



Experimental Study of a Double-Exposure Solar Cooker based on the Parabolic and Flat Reflected Surfaces

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Abstract— in this paper, the performance of a double-exposure solar cooker has been studied experimentally. Therefore, two similar systems were designed, constructed and tested under the same climatic conditions; and the effects of reflected surface in the box and parabolic parts of double-exposure solar cooker on its performance were studied. The results show that the flat mirrors in the box-type of the solar cooker affect about 18.5% and the mounted mirrors on the parabolic part affect about 25% on the performance of the solar cooker; also the effectiveness pattern of mounted mirrors on the parabolic curve on its performance has obtained. These results can be used in for the analysis, design and construction of new set up of these systems. This research was designed to develop double-exposure solar cooker performance and its tests were carried out in the Research Institute of Food Science and Technology, located at 36 latitude and 54 longitudes in Mashhad, Iran.

Index Terms—Solar energy, Solar cooker, Double-exposure solar cooker, Reflected surface, thermal performance

I. INTRODUCTION

Solar cookers use clean, available and low cost solar energy for cooking [1, 2]. These systems are suitable means to prevent the burning of fossil and forest resources and protect the environment. They have become the focus of researchers as a new approach to renewable energies (Panwara et al., 2011). Development of solar cooker capabilities and domain of their applications are two important subjects in this area. Many experimental and theoretical studies have been done to develop the capabilities of solar cookers and different methods have been employed to improve the thermal performance and their efficiency [3]. Shape, size, and type of solar cookers

are factors that can improve their performance and reduce the time of cooking.

Appropriating various sun tracking mechanisms to improve radiation absorption during the day and optimization of absorber plates [4], enhancing the applied geometry (truncated pyramid) to increase solar energy absorption without resorting to sun tracking systems [5], applying enhanced food vessel geometries to increase heat transfer [5], are among the strategies adopted and investigated regarding thermal and radiation performance optimization of solar cookers. Most of these investigations have been reviewed by R. M. Muthusivagami and colleagues. They reviewed the process of research and development in various types of solar cookers [6]. Studies on double exposure cookers first began in 2002. The simultaneous radiation of solar energy from above and below of the absorber plate increased the temperature from 140 to 165 and caused 30 to 60 minutes decrease in the boiling time compared to box-type solar cookers [7]. Installing some thermal fins on the vessel in a double-exposure solar cooker decreased its boiling time by 11-19% [8]. Using some simple fins on absorber plate in a box-type solar cooker increased its temperature by 7% and decreased its boiling time by 12%; this method can also be used in double-exposure solar cookers [9]. Employing an innovative design of the reflective surfaces, improved the maximum temperature of the absorber plate from 127.7 to 165 by applying two parabolic concentrators in a box-type solar cooker. In this design, the absorber plate receives the radiation energy of the parabolic plates from both sides. The device is installed on the kitchen wall and works without a sun tracking mechanism [10]. Some researchers investigated the design's performance through an analytic method and adopted numerical and experimental methods to study the modeling of the heat transfer process [11].

Following the previous studies, the present research aims to optimize and efficient use of the reflective surfaces geometry of double exposure solar cookers. For this purpose, the effects of both parabolic and box-type reflective surfaces on performance of a double-exposure solar cooker for the first time has been studied. So, two similar systems are made and some experiments have been designed and carried out. The results of this study have improved the technical knowledge of double-exposure solar cookers and can be used for designing, analyzing, and better exploitation of them.

A. New Setup Properties

The double-exposure solar cooker that is used in this investigation consists of a box-part with a double-glass at the bottom allowing the absorber plate to receive solar radiations on its lower side. The box is equipped with two flat mirrors (50 cm by 30 cm) and another mirror (50 cm by 50 cm), which are installed upon a wood frame connected with hinges on the upper side of the solar cooker. The walls of solar box are made of a wooden layer (thickness: 20 mm), the inner sides of which are covered with an aluminum foil (thickness: 0.2 mm). The height of the backside and front-side in the box-part are 32 and 17 cm, respectively. Junction fragments were sealed properly to prevent escaping air from system. At the top of the box-part, a glass plate (48 cm by 33 cm) of 4 mm thickness was fixed in position with silicone rubber to avoid breakage due to expansion and also to make the cooking space airtight.

