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DESIGN AND IMPLEMENTATION SINGLE AXIS TRACKER MODEL BASED ON MICROCONTROLLER FOR SOLAR COLLECTOR

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ABSTRACT :-

The present work is a design and implementation of a compact single-axes solar tracking system. The hybrid system a combination from mechanical and the electronic parts. A tracking system are used to track the sun position and let the solar collector facing the sun as long as possible. The single axis tracking system has the ability to rotate the solar collector in horizontal axis and in both clockwise and anticlockwise .The electronic system contains a microcontroller board connected to dual sensors and the output signal from the microcontroller will be input to one-axis motor. The experiments conduct for flat plate solar water collector in the first case non-tracking system and secondly case using tracking system. The experimentally results that the average obtained falling solar radiation on solar collector in the first case and the second case during the same time is (616 watt/m^2, 725 watt/m^2) respectively .This means an increase about 17.7 % at using tracking system and the average useful heat gain output of solar collector during the same time is (65.8 watt, 85.5 watt) respectively it mean increased about 30.4 % at using tracking system.

Key Words: Solar collector, tracking system, Microcontroller (Arduino), Thermal performance.

تصميم وتنفيذ نموذج تعقب احادي المحور يعتمد مسيطر دقيق لمجمع شمسي

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الخلاصة :-

العمل الحالي تصميم وتنفيذ نظام تعقب مدمج احادي المحور ودراسة تجريبية للاداء الحراري لمجمع ماء شمسي مسطح . النظام هجيني مكون من اجزاء ميكانيكية والكترونية. نظام التعقب يستخدم بتعقب موقع الشمس وجعل المجمع الشمسي يواجة الشمس لأطول فترة ممكنة ، يمتلك نظام التعقب احادي المحور القدرة لتدوير المجمع الشمسي بمحور افقي وبكلا الاتجاهين اتجاة عقارب الساعة والاتجاة المعاكس لدوران عقرب الساعة . النظام الالكتروني يحتوي على لوحة لمسيطر دقيق متصل بجهازاستشعار مزدوج مع اشارة خروج من المسيطر الدقيق تكون مدخلا الى محرك بمحور واحد.التجارب اجريت لمجمع ماء شمسي مستوي ،في الحالة الاولى بدون نظام تعقب والحالة الثانية بأستخدام نظام تعقب . نتائج التجارب لمعدل الاشعاع الشمسي الساقط على المجمع الشمسي في الحالة الاولى والثانية خلال نفس الفترة الزمنية هي (616، 725 واط/م^2) بالتتابع ، وهذا يعني زيادة بحدود 17.7% عند استخدام نظام تتبع ، ومعدل الحرارة المكتسبة للمجمع الشمسي خلال نفس الفترة هي (65.8واط ، 85.8 واط) بالتتابع وهي تعني زيادة بحدود 30.4 % عند استخدام نظام تعقب .

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NOMENCLATURE :-

A_c	Aperture area	(m^2)
C_p	Specific heat capacity of water at constant pressure	(kJ/kg.K)
I	Solar radiation	(Watt/m^2)
m^*	mass flow rate	(kg/s)
T_{inlet}	Fluid inlet temperature	(°C)
T_{outlet}	Fluid outlet temperature	(°C)
N	Number of reading measurement	-----

INTRODUCTION :-

Humans always used the sun's ray to convert it to a useful energy in their lives. Solar energy is the radiation produced by the nuclear fusions in the core of the sun. 30% of the ancient Greeks and Romans used the sun's energy in the construction of their building as the rays of the sun provided light and heat for indoor spaces. Socrates, a Greek philosopher wrote “In houses that look toward the south, the sun penetrates the entrance in winter”. Romans people were covering the openings of their south faced buildings by a glass to keep the heat of the sun in the winter [Robert Foster, Majid Ghassemi, Alma Cota, 2009].The solar energy actually reaches the earth and the sun produces enough power to provide the earth with its needs for all the year and this can happen in only 20 minutes [Robert Foster, Majid Ghassemi, Alma Cota 2009]. The twenty-first century is heading into a perfect energy storming. Rising of energy prices and the decreasing of energy availability and environmental growth concerns are rapidly changing the global energy panorama. Due to this growth and increasing, the demand for energy world wild is increased to more than double during the first half of the twenty-first and more than triple by the end of the century, for more statistics, one-third of the world's population lives in rural areas without any availability of the electric grid and about the half of the same people live without availability of safe and clean water [Durham E., 2009].

