SOLAR WATER BOILER WITH TRACKING SYSTEM

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ABSTRACT

A fresnel lens is much more efficient at collecting and directing the light rays and it produced a beam five times more powerful than the reflector system used previously. A solar cooker was one of the devices used to utilize the abundant solar energy by many researchers. There are many different designs used but most of them were at the experimental level. This project presents a new design that might be of good potential. In this project the use of a giant fresnel lens to concentrate the solar energy on a specially designed cooker will be introduced. This project is concerned with designing a solar cooker based on using a fresnel lens to concentrate solar radiation on a special receiver unit attached to a cooking pot. A solar tracking system was used as an integral part of this work to produce a complete setup ready for commercial utilisation. The system can be used as a general purpose solar cooker or for water boiling. This paper is presenting and comparing the results of two concepts investigated theoretically and experimentally. The results of the preliminary performance evaluation of this system are also presented.

Keywords: Fresnel lens, concentration, boiling, tracking system.

1. INTRODUCTION

Using solar energy directly for cooking would immediately help to reduce the need for fire wood. Solar cooking helps to fight deforestation and can improve living conditions at the same time, even in very remote areas. A lLarge amount of research work has been conducted on solar cookers since the late 19th century. There are many types of solar cookers such as the parabolic and hotbox type solar cookers which are available commercially, but they are not very popular due to some drawbacks. The hot box solar cookers are safe and need less attention but some are relatively heavy (10-14 kg), [1]. Modes of heat flow within the solar cooker and its path to the food in the cooking vessel have been studied by A.V. Rao and S. Subramanyam [2]. Their studies highlighted the importance of developing new solar cookers designs which might be more efficient, [3].

A fresnel lens replaces the curved surface of a conventional lens with a series of concentric grooves, moulded into the surface of a thin, lightweight plastic sheet. The grooves act as individual refracting surfaces, like tiny prisms when viewed in cross section, bending parallel rays in a very close approximation to a common focal length. Because the lens is thin, very little light is lost by absorption [4].

This work introduces a new design of a solar water boiler which can be utilized for many different applications, such as solar coffee maker, solar cooker, etc. this new concept is using a very efficient heat transfer technique to convey the solar heat into the fluid. The system consists of a fresnel lens concentrator, a receiver and a solar tracking system.

2. DESCRIPTION OF THE SYSTEM

To boil water using solar energy we need to concentrate the solar radiation in order to increase the local temperature at the collector surface to value higher than 100°C. There are many types of concentrators; most of them are of the reflecting type, which requires placing the receiver at a level higher than the concentrator. This condition usually results in a very inconvenient condition

for the household applications. The other option is to use a fresnel lens concentrator which allows for the positioning of the cooking pot more conveniently and easily accessible by the user during the cooking process.
In this project there were two designs for the solar water boiler. The first was a single fresnel lens of dimensions 880X550 mm^2 and a receiver located at the lower side of an insulated cooking pot. Heat is conducted through the bottom, side and the inner wall of the insulated cooking pot to the water inside the pot. The pot capacity was about 5 litres. Figure (1) shows the assembly of the first concept solar water boiler.

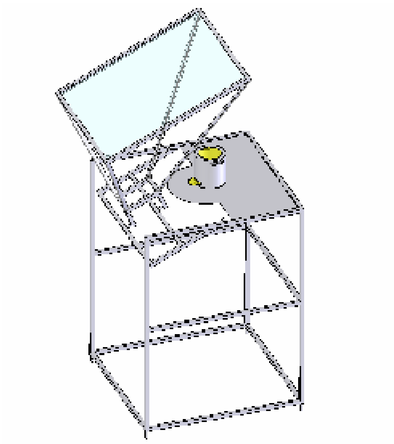

Fig. (1) Assembly of the first concept solar water boiler.

The second solar water boiler was designed to utilize the solar energy to supply a continuous flow of boiling water. On this concept two fresnel lenses each of dimensions of 550X440 mm^2 were used. The lenses were mounted on the same frame such that they will have two focal points 440 mm apart. Two receivers were used to collect the concentrated solar energy and convey it into the bulk of the water in the boiling pot.

The pot itself is considered as a water reservoir to preheat the water. When there is no immediate need of boiling water the solar energy is utilized continuously to heat up the water stored inside the boiler preheating reservoir. The hotter the water inside the reservoir the higher the amount of the boiling water flow rate that can be produced when boiling water is required.

The dominant heat transfer mode from the receiver to the water bulk inside the reservoir is by natural convection, which results in water circulation. If water vapour bubbles are generated at the receiver due to excessive solar heating the buoyant bubbles movement automatically accelerates the water flow and increases the circulation. This is illustrated clearly in Figure (2).

