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Original Research Article

A vacuum tube based improved solar cooker

Suhail Zaki Farooqui *

Faculty of Engineering Sciences, National University of Sciences & Technology, Islamabad, PNS – Jauhar, H.I. Rahamatullah Road, Karachi 75350, Pakistan

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ABSTRACT

A new type of improved solar cooker based upon the use of a single vacuum tube is presented in this paper. The proposed cooker utilizes a solar collector consisting of parallel plane rectangular glass mirror strips mounted inside a wooden frame and requiring one dimensional solar tracking through a common driver. The proposed design can be either installed over the roof top of a house or near a south facing window (in countries of northern hemisphere). Temperatures as high as 250 °C are attainable, making it suitable for all types of cooking. Due to larger collector area, the design offers substantially higher cooking power compared to other conventional solar cookers. Theoretical performance analysis and comparative experimental results at different times of the year with a 1.775 m^2 collector prototype have been included along with the cost/benefit analysis.

Introduction

For the developing countries especially, cooking is one of the basic and dominant end use of energy. Energy requirement for cooking accounts for over one third of the total primary energy consumption in many countries in the South East Asia [1]. Hence in the wake of the present day energy constraints and to reduce the large scale deforestation in these countries, it is very desirable to develop alternative, convenient and affordable methods of cooking, based upon the renewable energy sources.

Solar cookers of various designs are being used in many parts of the world since a long time as environmental friendly and cost effective devices to partially fulfil the cooking needs. The conventional box type solar cooker utilizes a horizontal double glazed top surface made out of transparent glass. Food is placed in the box below this surface, under airtight conditions. A booster mirror, mounted as the lid of the box reflects the sun rays into the box. This type of solar cooker requires frequent two dimensional solar tracking. Further, it requires that the food is placed inside the box once and taken out only after the cooking is complete. This makes it unsuitable for cooking most food items [2,3]. Though, the conventional design has been modified by many authors using several combinations of booster mirrors, etc. [4–6], it is still not quite user friendly.

Solar cookers based upon multiple vacuum tubes have been suggested and experimented by several authors [7–10]. The cooker presented by Balzar et al. [9] consists of a multiple vacuum tube collector coupled to long heat pipes directly leading to the oven plate. Another cooker presented by Kumar et al. [10] is a community type solar pressure cooker, in which the vacuum tubes and the pressure cooker are coupled together by a heat exchanger. This system is reported to supply heat at temperatures of up to 120 °C. The multiple vacuum tube based solar cookers have a special advantage, that they do not require solar tracking. Further, the cooking can take place inside a shade or a building, since the collecting part and the oven are spatially separated. The main disadvantages with multiple vacuum tube solar cookers are low maximum temperatures, utilization of many expensive vacuum tubes and long heating times. Further, they require more complex and expensive hot fluid circulation systems or evaporators and condensers. More recently, good reviews on solar cookers with and without thermal storage have been presented by [1,11,12].

A single vacuum tube based solar cooker, with substantially reduced heating time, easier usage and simple heat transmission system is reported in this paper. The solar collector is based upon the linear Fresnel concept [13], using long plane parallel rectangular mirror strips fixed in a rectangular wooden frame and rotatable with respect to individual longitudinal axes. All the strips are laser aligned to focus the incoming solar light on to a single longitudinally mounted fixed vacuum tube above the mirror frame. The well insulated cooking chamber is fitted through a silicon hose directly above the vacuum tube. The mirror strips are synchronously tracked during the day from east to west along the position of the sun, using an electronic, low powered (average 4 W), battery operated solar tracker. A less than two square metre collector area (1.775 m^2) has been found to transfer on the average nearly 250 W of thermal power to the fluid inside the vacuum tube and cooking

* Corresponding author. Address: Faculty of Engineering Sciences, National University of Sciences & Technology, Islamabad, PNS - Jauhar, H.I. Rahmatullah Road, Karachi - 75350, Pakistan. Tel.: +92 021 7681668; fax: +92 021 9040112.

E-mail address: drsuzaki@hotmail.com

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chamber, at 25° latitude and 67° longitude location. Fluid temperatures of up to 250 °C have been achieved this way inside the cooking chamber.

The linear Fresnel collector

The linear Fresnel collector concept has recently gained popularity for large solar thermal power plants. It has been proposed that this concept has the potential to substantially reduce the levelized costs of electricity (LCOE) of solar thermal power plants. On one hand these collectors may prove to be cheaper than the conventional parabolic trough collectors due to reduced tracking losses, and on the other hand they utilize an absorber tube which is fixed in space. This trait greatly reduces the complexity of the thermal oil circulation mechanism. Further, since the solar collector consists of plane parallel rectangular mirror strips of small widths, separated from each other by small distances, they pose little resistance to the flow of wind. The whole structure therefore can sustain substantially high winds in the open fields without any extra arrangements. Due to these multiple advantages, and with further improvements, these collectors have the potential to accelerate the market penetration of solar thermal power plants in the coming years.

