DESIGN, FABRICATION AND PERFORMANCE ANALYSIS OF A PARABOLIC SOLAR COLLECTOR WITH SOLAR TRACKING

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Abstract:

The sun is the source of the vast majority of the energy we use on earth. Most of the energy we use has undergone various transformations before it is finally utilized, but it is also possible to tap this source of solar energy as it arrives on the earth's surface. Solar stove is one of the methods of tapping the solar energy.

The solar stove can be classified into two types with heat box type and concentrating type. The heat box type solar stove is featured with simple structure, low cost, convenient utilization but is limited in efficiency with moderate temperature which can only be suitable to braise and bake the food in a long time resulting in more utilization limit. Now the concentrating solar stove is broadly applied with the feature of high cooking efficiency, high temperature, short cooking time and strong applicability.

This study describes the design, fabrication and performance testing of a parabolic concentrating solar stove. The concentrating collector was equipped with a solar tracking system using light dependant resistor to seek the maximum light of the sun.

Using this design, the parabolic concentrating solar stove with the tracking system, up to 50% more energy was collected than the fixed collector. Such performance enhancement will pay back for the extra initial cost and increase the utilization property.

Introduction:

No one knows for sure how long our fossil fuel resources of coal, oil, and natural gas will last. But we know they are finite, and we know they are being consumed at an ever increasing rate. We can stretch fossil fuel resources by taking every possible opportunity to use clean energy sources such as the sun, wind, geothermal, moving water and other sources of energy, unknown now, which may be discovered in the future [Keith and Kreider, 1978].

Solar cooking is a technology which has been given a lot of attention in recent years especially in developing countries. The solar radiation raises the temperature sufficiently to boil the contents in the pots.

The nature and availability of solar radiation

Solar radiation arrives on the surface of the earth at a maximum power density of approximately 1 kilowatt per meter squared (kW/m^2). The actual usable radiation component varies depending on geographical location, cloud cover, hours of sunlight each day, etc. In reality, the solar flux density (same as power density) varies between 250 and 2500 kilowatt hours per meter squared per year (kWh/m^2 per year). As might be expected the total solar radiation is highest at the equator, especially in sunny, desert areas [Elsayed et al, 1994].

Solar radiation arrives at the earth's outer atmosphere in the form of a direct beam. This light is then partially scattered by cloud, smog, dust or other atmospheric. We therefore receive solar radiation either as *direct* radiation or scattered or *diffuse* radiation, the ratio depending on the atmospheric conditions. Both direct and diffuse components of radiation are useful, the only distinction between the two being that diffuse radiation cannot be concentrated for use.

Most Middle East countries lie in the sunny belt of the world. It enjoys on average about 3600 sunshine hours per year. The annual average daily total solar insulation on a horizontal surface is about $20MJ/m^2$. In addition, the sky is usually clear with no fog or cloud, and it rarely rains. These are very favorable climates conditions for all solar energy applications. Thus, all solar energy applications are recommended to harness such enormous energy. No doubt solar cookers are good candidates for widespread use in the Middle East area.

Solar cooking and solar stoves

Frenchman Muxiao, designer of worldwide first set solar stove, developed the parabolic solar stove ordered by the king of France in 1860 for the army's utilization in Africa. Since the 1900s, many countries conducted the research on solar stove, among which some tapped indoor solar stove by use of heat-pipe technologies and optical theory. But in general, the utilization on solar stove was in small scale in the world [www.solarstove.com].

Solar cooking is a technology which has been given a lot of attention in recent years in developing countries. A reflective surface is applied to the collector to concentrate the heat onto the pots. The pots can be painted black to help with heat absorption. The solar radiation raises the temperature sufficiently to boil the contents in the pots. Cooking time is often a lot slower than conventional cooking stoves but there is no fuel cost [Ibrahiem and El-Reidy, 1995].

The Chinese first solar stove emerged in Shanghai in 1956. Under the efforts in several decades, solar stoves have been kept in an amount of more than 300,000 sets in China making it possible to be the country that has popularized and applied solar stove in the largest quantities in the world.

