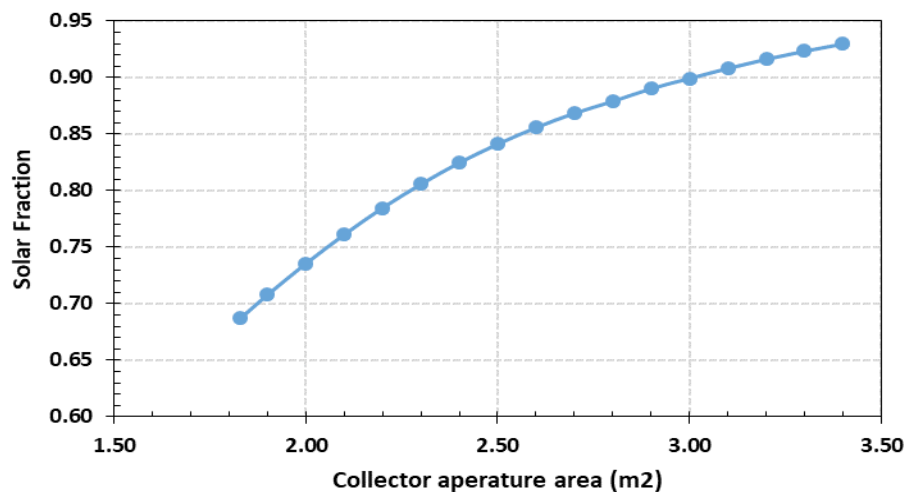

Figure (11). simulation results of stationary TSWH system at different collector areas

6.2 Experimental results

The results obtained during the experiments are recorded in 5 minutes interval time during the whole day, and the data are treated for further analysis and discussion. Table 2 presents experimental data recorded for tracking and non-tracking systems.

6.2.1 Compatibility test

The first step taken in the experimental work was to prove that the two systems are identical based on a comparison between thermal performances for both systems when they are oriented to the south in a fixed mode. The set of results for each one-day test have shown that systems were not exactly identical, and

therefore, certain procedures (i.e cleaning, changing components, chemical treatment) were taken to reduce the differences in performance of the both systems.

6.2.2 Both Systems are Stationary

The systems under consideration are treated to be identical in their performances as described above. The thermal behaviour of both systems A and B are tested according to the international standard code (ISO9459-2) for obtaining the characteristics equation for both systems. The results of energy and temperature obtained for both systems during the period from 13/03/2016 to 21/03/2016 are summarized in Table 2. The results are also plotted in Figure 12.

Table (2). Experimental data used for regression in case of systems are stationary

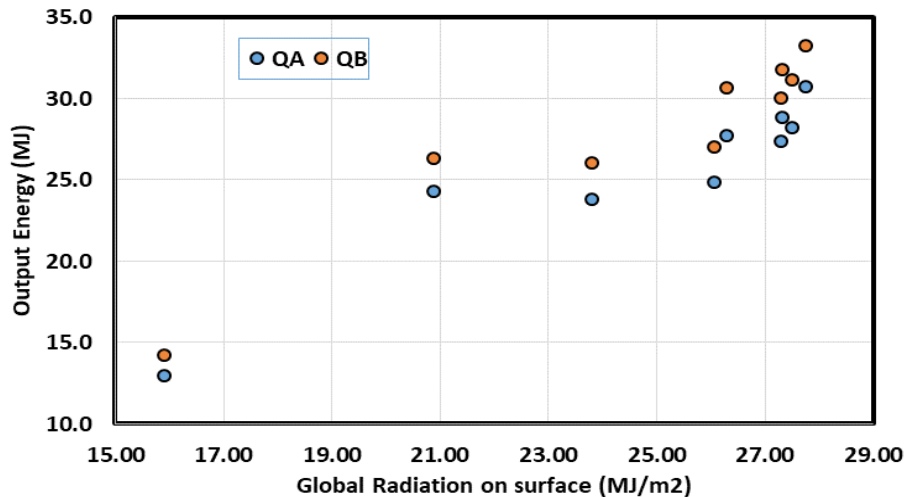| No	Date	QA (MJ)	QB (MJ)	H1 (MJ/m²)	$(T_{a(day)} - T_c)$
1	13/03/2016	12.94	14.25	15.90	-2.23
2	14/03/2016	24.83	27.04	26.06	-1.02
3	15/03/2016	28.86	31.75	27.31	-1.33
4	16/03/2016	27.71	30.67	26.29	3.72
5	17/03/2016	23.78	26.04	23.81	-1.43
6	18/03/2016	27.36	30.06	27.30	-0.92
7	19/03/2016	28.22	31.14	27.50	-0.07
8	20/03/2016	30.71	33.26	27.75	7.23
9	21/03/2016	24.30	26.35	20.87	9.51