Many scientist have studied the solar collector system. [P.Rhushi Prasad, H.V. Byregowda, P.B. Gangavati, 2010] presented experiment analysis of flat plate collector and comparison of performance with tracking collector. A flat plate water heater, which is commercially available with a capacity of 100 liters/day is instrumented and developed into a test-rig to conduct the experimental work. Experiments were conducted for a week during which the atmospheric conditions were almost uniform and data was collected both for fixed and tracked conditions of the flat plate collector. The results showed that there was an average increase of 40C in the outlet temperature. The efficiency of both conditions was calculated and the comparison showed that there was an increase of about 21% in the percentage of efficiency. [N. Ehrmann and R. Reineke-Koch, 2011] Used integration of double glazing with low e- coating and Transparent conductive oxides (TCO) coating into a flat-plate collector. Transparent conductive oxides (TCO) coatings were used as low e-coatings due to their optical selectivity with high solar transmittance. These coatings provided high efficiencies at temperatures above 100 °C as well as at low solar irradiation. [P. Sivakumar1, W. Christraj, M. Sridharan1 and N. Jayamalathi,2012] discussed improving the performance of a flat plate solar energy collector by changing the design parameters of the number of riser tubes and the arrangement of riser tubes in zig-zag pattern from the existing flat plat collector system. Experiments were conducted using copper tube in header and riser with different dimensions. The performance shows that the efficiency was 59.09% when increasing the number of riser tubes and its 62.90% in the zig-zag arrangement (Z-Configuration) of the riser tube.[Kalogeria SA.,1996] designed and constructed a one-axis sun-tracking system consisting of a control system with three light dependent resistor sensors and a DC motor. One sensor was responsible for direct beam detection; the second was cloud sensor and the third was the daylight sensor. The control system consisted of relay, timer, many resistors and electronic parts. When any of the three sensors was shaded, the motor was switched on. The system tracked the sun in E–W direction and the final rotational speed of the collector was 0.011 rpm. Various tests of the solar collector showed that the tracking mechanism was very accurate. The accuracy for100W/m^2 illumination was 0.28 while for 600W/m^2 illumination it was reduced to 0.058. [Drago P.,1978] evaluated an energy gain comparison between four flat plate collectors two of them were fixed, one with single cover and the other, double cover collector and two similar collectors with full tracking. The result showed that the efficiencies of the single cover were 5.7% and 10.1%, respectively for fixed and tracking cases and the efficiencies of the double cover were 17.4% and 21.8%, respectively for fixed and tracking cases. [Pavel Y.V., Gonzalez H.J., Vorobiev Y.V., 2004] analyzed experimentally and theoretically the collected energy in original tracking and non-tracking bifacial and non-bifacial PV solar systems. The calculated and measured tracking effect showed an increase of 30–40% in collected energy while for tracking case with bifacial panels and reflector collecting solar radiation for the rear face gave an increase in collected energy of 50–60% for the same panel .

The present study of this work presents design and implementation single axis tracker model based on microcontroller and it used to carry out for solar collector type flat plate collector and experimentally investigated by using tracking and non-tracking of solar collector of water heating. The solar radiation and useful heat gain is compared .

SOLAR COLLECTOR SYSTEM MODEL :-

The elements of solar water heater are showed in the block diagram as shown in **Fig. (1)**.The detail of these elements is the following:

A. Sun: It’s the main source of energy in the universe, it's made of chain of reactions, and most important one is the fusion of Hydrogen into Helium.

B. Sensor: In this model two types of sensors:

-Photoconductive Cell: VT900 series photoconductor, operating Temp. (-40 to +75 C^o), the sensor's main job is to identify whether there is a light or not (Day or Night).

-NPN Phototransistor: BP103, Silicon phototransistor suitable for application from 420 nm to 1130 nm with operation Temp. (- 40 to +80 C^o), the main job of this phototransistor is to identify the intensity of the light.

C. Arduino Uno: A microcontroller board. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, and a reset button. It contains everything needed to support the microcontroller**.** Operating voltage (5V), input voltage (7-12 recommended**),** DC current per I/O Pin (40mA), [W. Durfee, 2011].

D. Motor: one-axis motor with (12V, 300mA) operating power used to rotate the solar collector.

E. Holder: The holder is consisted of a stand connected to a shaft by a ball bearing to rotate the solar collectors. The shaft is also connected to a solar collector's carrier. The mechanical system powered by an electronic system to provide the suitable movement for the tracking system .