3. COMPARISON BETWEEN THE TWO CONCEPTS

Fresnel lenses are very efficient in concentrating solar radiation. The overall transmission is about 92% for a solar radiation wave length from 400-1100nm which covers a wide range of the solar radiation spectrum. Figure (3) shows the variation of transmission with wavelength for a standard fresnel lens.

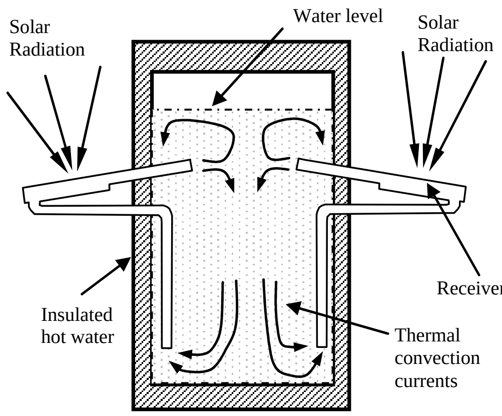

Fig. (2) Water thermal convection circulation in the second concept.

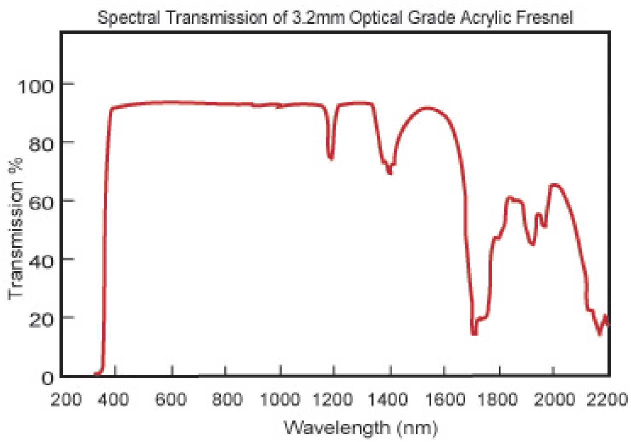

Fig. (3) Variation of transmission with wavelength [4]

The second water boiler can produce up to 200 ml of boiling water in one minute when the preheated water in the reservoir is at about 80°C. Figure (4) shows the relation between the water increase in temperature and the boiling water flow rate.

The experimental testing of the first concept was not very successful under the Malaysian cloudy tropical weather conditions due to the frequent interruption of solar radiation. Also the big amount of water in the boiler container required a longer time of continuous solar radiation before it reached the boiling temperature.

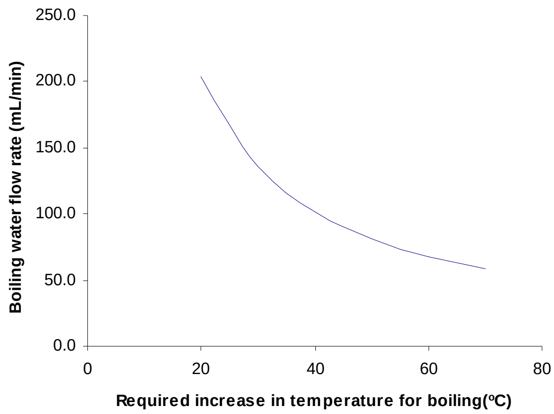

Fig. (4) Relation between the second concept output and required increase of temperature for water boiling.

The second concept was supplied with a two-way valve which allows the water coming from the receiver to be either re-circulated through the reservoir or discharged to the outer side for use. This design makes the amount of heat available from the solar radiation to be supplied at any time to only a limited amount of water in the receiver. The total amount of water in the receiver is only about 4 ml, which makes the rise of temperature very fast as indicated by Figure (4). Figure (5) shows students testing the second solar water boiler.

Fig. (5) Testing the second concept of the water boiler

4. THE SOLAR TRACKING SYSTEM

The function of the Solar Tracker is to adjust the tilting angle of the fresnel lens such that the concentrated sunlight remains focused onto the heat collector at all time during the day as the sun moves from the East to the West. In the evening, the Solar Tracker brings the fresnel lens back to facing the 'East' when the sun sets.
Figure (6) shows the block diagram of the Solar Tracker.

