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Thermal evaluation of a sun tracking solar cooker

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Abstract
Solar energy is one of many important types of renewable energy. Jordan is of great needs for renewable energy systems applications since it depends totally in generation of its required energy on imported oil. This study is an experimental work of tracking system developed for enhancing the solar heating using solar cooker. An electronic sun tracking device was used for rotating the solar heater with the movement of the sun. A comparison between fixed and sun tracked cooker showed that the use of sun tracking increased the heating temperature by 36% due to the increase in radiation concentration and using internal mirror reflectors. The programming method used for tracking control works efficiently in all weather conditions regardless of the presence of clouds. It can be used as backup control circuit in which relays are the essential control devices

Keywords: Electromechanical systems, hot box, solar cooker, solar energy, sun tracking..

1. Introduction

Neither gas nor petroleum can be produced in commercial amounts in Jordan, this fact makes Jordan, depends totally on, imported oil, for producing its required energy. As a consequence, a high petroleum bill is to be paid by the country every year, this forced researchers, and establishments, in Jordan to think seriously, to solve this problem, totally or partially. Official establishments, research institutes and centres started from nineties, to apply the renewable energy systems. Solar energy simply, is a natural energy, which does not have a limited supply; can be used again and again, and will never run out. Because of the suitable sunny climate most of the year's solar energy could be the main source of energy to Jordan that can be used in different fields' mainly in generation of electricity and for heating Solar cookers are rather important applications in thermal solar energy conversion. The uses of solar cookers for cooking purposes are spreading widely in most developing countries and in particular in villages and remote areas. The solar cookers must be of high quality, affordable, user friendly, light weight, stackable and a family size. Current designs of solar cookers are normally of box type and concentrators cookers. Solar cooker is relatively pollution free although the cost of environmental pollution during manufacture and construction should not be neglected. But operation and maintenance are free since no moving parts. The basic purpose of a solar box cooker is to heat things up - cook food, purify water, and sterilize instruments. A solar box cooks because the interior of the box is heated by the energy of the sun. Sunlight enters the solar box through the glass. It turns to heat energy when absorbed by the dark absorber plate and cooking pots. This heat input causes the temperature inside of the solar box cooker to rise until the heat loss of the cooker is equal to the solar heat gain. Temperatures sufficient for cooking food and pasteurizing water are easily achieved. Several research works [1- 3] were conducted on the thermal testing and performance evaluation for concentrating solar cooker and combined concentrating/oven type solar cooker, and the parameters that characterize the performance of the solar cooker. Evaluation of solar cooker thermal performance using different insulating materials was conducted by Mishra and Prakash, [4]. The hot box solar cooker was tested in an indoor solar simulator with covers consisting of 40and 100 mm thick Transparent Insulation Material (TIM) by Nahar et.al [5]. The addition of a plane reflector to a box-type solar cooker increases the obtained cooker temperature and thermal performances, Algifri and Al-Towaie [6]. A series of out-door experiments were performed on the double-glazed solar cooker, Kumar [7]. One of the earliest mathematical models to test the thermal performance of a Solar Cooker was presented by Garg et al [8] and Vaishya et al [9]. Also, Jubran and Alsaad [10] presented theoretical model for a single and double, glazed box-type solar cookers with or without reflectors. Whereas, Das et al [11] and Binark and Turkmen [12], and Ozkaymak [13] developed a mathematical model for a box- type solar cooker with three reflectors hinged at the top of the cooker. The main objective of this present work is to investigate two designs of solar cookers, to evaluate the thermal performance under different modes of operation such as at fixed position and moving on a tracking system.

2. Experimental set-up

The experimental tests on the solar cookers were carried out during the successive days from the 29th and 31st /10/2007 and 2nd /11/ 2007. Each experiment starts from 7:30 am in the morning until 16:00 pm in the afternoon. The electrical and electronic parts were tested and calibrated before being used on the various designs on both solar cookers. Both cookers are fixed at a position towards the south. The experimental work was fully carried out in the Renewable Energy laboratory at the Applied Science University, Amman-Jordan. The research work concentrated on testing the traditional black painted cooker with a tracking system toward the sun movement. Figure 1 show the solar cooker installed on a horizontal sun tracking system. It shows the base, motor and bearing and sun cooker