FLAT PLATE SOLAR COLLECTOR:-

Flat plate collectors of the many solar collector concepts are presently being developed. The relatively simple flat plate solar collector has found the widest application. Flat plate collectors can produce heat at sufficiently high temperatures to heat swimming pools, domestic hot water, and buildings. Flat plate collectors can easily attain temperatures of 40 to 100ºC. The main components of a flat plate solar collector are: Absorber plate, Tubes or Fins, Thermal insulation, Cover strip, Glazing, Container or Casing. Generally the collectors made of Aluminum box covered with glass and an Aluminum plate. The box contains four tubes connected to a main headers form the top and bottom. The pipes and plate are painted with black paint to increase the absorption of the sun's ray.In this project the tubes are in-Line with absorber plate.

The efficiency of flat plate collector can be evaluated by an energy that determines the portion of the incoming radiation delivered as useful heat gain (Q_u) and average of useful heat gain $(Q_u)_{av.}$ Which is calculated from equation (1) and equation (2) respectively:

$$Q_u = m^* C_p (T_{outlet} - T_{inlet}) \tag{1}$$

$$(Qu)av. = \frac{\sum Qu}{N} \tag{2}$$

After obtaining the useful heat gain, (Q_u), the efficiency (η) and average efficiency $(\eta)_{av.}$ of the flat plate collector can be calculated from equation (3) and equation (4) respectively:

$$\eta = \frac{Q_u}{A_c\, I} \tag{3}$$

$$(\eta)av. = \frac{\sum \eta}{N} \tag{4}$$

The principal measurements made in each data set are fluid flow rate, fluids inlet and outlet temperatures and solar radiation. All data are tabulated in a form (tables) for every hour starting from 9.00H until 16.00H. Data are then plotted in a graph Data analysis from the graph is essential to obtain the efficiency of the flat plate collector.

EXPERIMENTAL SETUP :-

The natural circulation of the solar water heater is used to conduct the experiment (without loading of water from collector).The dimensions of the flat-plate and pipe are chosen from available in market. Each pipe is 0.61m long and has an outer diameter of 0.018m and inner diameter of 0.014 m. The distances from pipe to pipe are 0.08 m, the distance between pipe and edge of plate is 0.05m and are gas welded at both the ends to a pipe of 0.03m diameter and 0.8m long of header . The absorbing surfaces and pipes are painted with black chrome selective coating. The absorber pipe assembly formed an inner box, which in turn is mounted in an outer box, the space between the absorber pipe assembly and the outer box is filled with rock wool an insulating material. To separate these parts an aluminum foil is used, then the box is covered with a 0.004 m thick clear toughened glass and an air gap between the plate and the glass cover is of 0.035m.The overall dimension of the collector is 0.65*0.35*0.3m and the effective area is 0.192 m^2 .Six thermocouples are used in the collector. The thermocouples are distributed as the following manner: three of them on the upper, middle and lower side of the absorber plate also one thermocouple on the pipe, another two on the inlet and outlet from the solar collector. The connection between the flat plate collector and the storage tank are in two parts; the return pipe and the flow pipe. The return pipe connects the outlet of the storage tank and the inlet of the collector together. The flat plate collector is oriented in such a way that it receives maximum solar radiation during the day. The temperature of the inlet and outlet from the collector and the ambient temperature were recorded using a digital thermometer. To calculate the mass flow rate, water was collected in the measuring flask for time duration of five minute from the outlet of the collector. All specification and dimensions of flat plate solar collector are shown **Table (1)**. Experiments were conducted on 2^{nd} and 3^{th} of the Jun 2015 between 09 am to 04 pm, experimental results as shown in table (3) for non-tracking of solar collector system and results in table (4) for tracking system of solar collector. The process of manufacturing the flat plate solar collector and Final solar collector is shown in **Fig. (2, 3, 4, 5 and 6)**.

DESIGN OF SOLAR TRACKING SYSTEM :-

The design of single-axis solar tracker system started from identify the weather its day or night through the sensor(Photoconductive Cell, VT 900) then the light intensity will be measured by the sensor(NPN Phototransistor, BP103)to send the signal to the Arduino Uno. This microcontroller is the heart of overall system. ATMEGA328 microcontroller requires a 5 volt regulated voltage supply. After receiving the signal from the sensor BP 103 the maximum signal will be known and send to pin2 to give order to operate the motor to rotate the collector towards maximum sun light then the motor will stop. The DC motor that has been used in the design system has the specification of (12 volts, 300mA current).As the light intensity changes, then the sensor BP103 will start search for the maximum light intensity within the path of the sun's ray. The specification of microcontroller board ATmega328 is shown in **Table (2)** [W. Durfee, 2011]. **Fig. (7)** shows the electrical circuit of solar tracker system designed in Proteus 8 professional software. Flow chart of solar tracker is shown in **Fig. (8)**.