The solar stove can be classified into two types with heat box type and concentrating type. The heat box type solar stove is featured with simple structure, low cost, convenient utilization but is limited in efficiency with moderate temperature which can only be suitable to braise and bake the food in a long time resulting in more utilization limit. Now the concentrating solar stove is broadly applied with the feature of high cooking efficiency, high temperature, short cooking time and strong applicability [Mohamed et al, 1998].

Description of solar stove:

Figure (1) shows the general layout of the proposed solar cooking system and its components. The solar cooking system is composed of three main components:

a) Focusing solar reflector:

The focusing solar collector utilizes optical systems, reflectors or refractors, to increase the intensity of solar radiation on the energy-absorbing surface. Higher energy flux on that surface means a smaller surface are for a given total amount of energy, and correspondingly reduced thermal losses.

A focusing collector can be vied as a special case of the flat–plate collector, modified by interposition of a radiation concentrator which serves to raise the low level of radiation on the absorber.

The solar collector is manufactured from sixteen reflection segments (0.4mm thickness) made from stainless steel. The segments were manufactured and spot welded together. Each segment has a trapezoidal shape to form the focusing solar collector.

Fig. 1 The solar cooker with sun tracking system

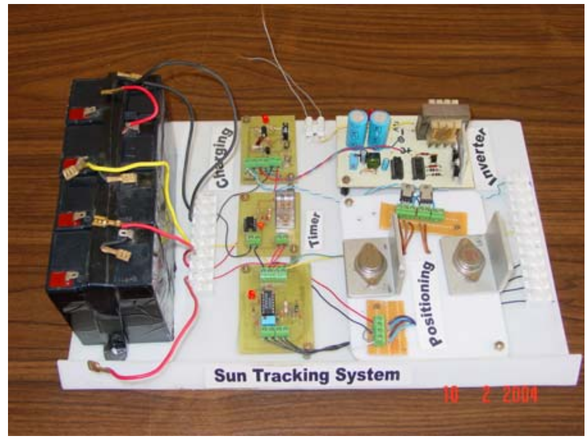

Fig. 2. Sun tracking control circuit.

The cooking pot was painted black to absorb as much radiated heat. Placing the stove in a sheltered area stops the wind from cooling the outside of the pot.

b) Base and Frame;

Table (1) below shows the description and price of each components of the stove:

Item number	**Description**	**Size**	**Material**	**Quantity**	**Cost $**
1	Solar reflector [16 reflective welded trapezoidal shape segments]	Diameter =1.25m [16 Tapered segments 250 to 50mm * 620mm length]	Stainless steel [0.4 mm thickness]	1	20
2	Pot	320mm diameter	Aluminum	1	5
3	Steel reinforcement ring	713 mm diameter	steel	1	1.5
4	Polar		Steel	1	12
5	Polar Arm	0.4 m length	Steel	3	6
6	Stand	0.7mm length * 0.9 mm diam. *0.002mm thick	Steel	1	4
7	Base Support [Long]	1.6 m	Steel	3	1.5
8	Base Support [Short]	0.88 m	Steel	3	1.5
9	Protective rubber ring	12.5 mm thickness	Rubber	1	2.5
10	Compass for direction		-	1	Test use
11	Protractor for slope		-	1	Test use
12	Pot holder	Steel bar	Steel	1	2
13	Anti-rust paint	-	paint	1	3
14	Labor cost				11
Total Cost					70

Six metal slides were welded together in a triangular shape to work as a base to support the stove. The stand is a metal cylinder with a suitable length for both safety and consistency condition.

The polar is a flexible metal pivot that gives the possibility of the solar reflector movement in only two opposite directions which were put in the top of the stand and connected by two screw bolts.