Figure 1. The tracking system of the solar cooker

The important parts of a hot box solar cooker include; a) outer box: the outer box of a solar heater is generally made of galvanized iron. b) inner heating Box: this is made of aluminum sheets. The inner box is slightly smaller than the outer box. It is coated with black paint so as to easily absorb solar radiation and transfer the heat to the heating (cooking) pots. c) thermal insulator: the space between the outer and the inner box tray including bottom of the tray is packed with insulating material such as glass wool pads to reduce heat losses from the heater. The insulating material should be free from volatile materials. d) mirrors: used inside the solar cooker to increase the radiation input on the absorbing space and fixed on the inner side of the main cover of the box. They will reflect the radiation entering the box directly to the container and helps to quicken the cooking process by raising the inside temperature of the cooker, e) glass lid: A glass lid covers the inner box or tray. This cover is slightly larger than the inner box. The glass is fixed in an aluminum frame. It was inclined at 32 degree with the horizontal on the top of the inclined heater. A rubber strip is affixed on the edges of the frame to prevent any heat leakage. f) Container: the heating container is made of stainless steel. These pots are also painted black on the outer surface so that they also absorb solar radiation directly. Three thermocouples at different locations were installed on the solar cooker. These locations are: a) Outer glass temperature, b) Metallic pot side temperature, and c) water temperature inside the pot. Also, ambient shaded and un-shaded temperature measurements were taken. Figure 2 shows schematic diagram of the dimensions of the solar cooker. Solar intensity radiation was measured by Kipp and Zonen Pyranometer type (CM5). A Digital multi-meter was used to record the output voltage in mV. The device records the data on an accumulative basis and shows the radiation on an instantaneous basis. The temperature measurements were carried out using K type thermocouple coupled to digital thermometer with range from -50 to150 oC. The accuracy of this thermometer is in the range of 0.3 oC for the temperature measurements between 1 to 99 oC.