Figure (12). Plot of measured output energy for both systems in fixed mode

The daily energy of hot water draw-off curves of the tested system of the day 13-03-2016 is presented in Figure 13 with insolation less than 16 MJ/m2, and Figure 14 shows the daily energy of hot water withdrawal results with high insolation over 16 MJ/m² for the day 20-03-2016.
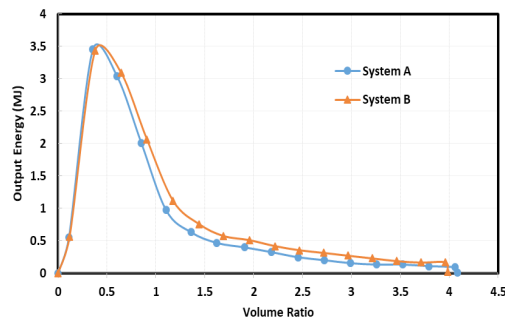
Figure (13). Daily energy of hot water draw-off for solar radiation less than 16 MJ/m²
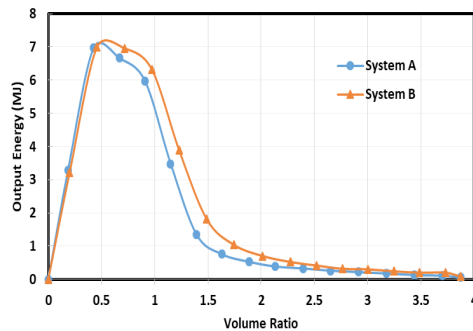

Figure (14). Daily energy of hot water draw-off for Solar Radiation more than 16 MJ/m2

A sample of hot water draw-off profile of the day 21-03-2016 is shown in Figure 15. The maximum recorded hot water outlet temperature from System A is 48.8 °C and for System B is 47.7 °C. it is very clear from the figure that the highest temperature is might be higher than the indicated ones because at the start the amount of hot water withdrawn should have the highest temperature. This could be attributed to many reasons, the more obvious one is that the time lag between the time of the solenoid valve for hot water withdrawn and the time in the data logger. In all cases this has very little effect on the results of the experiments.

Table 3 listed the nine days of experimental results considered for obtaining the energy system performance. The energy system performance equation for solar-only water heating system of System A, daily energy output (QA) excluding

the last point in Table 2 is obtained using multi-regression correlation with root mean square error (RMSE) equal to 98.26% as follows:

$$Q_a = 1.2675H + 0.277(T_{a(day)} - T_c) - 6.58 \quad .... \quad (1)$$

Where

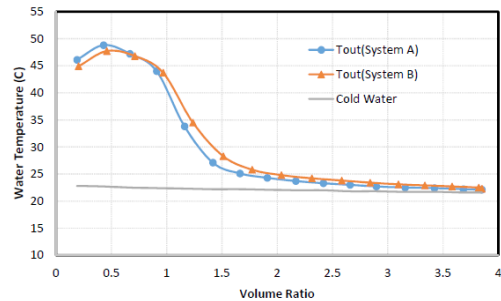H: daily solar irradiation on the collector aperture (MJ/m²)

Figure (15). Hot water draw-off curve of day 21-03-2016 with daily solar insolation 20.88 MJ/m²
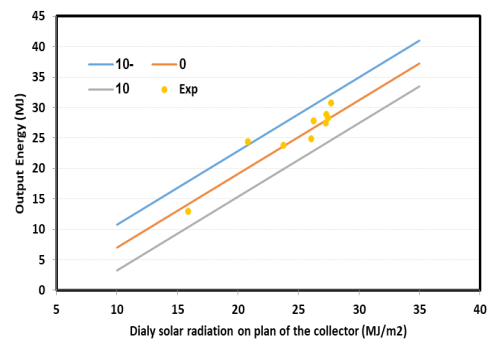

Figure 16. Energy output of the system A as a function of daily solar radiation

Ta(day): daily average ambient temperature during the test period (°C)

Tc : average source water temperature during the test period (°C)

The energy system performance equation (1) is presented graphically in Figure 16.