RESULTS AND DISCUSSION:-

A flat plate solar collector, with its one single axes sun tracking system have been designed, manufactured and tested. The performance of the solar collector was experimentally investigated with water as the heat transfer fluid, without draw-off water from storage to load. **Figure (9)** shows the variation of the average solar radiation intensity measured in the day of 2^{nd} of Jun 2015 using solar instrument at fixed of the flat plate solar collector, without using tracking system and in the day 3^{th} of Jun 2015 measured average intensity solar radiation on the same flat plate solar collector using tracking system. It can be shown from this figure that the average obtained solar radiation from the fixed collector during interval time daily (9-16) hour is 616 watt/m^2 and by using tracking system the average solar radiation is 725 watt/m^2.This means an increase about 17.7 % when are using tracking system.

It is noted from **figure (10)** that the gradual rise of outlet temperature of the water as a result of solar heating through the collector to reach average value of 44.6 C^o through time daily from (9-16) hour for non-tracking system while with tracking system the same solar collector and the same time the outlet temperature of water reaches up 51.5 C^o. Its mean the increase of about 15.4% when using tracking system for solar collector. Also it is noted from figure, that the outlet water temperature rises gradually until 13 hour then begins to drop as the solar radiation falling on the solar collector decrease and a shadow effect of the grooves of the absorber surface which reduces the energy collected and to increase thermal losses from the solar collector.

Figure (11) shows that the useful heat gain of the solar collector for non-tracking system reaches up to an average value of about 65.82 watt through time daily from (9-16) hour ,while the same collector using tracking system, the average value of useful heat gain reaches to 85.83 watt. This means the increase of about 30.4% when using tracking system for solar collector.

Figure (12) shows the instantaneous efficiency of the solar collector during daylight hours. It is noted that a gradual increase in efficiency due to cold water at the beginning of the day, due to a gradual increase of the heat gain until 13 hour and after that it start decreases gradually. From this figure it is noted that the average efficiency of solar collector during time daily between (9-16) hour for non-tracking system reach up to 53.56% ,while the same collector using tracking system, the average value of efficiency reach to 60.02%. This means the increase of about 12% when using tracking system for solar collector.

CONCLUSIONS :-

We have conducted experiment on performance analysis of solar collector system with tracking and non-tracking system. The solar radiation and useful heat gain of solar collector are increased (17.7 % and 30.4%) respectively with using tracking system.

RECOMMENDATION :-

An experimental investigation with double-axis tracking system compared to single-axis tracking system should be considered in future work .

Table (1) Specifications of the flat plate solar collector

Items	Dimensions
Glass cover	Number of glass cover (N) : 1 Thickness of glass cover: 0.004m Length of class cover: 0.77m Width of class cover: 0.38m Air space between inner cover and absorber plate: 0.005m Thermal emissivity of glass cover: 0.85-0.95 Thermal conductivity of glass:0.8W/m.K
Absorber plate	Number of pipes(n): 4 Distance between pipes from center to center(w): 0.08m Distance between center of pipe and edge of plate: 0.05m Length of absorber plate: 0.6m Width of absorber plate: 0.32m Thickness of absorber plate(d_{abs}):0.015m Length of pipe: 0.61m Outer diameter of pipe: 0.018m Inner diameter of pipe: 0.014m Thickness of pipe: 0.002m Outer diameter of header: 0.03m
Insulation	Thickness: 0.05m Thermal conductivity of insulator: 0.04W/m.K
Area of collector	Flat plate collector tiled with angle 33° to the horizontal surface Mass flow rate: 13.5 L/h Surface area of the collector: 0.192m^2
Frame	Length of frame: 0.78m Width of frame: 0.39m Height of frame: 0.1m Thickness of frame: 0.002m

Table (2) Specification of Arduino Uno board

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by boot loader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MH

Table (3) Results parameters of solar collector without tracking system

Time (hr.)	I (w/m^2)	$T_{amb.}$ (C^o)	T_{in} (C^o)	T_{out} (C^o)	Q (watt)	Efficiency %
9	516	26.5	29.0	30.8	28.35	28.60
10	610	28.3	29.8	33.6	59.85	51.10
11	690	30.5	32.7	38.2	86.62	65.38
12	745	35.5	37.4	43.5	96.07	67.16
13	790	40.5	42.2	48.5	99.22	65.41
14	635	39.2	47.3	52.1	75.60	62.00
15	505	37.8	51.5	54.3	45.48	46.90
16	440	36.4	53.9	55.8	35.42	41.92