The linear Fresnel collector consists of a number of parallel rectangular plane mirror strips mounted on individual longitudinal axes, inside a rectangular frame. Each mirror strip is laser aligned to reflect the incoming light from a perpendicular source to a fixed absorber tube mounted at an appropriate height over the frame. After the alignment, all the strips are connected to a common driver, which can cause them to rotate together with respect to their individual axes. With this arrangement, the combined light from all the individual mirrors with proper tracking, can remain focused onto the absorber tube, even if the light source is moved to the right or left, and does not remain perpendicular to the frame (Fig. 1). As the light source moves by an angle θ, the mirrors have to rotate by an angle $\theta/2$. A secondary semicircular reflector facing the frame, is mounted over the top of the absorber tube, to reflect any escaped light back to the absorber tube. It is to be mounted touching the top surface of the tube, so that the reflected rays have the maximum chance of entry into the absorber tube.

The alignment of the primary mirrors of the solar cooker described in this paper may be performed through a relatively simple purpose built alignment frame, as shown in Fig. 2. A horizontal bed consisting of two U-channels is mounted over a rectangular frame of steel pipes. A small wooden block perpendicularly fitted with a commonly available laser pointer can slide horizontally through the two U-channels. For alignment purpose, this frame is placed over the horizontally placed Fresnel collector bed. The laser pointer is slid directly above a mirror strip and the mirror is rotated until the reflected laser beam is received on the absorber tube. The particular mirror is fixed in this position, and the same process is repeated for each individual mirror, until all are aligned to reflect the incoming parallel solar radiation onto the absorber tube.

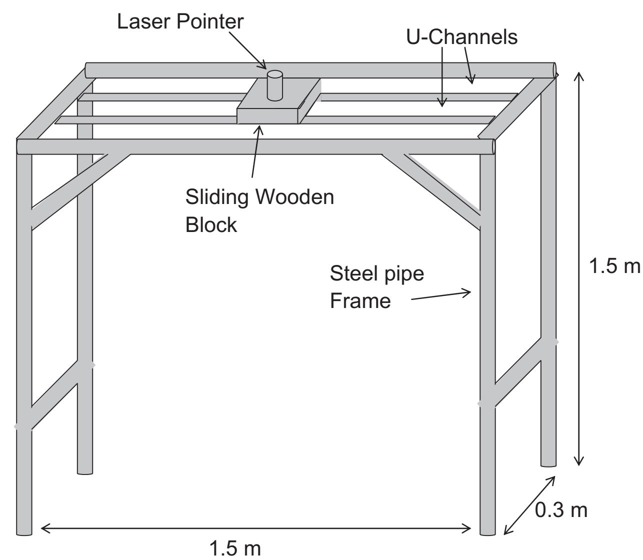

Fig. 2. The alignment frame with dimensions, for laser alignment of the primary mirrors in the linear Fresnel collector bed.

An analysis of the geometrical properties like effects of the height of the absorber tube above the primary mirrors, effects of the gap between the primary mirrors, number of primary mirrors and the effect of the relative focal length (in case of curved mirrors) of the primary mirrors relative to the distance between mirror and absorber tube have been carried out in [14]. The absorber tube being used in the subject solar cooker is the standard double-layered multicoated evacuated borosilicate glass tube with one open end. The other end of the tube is sealed. These low cost vacuum tubes are commonly used in modern solar geysers and can sustain temperatures of up to 300 °C. For the Chinese brand Tonghua used in the described setup (Model No. TH-58-1800, 1800 mm length, 58 mm outer diameter), the stagnation temperature is 270–300 °C. The absorptivity of the inner tube coated with Al-N/Al

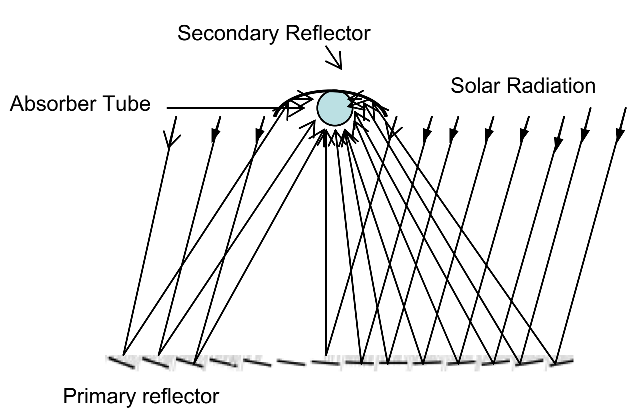

Fig. 1. Cross sectional view of the schematic diagram of a linear Fresnel collector. Primary mirrors reflect the incoming light onto the absorber tube. Any leaked radiation strikes the secondary reflector and is reflected back to the tube.

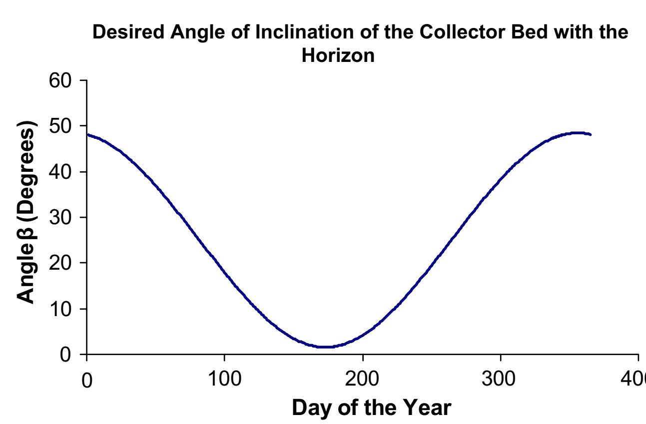

Fig. 3. Desired angle of inclination β of the collector bed with respect to the horizontal direction corresponding to each day of the year for 25° latitude test location.