While for the System B, the energy system

performance equation with RMSE equal to 95.47% is:

$$Q_B = 1.3315H + 0.3817(T_{a(day)} - T_c) - 5.69 \quad .... \quad (2)$$

6.2.3 System A Tracking and System B Stationary

The set of results obtained for twelve days of experiments during the period of 04/03/2016 to 01/04/2016 listed in Table 3 are shown in Figure 17. The hot water draw-off curves of the tested system is presented in this sub-section. Figure 18 shows the hot water draw-off curve of the day 25-03-2016 with insolation less than 16 MJ/m² and Figure 19 shows the daily withdrawal results with high insolation over 16 MJ/m² for the 26-03-2016.

Table (3). Experimental data used for regression System A tracking and System B stationary

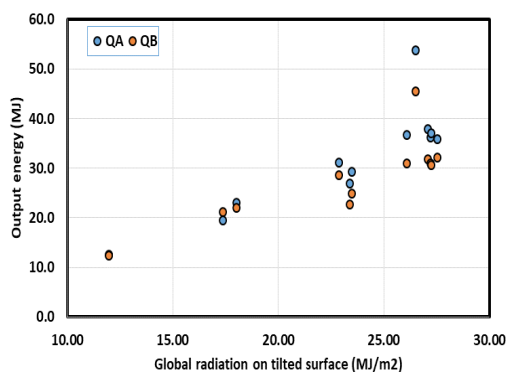| No	Date	QA (MJ)	QB (MJ)	HA MJ/m²	HB MJ/m²	$(T_{a(day)} - T_c)$
1	04/03/2016	35.83	32.11	32.98	27.55	-2.02
2	05/03/2016	19.50	21.14	16.90	17.38	4.30
3	23/03/2016	26.86	22.71	27.49	23.39	-0.59
4	24/03/2016	53.72	45.41	32.51	26.51	1.92
5	25/03/2016	12.46	12.34	13.16	11.95	-3.86
6	26/03/2016	29.23	24.78	29.77	23.49	-2.50
7	27/03/2016	36.19	30.94	34.37	27.23	-1.67
8	28/03/2016	36.61	30.87	32.59	26.08	4.25
9	29/03/2016	37.01	30.68	34.49	27.24	2.07
10	30/03/2016	37.94	31.71	34.32	27.08	4.47
11	31/03/2016	23.09	21.99	20.96	18.00	5.24
12	01/04/2016	31.07	28.52	28.05	22.86	8.71

Figure (17). Plot of measured output energy for System A tracking and System B fixed
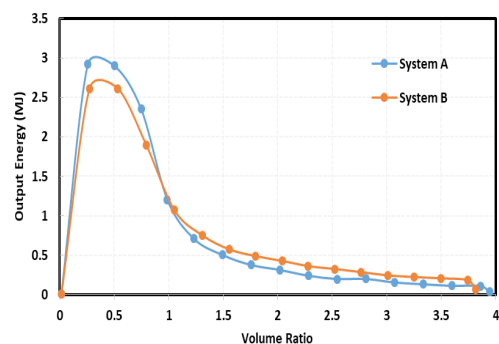

Figure (18). Daily energy of hot water draw-off for Solar Radiation less than 16 MJ/m²
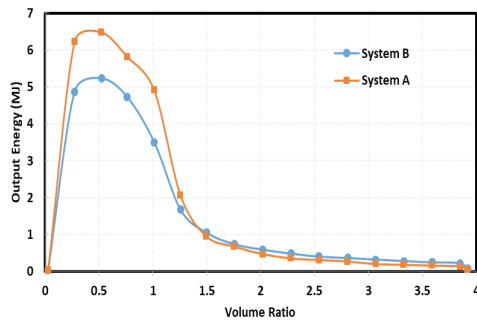
Figure (19). Daily energy of hot water draw-off for Solar Radiation over than 16 MJ/m²

It is very clear from Figure 18 when the solar global radiation on the collector surface is less than 16 MJ/m² (System A 13.16 MJ/m², and System B 11.95 MJ/m²), the difference in performance is smaller than the difference in case of high insolation over 16 MJ/m² (System A 29.77 MJ/m², and System B 23.49 MJ/m²). In both cases the tracked System A outperform the non-tracked System B although the System B is better in performance than System A in case of both are stationary. This of course attributed to the enhancement of tracking system to the solar radiation and harnessing more radiation than the stationary one. In the case of low insolation, a sample of hot water draw-off profile of the day 23-03-2016 is shown in Figure 20.
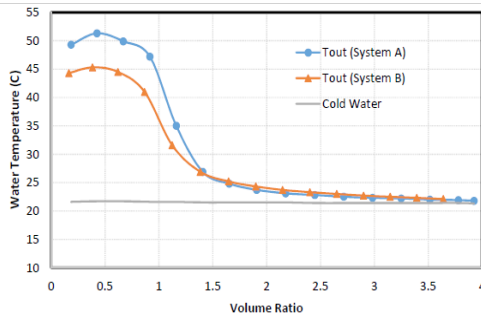

