Influence of Various Heat Retaining Materials on Thermal Performance of Box Type Solar Cooker

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Abstract With its non-polluting nature, unlimited free supply and worldwide availability, solar energy is a most attractive non-conventional energy source. The solar energy is used for cooking, heating, lighting, pumping, electricity generation, etc. Solar cooking is the effortless, secure and most suitable way to cook food without consuming fuels. So, many countries in the world are using different types of solar cooker. Generally, solar cooker consumes more time to cook food compared to other conventional cooking devices. In this paper, the performance of box type solar cooker is investigated using various materials to increase heat retaining capacity of the cooker and hence to minimize cooking time. Readings of temperature vs. time were taken by placing different materials like black sand, brown sand, marbles, salt, small rocks, abrus and pebbles at the base of the solar cooker. From this analysis, it was found that marbles achieve a maximum temperature of 207.8 °C in 180 min which can be helpful in reducing the time for cooking.

Keywords Box type solar cooker, Performance, Heat retaining material, Cooking time, Temperature

1 Introduction

Due to several issues like limited sources of fossil fuels, increasing energy consumption, pollution, global warming, etc., almost all countries have turned towards the use of non-conventional energy like solar, wind, geothermal, tidal, etc. In today's scenario, around 14% of total energy demand of the world is accomplished by renewable energy sources and this will increase significantly in future [1]. Among the non-conventional energy sources, solar energy is more favorable

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compared to others as it is permanent and freely available as well as there are no pollution-related issues. The solar energy has wide applications like cooking, drying, water heating, space heating, electricity generation, etc. Among various solar energy applications, solar cooking is the most significant as it directly affects the mass population. In many countries of the world, especially in rural areas, people use non-commercial fuels like firewood, kerosene, agricultural waste, cow dung, etc. [2]. Their compulsion is lacking the access to modern energy sources or expensiveness for their incomes. With the environmental pollution and economic burden, there are also some respiratory diseases originate from the utilization of such fuels [3–4]. Solar cooker has a great potential to solve these problems and it is effective for such countries especially in the domestic sector, where plenty of solar energy is available during the most of the time of a year.

2 Solar Cooker

The solar cooker is an appliance that absorbs solar radiation, converts it into heat, retains the heat and transmits it to food through cooking pot walls. It can be used for heating or cooking food or drink. Also, it can be utilized to achieve vital processes mainly pasteurization and sterilization. Box type, panel type and paraboloid concentrator type solar cooker are some of the widely used models. The box type solar cooker is drawing more attention from the available models of solar cookers due to simple design and ease of handling. Box solar cookers can be used to cook rice, vegetables as well as to prepare simple cakes, boil eggs, dry grapes, roast cashew nuts, etc. But, they have their own limitations like not possible to cook food which needs high temperature, need more time in range of 2–3 hours to cook food. It is the most affecting factor for users to accept solar cooking. Researchers, scientists and academicians are taking keen interest in design, development and testing of solar cookers to improve the performance in terms of cooking time and hence to increase the possibility of acceptance by users. Kammen and Lankford [5] compared the performance of two box type solar cooker made from prefabricated cardboard kit and plywood. The cardboard oven exhibited a maximum temperature and sufficient thermal stability as compared to that of the plywood model. Grupp et al. [6] introduced a new model of the box type solar cooker in which the pot is fixed with the absorber plate for better conduction heat transfer. Under Rajasthan climatic conditions, Nahar [7] developed and compared the performance of a double reflector animal feed box solar cooker with a transparent insulation material (TIM) with a single reflector animal feed box solar cooker without TIM. Gaur et al. [8] showed that the performance of a solar cooker can be improved by using a utensil with a concave shape lid instead of a plain lid as the stagnation temperature increases about 2–7% for a utensil having a concave lid than a normal lid. Pande and Thanvi [9] developed a new design of solar cooker with step fashion of the inner box. It was fixed on the angle stand to tilt in different seasons. This type of cooker could save 35–40% of the cooking fuel. Reddy and Rao [10] proved that the

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performance of conventional box solar cooker can be improved by introducing the cooking vessel with a central cylindrical cavity lugs instead of a conventional vessel on the floor or on lugs. A box solar cooker with a plane booster mirror reflector was designed for the Egyptian climatic conditions by Ibrahim and El-Reidy [11]. The performance of the cooker was evaluated for over two years under different climatic conditions and it was found that the cooking pot covered with an airtight plastic transparent cover gives better heat transfer rather than with an ordinary metallic cover. Mirdha and Dhariwal [12] modified the design of box type solar cooker by using booster mirror to fix on a south facing window and showed that the new cooker can provide higher temperature throughout the day and round the year as compared to convention solar cooker. Galip et al. [13] designed and tested a solar box cooker with two-axis sun tracking system using a shadow stick on the glazing according to the climate conditions of Turkey. The approach discussed in this paper is to look at heat retaining materials in improvement of performance.

3 Heat-Retaining Materials

Solar cooker consumes more time for cooking or heating and it is a big disadvantage of solar cooker. Attaining high temperature within a short period of time and retaining the same temperature for a longer period of time are important to reduce cooking time in a solar cooker. In this paper, the performance of box type solar cooker is evaluated using different heat retaining materials like black sand, brown sand, salt, small rocks, abrus, marbles and pebbles as shown in Figure 1 to 7.

4 Experimentation

4.1 Description of the Solar Cooker

The outer box of the cooker is made of wood in order to reduce heat loss, the inner box is made of aluminium sheet and the upper cover has a large glass window to let in sunlight. The fiberglass is used as an insulator under the absorber plate, and

Figure 1 Black sand.