Table (4) Results parameters of solar collector with tracking system

Time (hr.)	I (w/m^2)	T_{amb} (C^o)	T_{in} (C^o)	T_{out} (C^o)	Q (watt)	Efficiency %
9	645	26.9	29.0	32.5	55.12	44.50
10	720	29.4	31.6	36.6	78.75	56.96
11	795	31.6	36.1	42.9	107.10	70.16
12	825	37.2	41.8	48.9	111.82	70.59
13	830	41.5	48.3	56.1	122.85	77.08
14	788	39.4	55.6	62.3	105.52	69.74
15	645	38.1	61.4	65.2	59.85	48.32
16	555	37.3	64.5	67.4	45.67	42.85

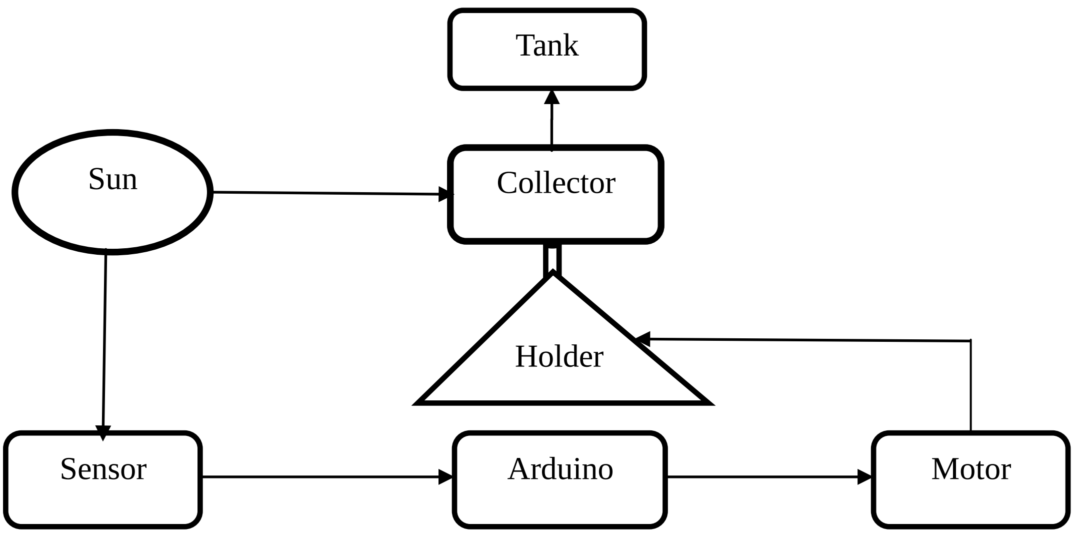

Fig. (1) Block diagram of solar collector system model

Fig. (2) Aluminum tubes welded on aluminum flat plate

Fig. (3) Thermal insulation between the bottom of the frame and the lower side of the absorber plate.