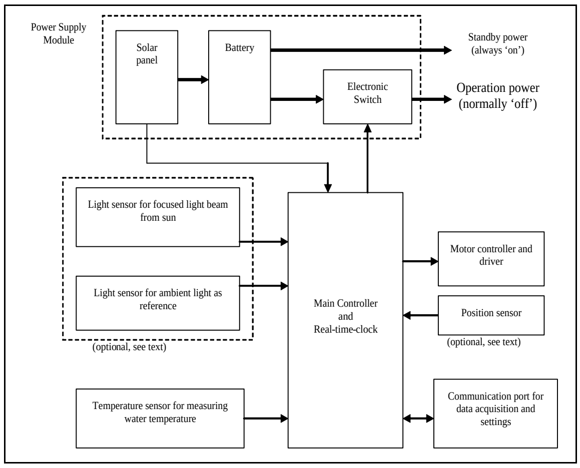

Fig. (6) Block diagram of the Solar Tracker

5. DESIGN FOR LOW POWER CONSUMPTION

The main electrical requirement of the Solar Tracker is low electrical power consumption. The electrical power source must be completely derived from solar energy. From Figure (6), the 'power supply module' of the Solar Tracker is made up of a solar panel, a re-chargeable battery, and an electronic switch. The 'power supply module' provides a 'standby power' which is always 'on', and an 'operating power' which can be turned 'off' by the Main Controller, sending a command to the electronic switch.

During the day, or when sunlight is sufficiently high, the Solar Panel constantly charges the re-chargeable battery as well as supplying electrical power to the whole Solar Tracker. The output of the Solar Panel is also continuously monitored by the Main Controller.
For most of the time, the Main Controller would turn 'off' most circuitry of the Solar Tracker by turning 'off' the electronic switch. The Main Controller would then go into low power 'standby' mode consuming only the 'standby power' derived directly from the battery.

The Main Controller would periodically 'wake up' to check the output of the Solar Panel. If the output of the Solar Panel is higher than a pre-set value, the Main

Controller would move the fresnel lens into a tilting angle for optimum sunlight exposure. Otherwise, the Solar Tracker would remain in the 'standby' mode.
In the 'standby' mode, to keep absolutely low power consumption, only the Microprocessor IC and the Real-time-clock of the Solar Tracker is 'alive' (i.e. supplied with the 'standby power'). The Microprocessor would be 'sleeping' most of the time consuming only a few micro-amps of current. The Microprocessor would 'wake' up periodically to check if the sunlight is resumed, while the Real-time-clock keeps 'ticking' to keep the true 'time-of-day' value necessary for the Main Controller to estimate the position of the sun.

6. FRESNEL LENSE TILTING ANGLE CONTROL

There are two strategies in controlling the tilting angle of the Fresnel lens. For simplicity, the Main Controller may guess the optimum tilting angle by checking the 'time-of-day' value with the 'Real-time-clock'. From there, it would translate the 'time-of-day' value into the pre-set tilting angle by referring to a translation table stored in its memory. As such, a table of 'time-of-day'-to-'tilting angle' translation needs to be acquired experimentally for every new positioning of the complete experiment set-up. The translation table can then be downloaded into the memory of the Main Controller for reference. For this control strategy, only a simple position (angular) sensor is needed, which is just a few resistors and potentiometer. At the end of the day, at the pre-set time in the evening, the Main Controller would bring the fresnel lens back to facing the 'East'.

Alternatively, the more expensive control strategy would involve light sensors for constantly monitoring of the sunlight focused onto the 'heat collector'. The light sensors, mounted in the vicinity of the 'heat collector', serve as a negative feedback for position (or angular) control of the fresnel lens. In this way, the position of the experiment set-up can be varied without having to acquire the translation table as described in the previous paragraph. The Main Controller would adaptively finds the optimum tilting angle of the fresnel lens based on feedback from the light sensors.

7. DATA ACQUISITION AND DOWNLOADING

Water temperature of the Water Boiler is periodically measured and recorded by the Main Controller. The measurement, after filtering and signal conditioning, is converted and recorded in 8-bit resolution (i.e. 255 steps). The measurement will be kept in the memory of the Main Controller until it is downloaded to the computer for analysis. The acquired data, together with the calibration data used by different control strategies described in the previous paragraph, can be downloaded / uploaded using the 'communication port' as shown in Figure (6).

8. CONCLUSION

Boiling water using solar energy at the household level was achieved successfully by utilising concentrated solar energy on a small mass flow rate of water. A boiling water flow rate of up to 200 ml/min was produced by the continuous flow of boiling water. The presence of a solar tracking system was found to be very important and can not be avoided for such application. A fresnel lens water boiler can be developed to be a very convenient alternative for water boiling for many applications such as coffee making, fast noodle preparation and many other similar applications. The system can also be considered for medical applications in rural and remote areas.

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