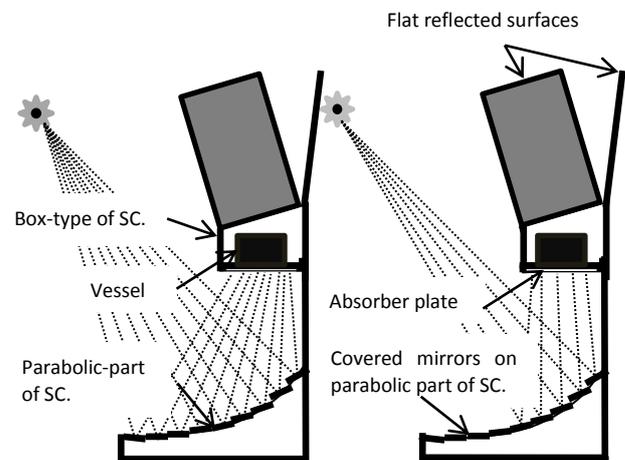
The parabolic part of system is composed of 9 mirrors, 10 by 50 cm, which are mounted on a parabolic curve and are set manually. Exposing mirrors to the sun radiation are manually set for the sunlight be concentrated on the adsorbent plate. The absorber plate is a black steel sheet, 46 by 27 cm and 0.2 cm thickness. The absorber plate is mounted horizontally and receives solar radiation from two sides. A commercial cooking vessel, of 20 cm in diameter and 10 cm in depth, was placed in the center of the box-part. The cooking vessel is made of an aluminum sheet of 0.2 cm thickness and the outer surfaces of the cooking vessel are painted black. A photograph of the solar cookers prototype is shown in Fig. 1.



Figure 1. Photograph of the two solar cookers prototype.

B. The Measurements Method

For determining the effects of reflected surfaces of a double-exposure solar cooker, two prototypes were made and were experimented. Two series of experiments have been performed under prevailing weather condition in Mashhad. Mashhad is located in Iran at 37 N latitude and



54 W longitudes; the altitude of Mashhad is 985 m above sea level. Fig. 2 shows a schematic plan of two double-exposure solar cookers. The figure shows paths of solar radiation and mounted covered mirrors on parabolic part in the first series of experiment.

Figure 2. Schematic plan of the double-exposure solar cooker and paths of solar radiations; left: system 1 & rghit: system 2.

The experiments were conducted from May 4th to 12th, 2013. During the experimental period, the following quantities were measured: ambient air temperature T_a , water temperatures in the cooking vessel T_w and total solar radiation I on a horizontal surface. All temperatures are measured by a 2_ channel testo 922, using thermocouples of probe k (NiCr- Ni) type with accuracy ($\pm 0.5^\circ\text{C} + 0.3\% \text{ mv}$).

Based on the International standard for performance testing of solar cookers, Thermocouple sensors were immersed in the water 5 cm above the vessel bottom [12]. The water temperature in the vessel was sampled every five minute and also solar radiation on a horizontal surface was recorded during the tests. Solar radiation was measured by a TES/1333 solar power meter made in Taiwan, with an accuracy of ± 10 w/m² and maximum uncertainty 5.8 w/m².

C. Results and Discussion

1) Reflected Surfaces of Parabolic Part effects

In the first series of experiments, the effects of mounted mirrors on the parabolic part of solar cookers were investigated. In the first experiment, two identical vessels were filled by the same quantity of water (1.0 L); and two mirrors of parabolic part in system 2 were covered in order to compare its performance with the other one. Fig. 3 shows the results of this experiment.

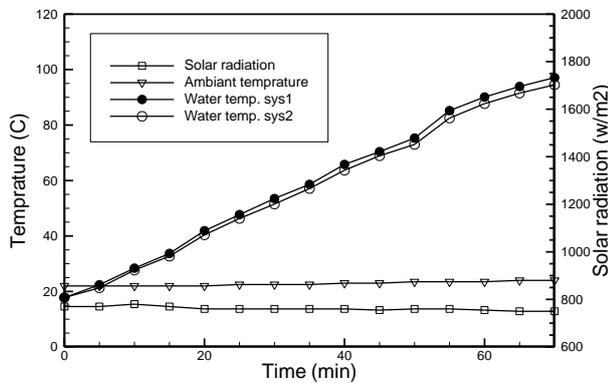


Figure 3. The effect of the reflected surface of parabolic part; Comparison between the water temperatures in both systems. Experiment was conducted on May 10th, 2013 starting at 10:10 A.M.

