ICMIEE20-135

Performance Comparison of Parabolic Solar Cooker Using Different Reflecting Materials

Sabrina Sabiha[1,*] *A.N.M. Mizanur Rahman* [2]
[1] UG student, [2] Professor
Department of Mechanical Engineering, KUET, Khulna-9203, BANGLADESH

ABSTRACT

Solar energy is used for various purposes like water heating, cooking, drying, distillation, electricity generation and many more. Solar cookers that uses solar energy for cooking foods can be of various types. But whatever be the type, it is the cleanest, simplest and most convenient way of cooking food without using any fuel. Earlier a parabolic dish type solar cooker, with an aperture diameter of 106 cm and focal length 54 cm using plane glass as reflecting material, was developed and tested in 2014. The maximum temperature inside the cooking pot was found as high as 97°C in April at a radiation level of 329-389 W/m^2. As plane mirror is difficult to give the shape of a sphere, pieces of plane mirror were used to construct the reflector. In the present study, different reflecting materials (glass, aluminum foil and stainless steel (SS) sheet) were used to compare the performances of the same cooker. The objective was to choose the proper reflecting material for efficiency and convenience. With the same cooker, only the reflecting materials were changed during the study and for that one set of experiments were conducted for all possible changes and then the reflecting material was changed for other sets. So, it was not possible to conduct all experiments under the same radiation level. The performance of the cooker was found quite satisfactory with all three reflecting materials. The maximum temperature inside the cooking pot with glass as reflecting material was found as 92°C in September at a radiation level of 331 W/m^2. The same values with other reflecting materials are: with aluminum foil 90°C in October at a radiation level of 303 W/m^2 and with SS sheet 95°C in March at a radiation level of 387 W/m^2. Due to different time of the year the radiation level varied and different times were required for completion of cooking for a particular reflecting material. Comparing the results it can concluded that glass is the best as reflective material for parabolic dish solar cooker.

Key Words: Solar cooker, parabolic dish, concentrating cooker, reflecting material and their comparison.

1. Introduction

The human communities in the rural and remote areas are continuously facing the challenges of providing basic necessities such water, food and energy. With global warming, more and more areas are affected by lack of drinking water and energy resources to prepare food. The energy required for cooking in remote areas of developing countries is derived mainly from biomass fuels such as fire wood and agricultural waste. The combustion of these fuel resources leads to many environmental and health problems. Wood burning is a large source of CO_2 emissions to environment that contributes to global warming. The unplanned use of fire wood for cooking also contributes to deforestation and reducing carbon uptake by forests. In addition, the pollution which occurs during fire wood combustion causes a variety of diseases that results from smoke inhalation. On the other hand, in some arid remote areas like desert even fire wood is not available. The basic solution for those areas is to provide a technique capable of using renewable energy source to reach the boiling temperature of water for disinfection purpose, which is sufficient to kill the pathogenic bacteria, viruses and parasites, and the appropriate energy required for obtaining healthy consumable food and the solution is 'the solar cooker'. Among the clean energy technologies, solar energy is recognized as one of the most promising choice since it is free and provides clean and environmentally friendly energy. The earth receives 3.85 million EJ of solar energy each year [2]. Solar energy offers a wide variety of applications in order to harness this available energy resource. Among the thermal applications of solar energy, solar cooking is considered as one of the simplest, the most viable and attractive options.

There are several varieties of solar cookers and they have been classified into two main categories: the direct solar cooker and the indirect solar cooker. For the direct cooking systems, the cooking pot is placed directly inside the solar cooker. In case of the indirect cooking systems, the cooking pot is separated from the collector and the solar energy is collected by an intermediate absorber and it is then transported to the cooking pot using a heat transfer medium. The direct solar cookers are again grouped into three: box cooker, panel cooker and parabolic cooker. The concentration ratio of parabolic solar cooker is higher than other two types. The parabolic solar cooker can achieve higher temperatures than the box cooker or panel cookers and it can be used for cooking by grilling and frying process and for water boiling. Parabolic solar cookers use a parabolic-shaped reflector to direct the sunlight to a small area in order to generate intense heat for cooking. Due to this reason, proper choice of reflective materials is highly important to achieve the highest performance.

Parabolic and box type solar cookers were studied by Abou-Ziyan [3] and it was found that the rate of cooking for parabolic solar cooker is higher than that for box type solar cooker. According to the findings of Pranab et al. [4], heating water in parabolic solar cooker is faster in comparison to box type cooker. A parabolic portable solar kitchen was studied by Arenas [5] under Spanish climatic conditions. He reported that 1.5 liter of water reaches a temperature of around 95°C after 90 min. Under the Indian environment the time required for heating 0.5 kg of water from 38.7°C to 95.15°C was around 40 min. A parabolic dish type solar cooker was tested by Aidan [6] under Nigerian climatic conditions and it was proposed as a solution for cooking to minimize the purchase of other cooking fuels. Avilés and Mauricio [7] presented a thermal mathematical model based on the energy balance equations for the different elements of parabolic solar cooker. Based on their report, a mass of water of 4.2 kg takes around 120 min to achieve a temperature of 90°C. A parabolic solar cooker was studied for rural households and refugee camp by Masum Ahmed [8]. They achieved 58.2°C maximum water temperature from the first prototype of Stainless Steel reflector. After that, 74.5°C maximum water temperature was achieved from the second prototype using Aluminum foil. Finally, the third prototype was used Mylar tape as a reflective material and 74.5°C maximum water temperature was achieved from the third prototype. Akoy and Ahmed [9] had constructed three different solar cookers. The primary objective of that research was to find the best thermal performance of the constructed solar cookers. The highest temperature from the parabolic solar cooker was 86.5°C. Moreover, the second best was the box-type solar cooker because the highest temperature was 52.36°C. Finally, the panel-type was the least among the three. The highest temperature from the panel-type solar cooker was 43.5°C. Joshi [10] and his team had completed a design of a small scale hybrid solar cooker. In this design five solar panels, each of 15W had attached with this cooker. The efficiency of Improved Small Scale Box Type Hybrid solar cooker (ISSBH) was 38% and the estimated cost was ($120).