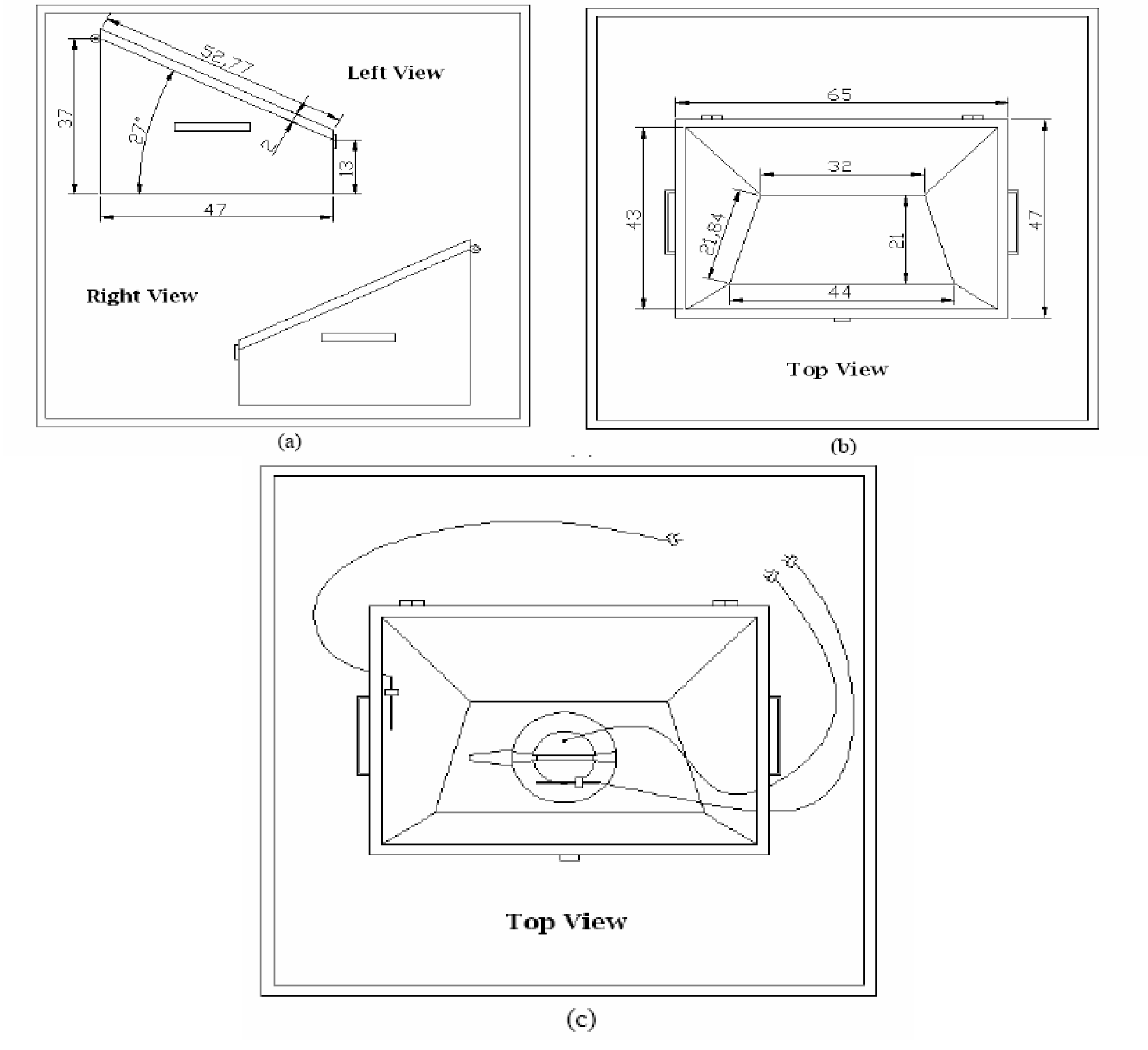

Figure 2. Three dimensional views of the designed solar cooker, (a) and (b) are cooker dimensions in cm, and (c) thermocouple connections in the cooker

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3 Electromechanical systems

The electromechanical system consists of one driver rotating about the vertical axis as shown in Figure 3, it can be seen that the system has one DC source and step down transformer. The DC source, to supply network into 24 VDC to power the PLC. The step down transformer, converts 220 VAC into 24 VAC to supply the electrical motor (M), PLC system chosen was of the LOGO 24 RC because it suits this application. Also, it is fairly simple and cheap in cost. The present stepwise tracking simplifies the work of the system without great loss in power. The estimated consumed power by the electrical motor and control system is less than 3% of the collected energy by the tracking system

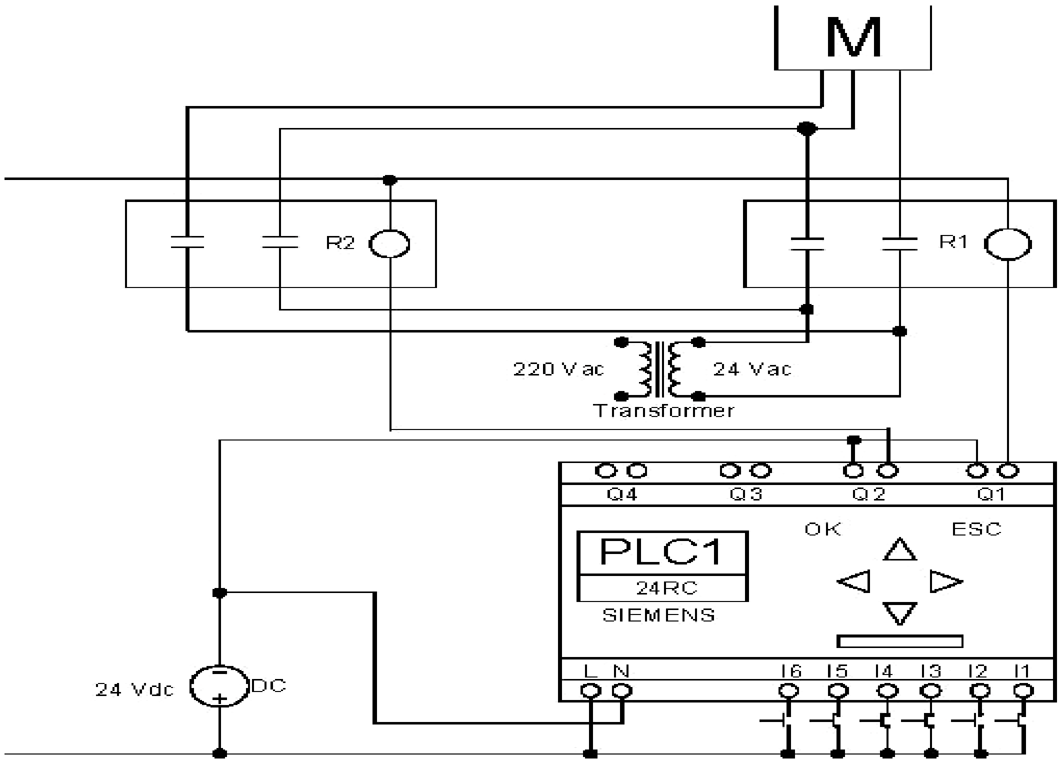

Figure 3. The electromechanical circuit for vertical control. 'Software used Microsoft Visio'