The results show that the water temperature in system 2 with 7 mirrors in parabolic part and 76.7% ratio in its reflected surface decreased about 3% comparing to the solar cooker with 9 mirrors in system1. In the second experiment, 3 mirrors of parabolic part in system 2 were covered and its performance were compared with the other one. Fig. 4 shows the results of this experiment.

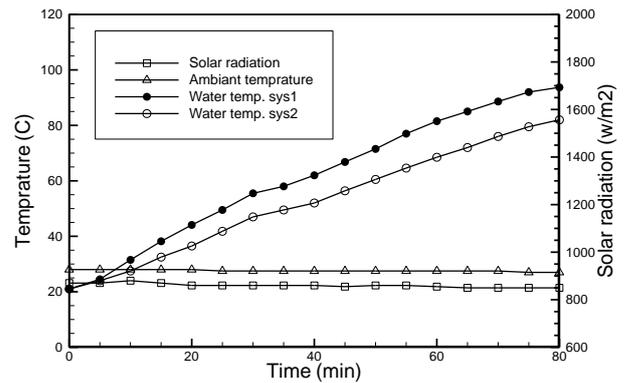


Figure 4. The effect of the reflected surface of parabolic part; Comparison between the water temperatures in both systems. Experiment was conducted on May 5th, 2013 starting at 11:45 A.M.

The results show that the water temperature in the vessel of system 2 with 6 mirrors in parabolic part and 66.3% ratio in its reflected surface is about 13% less than the solar cooker with 9 mirrors in system 1. In the third experiment four mirrors of the parabolic part in system 2 were covered and its performance compared with the other one. Fig. 5 shows the results of this experiment.

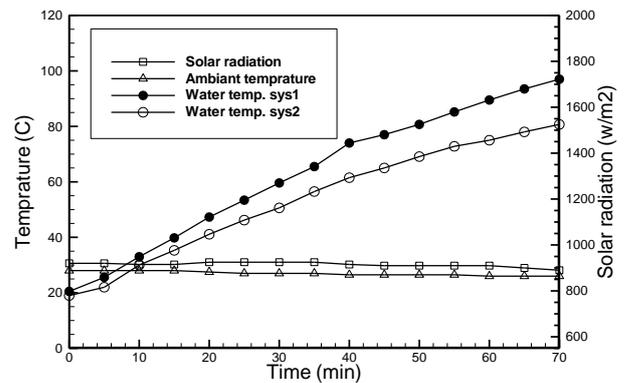


Figure 5. The effect of the reflected surface of parabolic part; Comparison between the water temperatures in both systems. Experiment was conducted on May 6th, 2013 starting at 11:30 A.M.

The results show that the water temperature in the vessel of system 2 with 5 mirrors in parabolic part and 55.8% ratio in its reflected surface is about 17% less than the solar cooker with 9 mirrors in system 1. In the fourth experiment all mirrors of the parabolic part in system 2 were covered and its performance compared with the other one. Fig. 6 shows the results of this experiment.

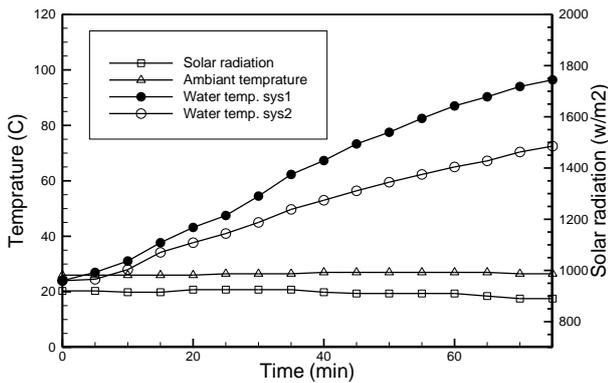


Figure 6. The effect of the reflected surface of parabolic part; Comparison between the water temperatures in both systems. Experiment was conducted on May 10th, 2013 starting at 11:30 A.M.

The results show that the water temperature in the vessel of system 2 without any mirrors in parabolic part and 0% ratio in its reflected surface decreased about 25% less than the solar cooker with 9 mirrors in system 1.