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Figure 2 Brown sand.

Figure 3 Salt.

Figure 4 Small rocks.

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Figure 5 Abrus.

Figure 6 Marbles.

the gap between the tray and the box is also filled with fiberglass wool insulator. The metal box is painted black all around the inner surfaces. Four mirrors are attached at sides of the cooker for more concentration of heat. Figure 8 shows the experimental setup.

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Figure 7 Pebbles.

Figure 8 Experimental setup.

4.2 Experimental Tests

The test was conducted with measurement of temperature using a digital thermometer with a measurement range of -50 °C to 300 °C and resolution 0.1 °C. Tests were conducted from 10:30 AM to 1:30 PM for each material from 3 April to 10 April 2016. The readings of temperature were taken at every fifteen minutes. The probe of the digital thermometer was attached to the center of the absorber plate during the test. Any influence of wind speed is assumed to affect cooker equally.

5 Results and Discussion

The temperature of absorber plate placed in the solar cooker was measured during three hours by placing different material and results are shown in Table 1. It shows that the maximum temperature achieved by absorber plate without placing any material was 136.9 °C at the end of three hours. The maximum temperature achieved by absorber plate by placing black sand, brown sand, salt, small rocks, abrus, marbles and pebbles in the solar cooker was 184.7 °C, 192.7 °C, 161.9 °C,

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Table 1 Testing results for different materials.

Time (Min)	Temperature (°C)							
	Without material	**Black sand**	**Brown sand**	**Salt**	**Small rocks**	**Abrus**	**Marbles**	**Pebbles**
0	34.2	33.9	34.6	34.1	33.6	33.7	34.8	34.4
15	57.3	50.1	50.8	49.1	49.3	49.5	53.4	51.7
30	63.8	65.2	75.6	65.9	64.8	61.8	62.4	78.5
45	71.5	88.0	93.8	81.4	78.2	77.7	70.9	92.3
60	80.1	97.6	100.6	92.6	91.4	89.3	88.8	101.8
75	89.4	116.5	125.9	102.8	105.6	105.6	103.2	127.1
90	98.9	128.8	136.8	116.5	122.5	118.8	112.7	143.6
105	109.3	145.3	154.5	132.8	139.6	127.1	131.3	169.4
120	121.5	160.7	171.1	152.9	155.7	141.7	153.4	178.9
135	130.2	174.4	189.5	156.3	168.1	145.8	189.1	191.6
150	135.6	181.9	192.3	159.2	175.6	149.9	204.3	198.5
165	137.2	183.5	192.5	161.8	179.2	151.2	205.9	201.6
180	136.9	184.7	192.7	161.9	179.0	150.8	207.8	201.2

179 °C, 150.8 °C, 207.8 °C and 201.2 °C respectively. Generally, 121–177 °C is the ideal temperature for box solar cookers to cook food retaining nutrients, moisture, and flavor. It takes about 1.5 to 3 hrs for cooking depending upon the items being cooked and the intensity of solar radiation. The heat retaining capacity of marbles is more than other materials. So, if marbles are placed inside the solar cooker, it can reduce the cooking time. A graph is plotted for comparison of different materials in terms of time vs. temperature as shown in Figure 9.

6 Conclusion

A modified box type solar cooker was made using four mirrors for more concentration of solar radiations. By placing different materials like black sand, brown sand, marbles, salt, small rocks, pebbles, abrus & limestone inside of solar cooker, the temperature of the base was measured with a digital thermometer at 15 minutes interval. As per the readings were taken for the solar cooker without any material, the highest temperature obtained was 136.9 °C. Based on the performance analysis of solar cooker using different heat retaining materials, it was found that the highest temperature was recorded for marbles and it was 207.8 °C. So, a box type solar cooker with marbles at its bottom surface can increase the temperature around 70 °C which can reduce cooking time.

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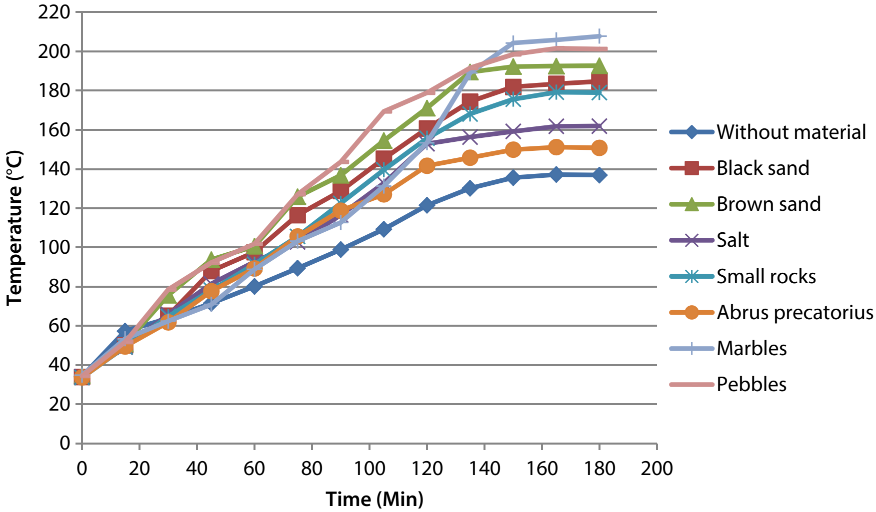

Figure 9 Comparison of different materials for temperature vs. time.

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