4. Control system programming

Computer software MATLAB has been developed to determine the different solar angles for Amman, to calculate the optimal positions of the tracking surface during the day light hours. Day light hours were divided into 4 identical time intervals T1, T2, T3 and T4, As shown in Figure 3, during which the motors speeds (deg. /second) were determined. Then, the PLC programme was done using Software LOGO Soft-Comfort-V5.0 based on the solar angles analysis and motor speed calculations. The motor of vertical tracking will be idle for 15 to 35 min and works for a few seconds. Two types of motions were specified by the developed program: forward motion and backward motion. From the theoretically calculated values the forward motion covers the intervals of time T1 and T2 in Figure 4. While the backward motion will cover the intervals of time T3 and T4 which begin from noon till sunset where β is maximum

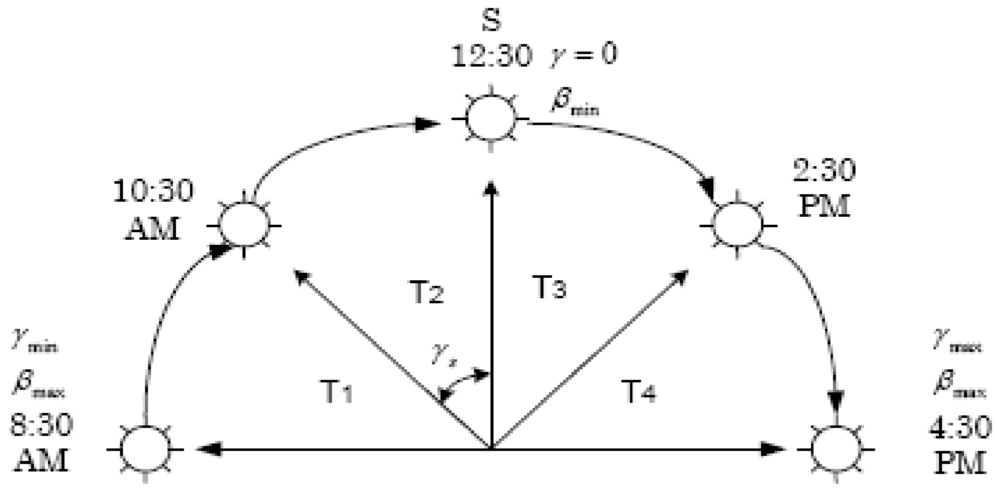

Figure 4. The division of daylight time into four intervals

5. Results and discussions

Figure 5 shows the solar intensity (i.e. electrical power) versus time of the day. The intensity of solar radiation reaching the earth surface varies from zero during the night to about 980 W/m^2, on a clear noon for both systems. Hence, the radiation intensity depends on the hour of the day. It can be seen that the solar intensity measured by Inclined Pyranometer used for tracking system where higher than that of the Inclined Pyranometer used for fixed system for most of the time. Figure 6 shows the effect of solar intensity on water temperature inside the cooker pot for two different systems .It can be seen that the water temperature increases for both systems as the solar intensity increases (Figure 5) till noon with an average increase of 25%, then decreases as the solar intensity decrease (Figure 5). It was found that the water temperature for the tracking system is higher than the fixed cooker in the morning period by 36% due to the increase of the radiation concentrations on the absorbency basin, especially in the morning hours, that decreases the heat capacity in the basin

Figure 7 shows the increases in the temperature of the external glass (on top of the transparent cover) as the solar radiation incident on glass increases. But the temperatures are lower than the cooker pot water temperature (Figure 6), due to the effect of air cooling on glass. Energy is transferred from the water to the glass cover principally by the water vapor evaporating from the water surface and then loosing its heat of vaporization to the glass cover. It can be seen that tracking system has increased the external cover temperature of about 10% due to the increase of the temperature of the vapor inside the cooker, and attributed to the high concentration of incident sun's rays passed through the transparent cover to a black evaporating pan.