2) Reflected Surfaces of Box-type effects

In the second series of experiments, the effects of the flat mirrors that are mounted on the box part of solar cooker were investigated. In all the experiments of this series, two identical vessels were filled with water (1.0 L). In the first experiment, two side-view mirrors of box part in system 2 were excluded and its performance were compared with the other one. Fig. 7 shows the results of this experiment.

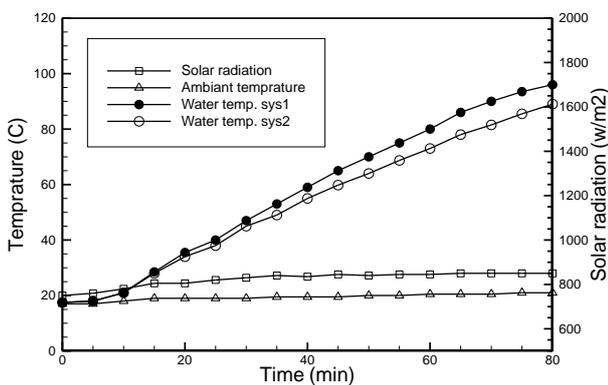


Figure 7. The effect of the flat mirrors of the box-part; Comparison between the water temperatures in both systems; Experiment was conducted on May 4th, 2013 starting at 8:30.

The results show that the water temperature in system 2 with one flat mirror decreased about 9% less than the solar cooker with three flat mirrors in system 1. In this state the ratio of reflected surface in box-type to maximum reflected area in this part is 45.4 %. In the second experiment all three flat mirrors of box- part of solar cooker in system 2 were excluded and compared with the other one. Fig. 8 shows the results of this experiment. In this state the ratio

of reflected surface in box-type to maximum reflected area in this part is 0%. The results show that the water temperature in system 2 decreased about 13.5%, comparing with the solar cooker with three flat mirrors in system 1.

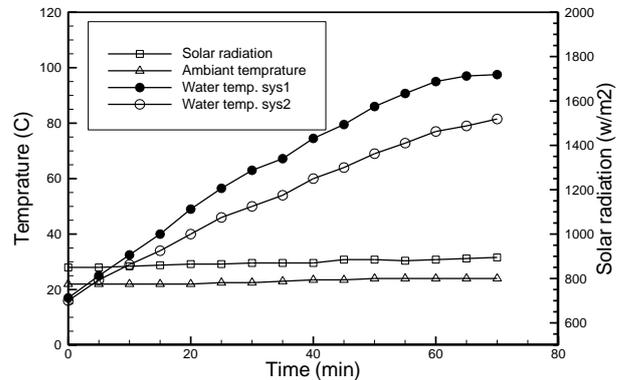


Figure 8. The effect of the flat mirrors of box-type; Comparison between water temperatures in the both systems; Experiment was conducted on May 4th, 2013 starting at 10 A.M.

A summary of the results of both series of experiments are shown in Table 1. The ratio of reflected surface, maximum temperature difference and percentage of effect in the performance of solar cooker in each state has been reported in the table. In this research, the difference of water temperature in both systems was considered as equal to performance difference in two systems [13-14].

Table 1: The results summary of study in double-exposure solar cooker based on reflected surface

Types of Experiments	Ratio of Reflected Surface	Max. Temperature Difference	Percent of Effect
All mirrors in parabolic part	1	0	0
Two mirrors of the parabolic part covered	0.767	2.4	3
Three mirrors of the parabolic part covered	0.663	13	14
Four mirrors of the parabolic part covered	0.558	16.3	17
All parabolic mirrors removed	0	24	25
Two side-view flat mirrors removed	0.454	8.5	8.85
All flat mirrors removed	0	18	13.5

In figure 9 the results of experiments 1-4 has been shown; the maximum difference of water temperature is presented according to ratio of reflected surfaces in parabolic part of solar cookers.