Fig. (4) Paint all of plates, pipes and headers in black tincture

Fig. (5) The final form of solar collector parts assembly

Fig. (6) The final assembly for Experiments

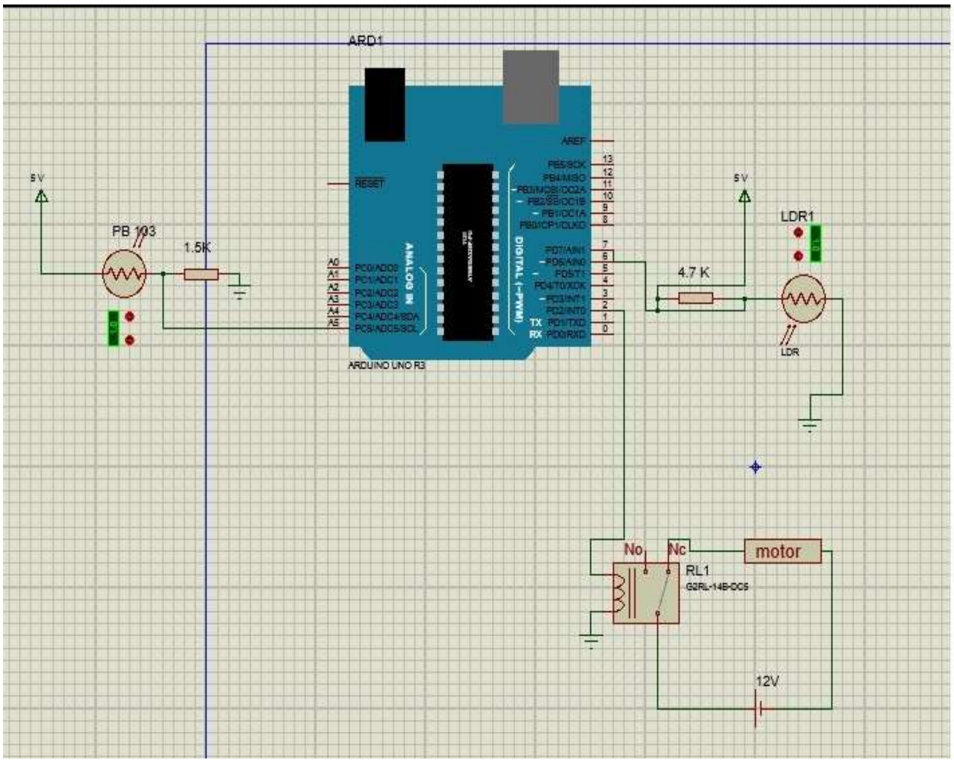