Figure (20). Hot water draw-off profile of the day 23-03-2016

Table 3 listed twelve days of experimental results considered for obtaining the energy system performance of the second case. The energy system performance equation for solar-only water

heating system of System A is obtained using multi regression correlation as follows:

$$Q_A = 1.1488H + 0.2765(T_{a(day)} - T_c) - 0.31 \quad .... \quad (3)$$

The above equation is obtained after eliminating the data of row 3 and 4 in Table 5 as have shown large residual. The data correlation have shown that the root mean square error (RMSE) is 98.81%.

6.3 ANALYSIS OF THE RESULTS

The input/output energy equations for both systems eq.1 and eq.2 were not the same which means the systems are not identical in performance although they are from the same type and manufacturer. This attributed to the difference in operating periods of the systems. If we consider the System B is the reference as it has better performance than System A, from the statistical analysis in Table 4, the maximum discrepancy or deficiency in performance of System A is 9.6%, and the minimum deficiency is 7.67% with an average discrepancy of 8.74%. As the minimum, maximum and the average discrepancy are very close, then we can consider that the System B outperform the System A by 8.74% in the further calculations.

In the second set of experiment, System A outperform System B (as System A is tracking the sun) with an average increase about 12.43% as shown in Table 5. It can be seen from Table 5 that the experiment data of the second day is the only one where the System B outperform the System A. The only reason might be considered for this behavior is in that day the diffuse ratio is the highest day with over 53%. The overall improvement performance of the tracking system can be calculated by eq. 4, and is summarized in Table 5.

$$Q_{A(overall)} = Q_A + 0.0847Q_B \quad .... \quad (4)$$

From the aforementioned experimental data obtained, the overall average improvement in the sun tracking thermosyphon solar water heater performance is 21.17% over identical stationary one as shown in Table 5. This result is very reasonable compared to the simulated results obtained by TRNSYS for one-axis tracking system of 38.7%.

Table (4). The discrepancy in performance between System A and B (both systems are stationary)

	Q_A	Q_B	Discrepancy %
1	12.94	14.25	-9.2127
2	24.83	27.04	-8.18169
3	28.86	31.75	-9.12632
4	27.71	30.67	-9.66095
5	23.78	26.04	-8.69395
6	27.36	30.06	-8.96729
7	28.22	31.14	-9.35601
8	30.71	33.26	-7.66753
9	24.30	26.35	-7.80615
Average			-8.7414

Table 5. Comparison in performance of System A (tracking) and System B (fixed)

	Q_A (MJ)	Q_B (MJ)	Discrepancy %		8.74% of QB	QAoverall (MJ)	Improvement %
1	35.83	32.11	11.59	11.59	2.81	38.63	20.33
2	19.50	21.14	-7.73	-	1.85	21.35	1.01
3	26.86	22.71	18.30	18.30	1.98	28.85	27.04
4	53.72	45.41	18.30	18.30	3.97	57.69	27.04
5	12.46	12.34	0.96	0.96	1.08	13.54	9.70
6	29.23	24.78	17.94	17.94	2.17	31.40	26.68
7	36.19	30.94	16.96	16.96	2.70	38.89	25.70
8	36.61	30.87	18.58	18.58	2.70	39.30	27.32
9	37.01	30.68	20.64	20.64	2.68	39.69	29.38
10	37.94	31.71	19.67	19.67	2.77	40.72	28.41
11	23.09	21.99	5.00	5.00	1.92	25.01	13.74
12	31.07	28.52	8.93	8.93	2.49	33.56	17.67
Average			12.43	14.26			21.17

7. CONCLUSIONS

The paper focused on enhancing the thermal performance of thermosyphon solar water heaters by making the solar flat plate collector following the sun in single-axis tracking. The collector is tracking the sun in a range of 70° from east to west with surface tilted angle 45° from the horizontal to keep the sun's rays nearly perpendicular to the absorber's area. Detailed design and manufacturing of single axis tracker system for thermosyphon SWHs with flat plate collector is performed.