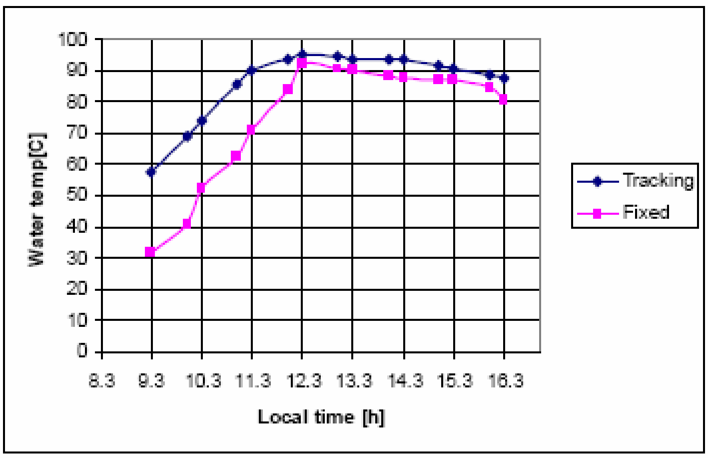

Figure 5. Power intensity dropped on the external glass for both

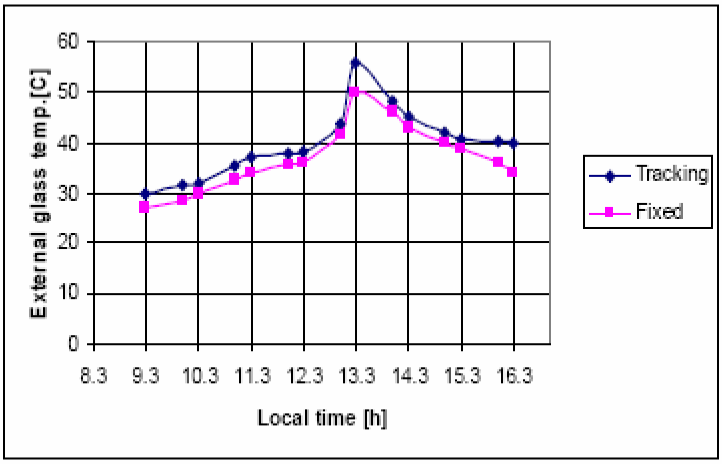

Figure 6. Temperature variation of pot water for both fixed cooker and sun tracked solar cookers

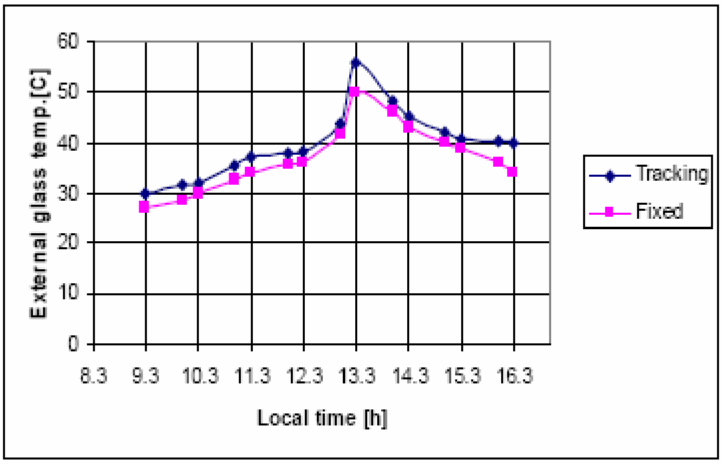

Figure 7. Temperature variation of the external glass for both fixed cooker and sun tracked solar cooker

6. Conclusions

Introducing the sun tracking system to a solar cooker has improved the thermal performance of the traditional fixed system by 36%. This means that there is scope to improve the poor performance of the solar cookers. Also from the results of this work, the following conclusions may be made: By using the sun tracker the pot water temperature increases, and the thermal capacity of the water decreases, by which the evaporation rate increases. Also the amount of solar intensity fallen over the sun tracked solar cooker has increased by 20%. The programming method of control works efficiently in all weather conditions regardless of the presence of clouds. It can be used as backup control circuit in which relays are the essential control devices.

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