Fig. (7) Electrical circuit of solar tracker system

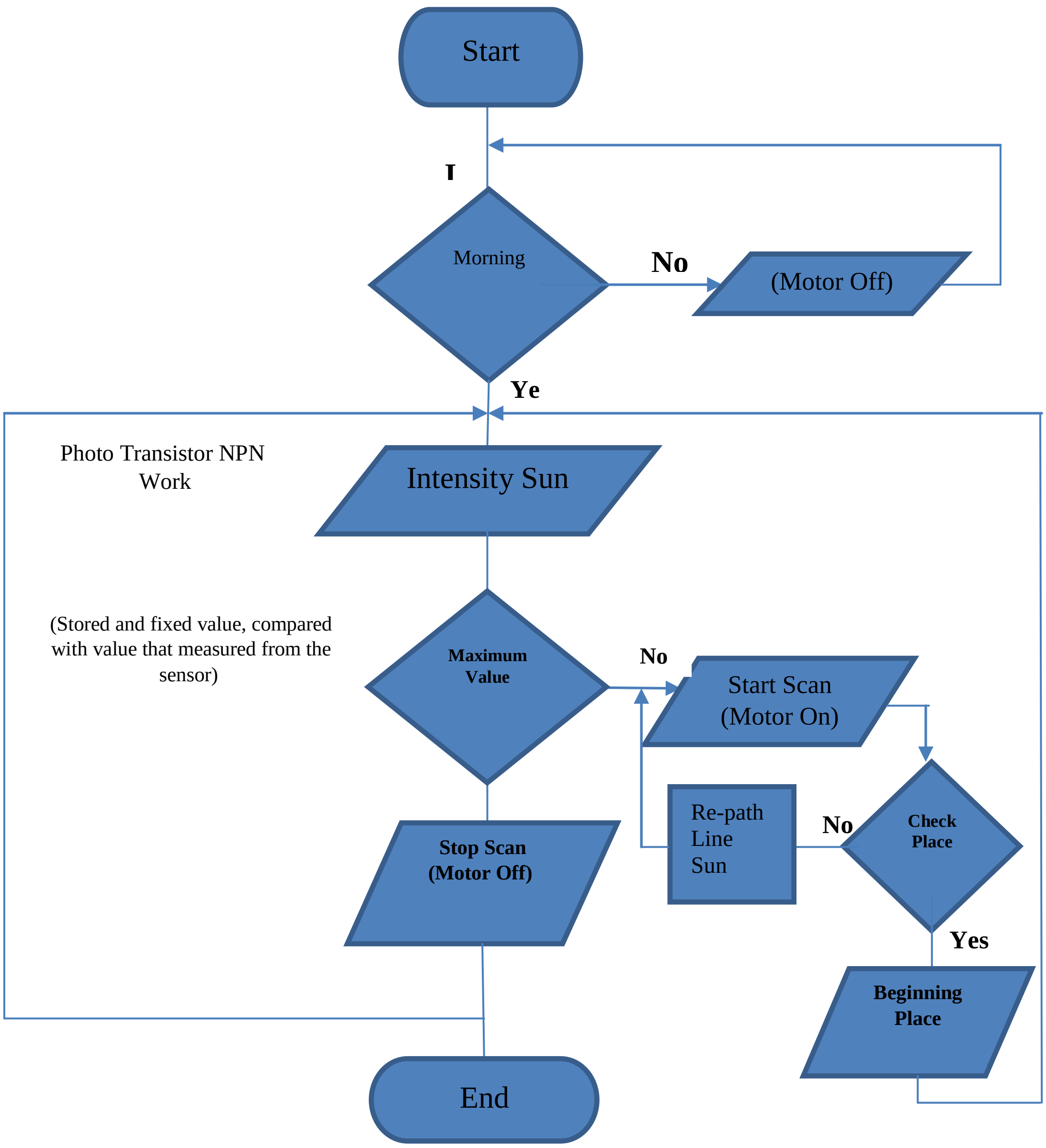

Fig.(8) Flow chart of solar tracker

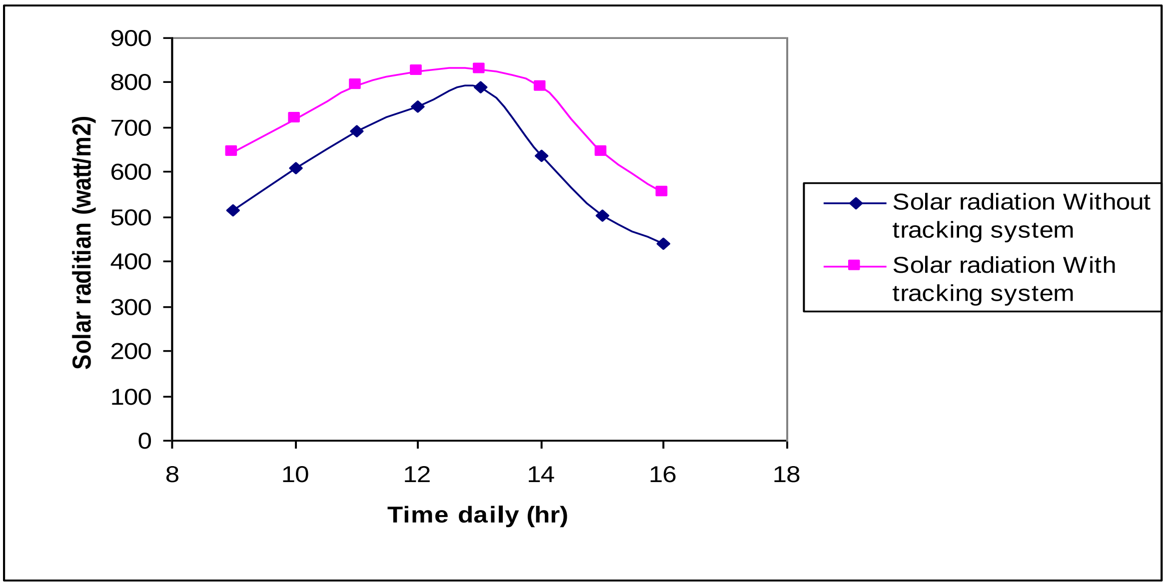

Fig. (9) Solar radiation without tracking and with tracking system in 2nd, 3th of Jun 2015