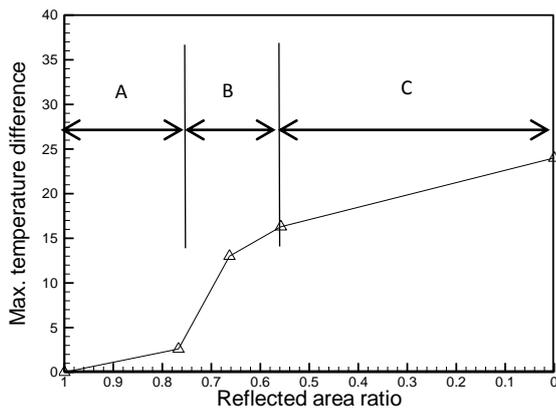


Figure 9. The performance differences of two systems based on the reflecting surface ratio (parabolic part).

The results show that the effect of reflected area ratio in the region A on the thermal performance of solar cooker is little, in the region B its effects sharply rises and in region C is also little. For predicting the effects of the parabolic reflective surfaces on the performance of double-exposure solar cooker, three curves were fitted on the three regions in fig. 9 and their mathematical relationships were obtained. The obtained mathematics relations are shown below.

$$\text{Part A: } \Delta T_{max} = \frac{(\Delta u)_{max}}{mc_p} = -11.159\left(\frac{A_p}{A_{p,max}}\right) + 11.159$$

$$\text{Part B: } \Delta T_{max} = \frac{(\Delta u)_{max}}{mc_p} = -126.98\left(\frac{A_p}{A_{p,max}}\right)^2 + 101.6\frac{A_p}{A_{p,max}}$$

$$\text{Part C: } \Delta T_{max} = \frac{(\Delta u)_{max}}{mc_p} = -13.799\left(\frac{A_p}{A_{p,max}}\right) + 24$$

In the above relationships u is internal energy, m is mass of the water and c is the heat specific capacity of water; also A_p is the area of reflected surface (in system 2) and $A_{p,max}$ is the maximum area of reflected surface (in system 1) in the parabolic part of solar cooker. These relations explain the effect of parabolic mirror position on the solar cooker performance. Evaluation of the obtained relations show that; the effect of part B with two mirrors, on the performance of solar cooker, is more than 4.5 times than part A with the same number of mirrors, and approximately twice as much as part C with five mirrors. The three regions A, B and C are shown on the parabolic part of solar cooker in figure 10.

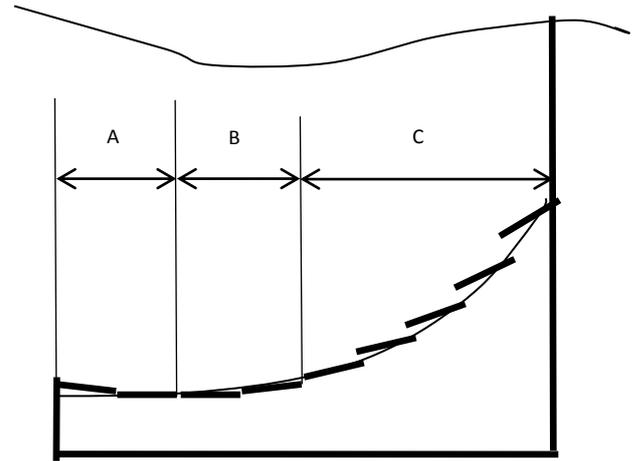


Figure 10. Three regions of reflected surface that are mounted on parabolic part of solar cooker.

Based on this result for some applications, the A and C regions of parabolic mirror can be removed, thus the system will be lighter and cheaper. But the mirrors that mounted on the central part of parabolic curve (part B) have determinant effect on the solar cooker performance. These results can be used in performance analysis, exploitation conditions and design of double-exposure solar cookers.

D. Conclusion

On the basis of a comparative experimental study on the two double-exposure solar cookers, which have been tested under the same climatic conditions, the following conclusions have been drawn:

- The effects of the different parts of parabolic mirror of SC. on its thermal performance were investigated.
- The parabolic curve, is divided into three areas and for each of which, a mathematical relation is extracted that can be used in analysis, design, and proper positioning of these systems.
- Based on the experiment results we can design a new setup of solar cooker; for high temperature or heat load, more reflective surfaces can be mounted in B region and for other thermal conditions, mirrors on A and C regions can be removed.
- Comparing between the reflective surfaces in box-part with parabolic-part shows that the parabolic part is more effective than the box-part on the performance of solar cooker.
- The effect of the both side-view mirrors on thermal performance of SC. was evaluated; that shows removing them reduces 8.5% in its thermal performance.



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