Designed system is simulated with TRNSYS for several scenarios, simulation results revealed that 38% extra energy can be harnessed in case of single-axis tracking system over stationary one. The system solar fraction is increased from 68% in case of stationary system to 92% in one-axis tracking system.

Experimental investigation revealed that overall average improvement in the sun tracking

thermosyphon solar water heater performance is 21.17% over identical stationary one, which is very reasonable compared to the simulated one.

8. REFERENCE

[1]. Ibrahim S, 1998. *Prospects of renewable energy in Libya. Renew Energy, 14, pp 135-141*

[2]. Bannani, F. K. Sharif, T. A. and Ben-Khalifa, A. O. R., 2006. *Estimation of monthly average solar radiation in Libya, Theoretical and Applied Climatology, 83, (1–4), pp 211–215.*

[3]. Renewable 21, Global Status Report, 2013. http://www. unep.org/pdf/GSR2013.pdf.

[4]. Sadhishkumar S., Balusamy T., 2014. *Performance improvement in solar water heating systems—A review, Renewable and Sustainable Energy Reviews, 37, pp 191-198.*

[5]. Chandresh Sharma, Rajendra Karwa, 2014. *Experimental Study on an Enhanced Performance Solar Water Heater. International Journal of Computer Applications, pp 20-25.*

[6]. Sina Jahangiri Mamouri, André Bénard, 2018. *New design approach and implementation of solar water heaters: A case study in Michigan, Solar Energy, 62 (1), pp 165-177.*

[7]. Rijo Cherianm Lasithan L G, 2016. *Performance enhancement of solar water heater using compound parabolic reflector and numerical simulation of thermal losses, International Conference on Energy Efficient Technologies for Sustainability (ICEETS), 7-8 April 2016.*

[8]. Sheng Xue H., 2016. *Experimental investigation of a domestic solar water heater with solar collector coupled phase-change energy storage. Renewable Energy, 86, pp 257-261.*

[9]. Mohammad Ali Fazilati, Ali Akbar Alemrajabi, 2013. *Phase change material for enhancing solar water heater, an experimental approach. Energy Conversion and Management, 71 (7), pp 138-145.*

[10]. Mustafa, Ismail.N.R., 2013. *Collectors innovation to increase performance solar water heater. International Journal of Research in Engineering and Technology. 2, (9), pp 464-470.*

[11]. Herrero R. Martín, A. García Pinar, Pérez García J., 2011. *Experimental heat transfer research in enhanced flat-plate solar collectors. World renewable energy congress, pp 3844-3850.*

[12]. Risztina Uzuneanu, Alexandrina Teodoru, Tanase Panait, 2011. *Optimum tilt angle for solar collectors with low concentration ratio, Advances in fluid mechanics and heat & mass transfer, pp 123-128.*

[13]. Fanney A.H. and Klein S.A., 1998. *Thermal performance comparison for solar hot water systems subjected to various collector and heat exchanger flow rate. Solar Energy, 40,(1), pp 1-11.*

[14]. Michaelides I.M., , Kalogirou S.A., Chrysis I. , Roditis G., A. Hadjiyianni C, H.D. Kambezidis d , M. Petrakis d , S. Lykoudis d , A.D. Adamopoulos, 1999. *Comparison of performance and cost effectiveness of solar water heaters at different collector tracking modes in Cyprus and Greece. Energy Conversion & Management 40, pp 1287-1303.*

[15]. Saed J.M., Abdunnabi M.J.R., Essnid A. A., Buishi A. M. A., 2017. *New Designed Thermosyphon Solar Water Heater with Small Sized Parabolic Trough Collectors,JSESD,6 (2), pp 30-41.*

[16]. Chong, K. K., Wong, C. W., Tunku, U., & Rahman, A., 2010. *General formula for one-axis sun-tracking system. INTECH Open Access Publisher.*

[17]. Alla Omar Abusalama, 2017, *Enhancing Thermosyphon Solar System Performance using simple and robust tracking system, M.Sc. thesis. Tripoli University.*

[18]. Klein, S.A., et al, 2010, *TRNSYS 17: a transient simulation program, Solar Energy Laboratory: Madison University of Wisconsin, USA.*

[19]. Abdunnabi M.J.R, 2012. *Optimum values of tank volume to collector area ratio of thermosyphon solar water heaters for Libyan families, JSESD, 1 (1), pp 25-31.*