C) Tracking system

Fig (2) shows the sun tracing control circuit. The tracking system tries to collect the largest amount of solar radiation and convert it into usable form of energy. The sun tracking system is consisting of three main parts [Khalil and El-Singaby, 2004]:

1) LDR [Light Dependant Resistors]:
2) PMDC Motor [Permanent Magnet Direct Current Motor]
3) Tracking system control circuit:

A simple solar tracking system was used with the solar cooker to increase the energy absorbed by the system. The tracking system consisted of:

- Timer circuit, the main objective of the timer circuit is to reduce the energy consumed by the position circuit. The timer circuit, which triggers the tilting system, has to remain dormant for 30 min., during which time it must consume as little current as possible. To achieve this, a 555 timer chip (ICI) has been used. [It consumes only 100 micro amps when in the off-state].
- The positioning system, in this study, is composed of three-main subsystems. A light dependant resistor [LDR], as a bridge, a permanent magnet DC-motor (24volt) and a driving circuit [Darlington Configuration].
- Charging circuit, are served by the circuit: prevention of excessive charging currents and illumination of the LED as an approximate indication of charge completion. The available current to the battery and can be arranged to terminate fast charging.
- Inverter, DC-to-AC converters are known as inverters. The function of an inverter is to charge a DC input voltage to a symmetrical AC output voltage of desired magnitude and frequency.

Experimental procedure:

Safety precautions were carefully taken into considerations while performing the experiments. Experiments were performed in a clear area on the roof [Fourth floor] of the Faculty of Engineering and technology at the Arab Academy for science and Technology – Abu Kier – Alexandria (Latitude 31^o 31' N and Longitude 29^o 55' E) EGYPT.

The pot was filled with a 0.5 kg of water at a temperature of 26^{o}C to start the experiment. The starting position was adjusted to the sunset position using a compass and then the tracking system was then turned on to allow the positioning system to follow the sun direction.
Six thermocouples were fixed in the system to determine the maximum temperature on the pot surface [focus]. One thermocouple was used to measure the ambient temperature. Another two thermocouples were placed in the water inside the pot to measure the water temperature. The collector inclination angel was measured using a protractor fixed to the base.

Experimental Results and discussion:

Tests were performed during several days, summer and winter 2004. Figure 3 shows the selected test results in January 2004. The plotted results represent three different tests in different weather conditions [cloudy day, clear day, sunny day]. Figure 4 shows the results for the summer tests.

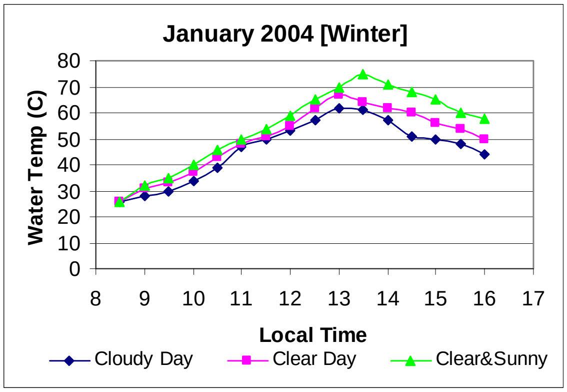

Fig (3) Experimental test results for three days in winter.

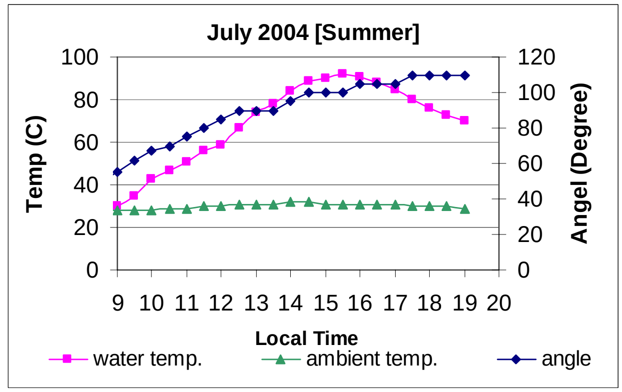

Fig. (4) Experimental test results for a summer clear day.

Conclusions:

Solar stoves have the potential to increase energy supply and security in rural households, but they must be affordable, accessible and of good quality.

The solar stove with tracking system was designed and manufactured to investigate the performance of the system in the Middle East region.

Field testing has been very promising, and some modifications were recommended to the system to improve its performance and reliability. The next step is recommended for the future work is to study the importance of the price and efficiency of solar stoves, and the importance of promoting the concept.

As a conclusion for this study, it is found that the system used is very durable and power efficient. It has been proved that the sun tracking system increases the performance of the solar stove by up to 50% than the fixed stove.

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