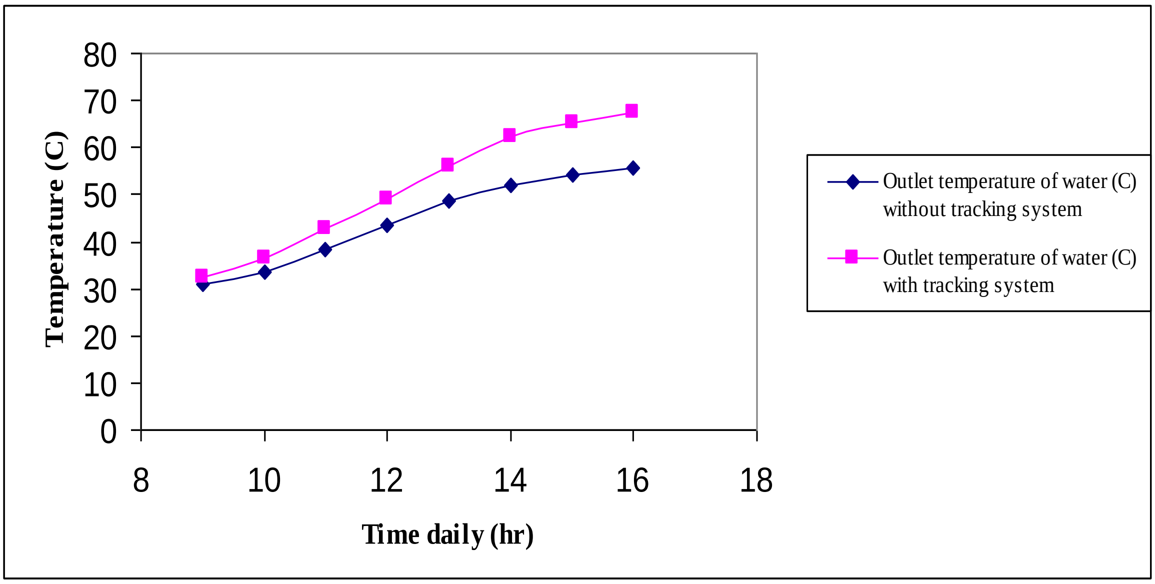

Fig. (10) Outlet temperature of solar collector without and with tracking system

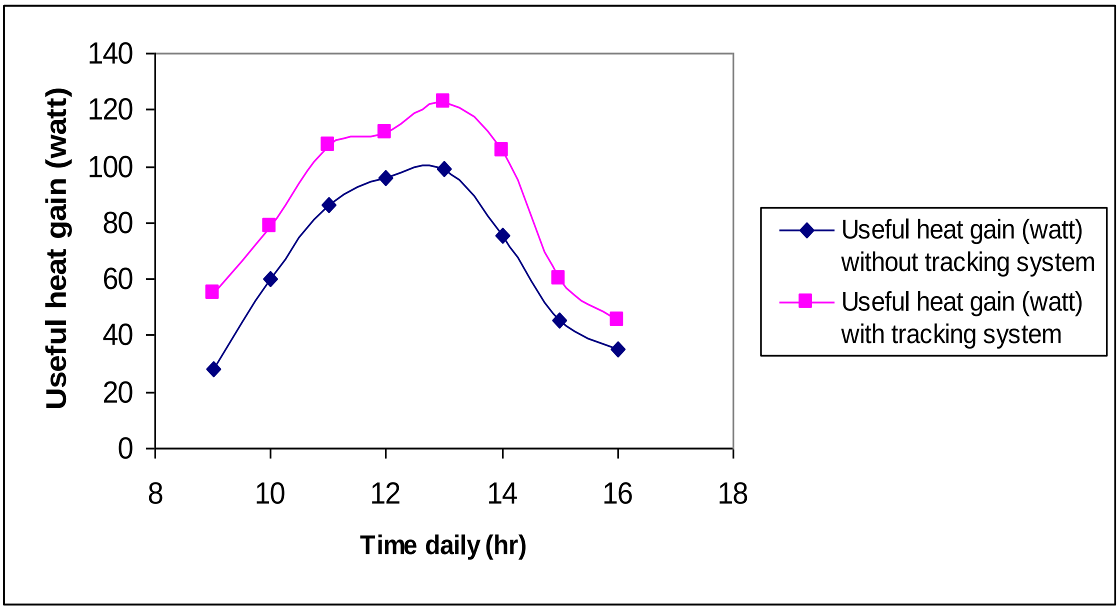

Fig. (11) Useful heat gain of solar collector without and with tracking system

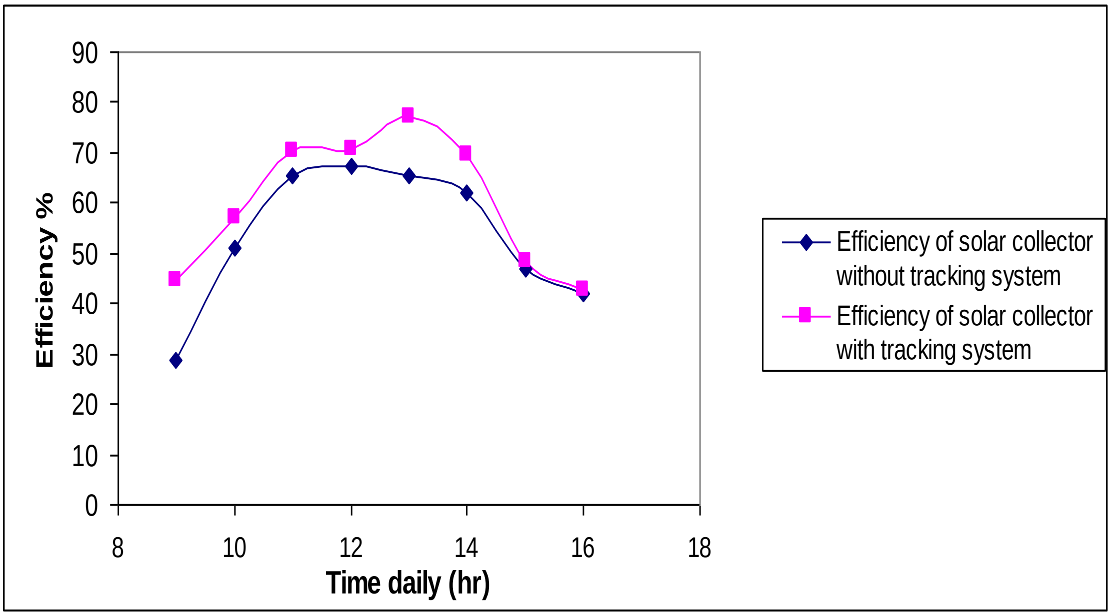

Fig. (12) Efficiency of solar collector without and with tracking system

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