In the past, attempts were made to develop different types of solar cooker like box type, funnel type, box type with plane reflector and spherical one in the Department of Mechanical Engineering of KUET and satisfactory results were found. In 2014, a parabolic dish type solar cooker with an aperture diameter of 106 cm and focal length of 54 cm using plane glass as reflecting material was developed and tested by E. B. Joyee [1]. For that spherical solar cooker the reflector was constructed from a large number of small pieces of plane glass mirror. First the parabolic structural shape was made from GI wire and GI sheet. Then pieces of plane glass mirror was attached on the sheet with adhesive. It was not possible to make all pieces uniform and to a specific shape. Using plane mirror it is difficult to give the exact shape of a paraboloid, so pieces of plane mirror were used to construct the reflector. Each piece of plane mirror might reflect the light rays to different directions if not properly oriented and hence will affect the performance of the solar cooker. Thus, it needs careful attention and knowledge of light reflection principles while constructing the reflector. In the present study, the focus was given to test the performance of the parabolic cooker using different types of reflecting material (glass, aluminum foil and stainless steel sheet) so that the performances could be compared. The reflectivity of glass, stainless steel and aluminum are about 0.90-0.95, 0.60-0.900 and 0.766-0.993 respectively. The objective was to choose the proper reflecting material for efficiency and ease of construction. With glass the construction is relatively complex than with stainless steel sheet or aluminum foil. The structure of the same parabolic dish solar cooker which was used in 2014 was used in this work by changing the reflecting materials. For glass, the same glass was used which is more than 5 years old. Also, it was not possible to keep a common environment for all the cases. One set of experiments were conducted and then the reflecting material was changed and the experiments were conducted for others. Temperature inside the cooking pot was measured with a thermocouple, the cooking time was measured with a watch and the intensity of solar radiation was measured with a Solarimeter.

2. Experimental Setup

The cooker was set under open sky orienting the reflector towards the sun. The cooking pot with desired amount of rice and water was kept on its position (nearly at the focal point of the reflector). For confirmation, it was observed that the reflected rays fall on the bottom of the cooking pot. It must be ensured that maximum reflected rays fall on the bottom of the cooking pot and the direction was adjusted every one hour interval by tilting the reflector by 15^{o}. It must also be ensured that the outside of the cooking pot is edified from most sides.

3. Experimental Equipment

To evaluate the performance of the parabolic solar cooker the following equipment were used:

- **Solarimeter:** Solarimeter was used to measure the instantaneous value of intensity of radiation of the sun in W/m^2 and also the total radiation in Whr/m^2 during the experimental period.
- **Thermocouple wire:** The junction point of the K-type thermocouple was drenched in the cooking pot to measure the instantaneous temperature and rising trend of temperature inside the cooking pot.
- **Digital temperature indicator:** This is the display unit of the thermocouple and the device displays the instantaneous temperature within the cooking pot.

4. Experimental Procedure

The first set of experiment was conducted with glass as the reflecting material. Necessary amount of water required for each experiment (the details are shown in the tables) was taken into the cooking pot and kept it on the holder for cooking as shown in Fig. 1.

Fig 1: Parabolic dish type solar cooker using glass pieces

The cooking pot was covered with the lid. It is to be noted that although parabolic reflector, but it could not truly concentrate the radiation to a point. The orientation of the reflector was set in such a way that the beams of reflected radiation incident on to the bottom and side of the cooking pot. The orientation was changed time to time every one hour (i.e., 15^o of sun's rotation) as the sun's direction changes. A K-type thermocouple with display unit was inserted inside the cooking pot. The temperature inside the cooking pot was recorded from the temperature display unit every 10 minutes intervals. Simultaneously, the intensity of radiation of the sun was recorded from a Solarimeter. At the time when temperature within the cooking pot was raised around 75° to 80°C, the required amounts of rice and dal was poured into the cooking pot by opening the lid. When the cooking is completed, the experiment was finished. For same loading, the experiment was conducted for three days and the average value was chosen. When one set of experiment was completed, the reflecting material was changed and another set of experiments were conducted. Three reflecting materials were used in this work. Fig. 2 shows the photographic view of the experimental setup with stainless steel sheet as the reflecting material.

Fig 2: Parabolic dish type solar cooker using SS sheet

5. Data Collection for Performance Test

Predetermined quantity of rice and dal were used at various sets of experiment. For each set of experiment, a measured amount of rice and dal were taken. The maximum temperature inside the cooking pot and finally total cooking time were measured. Complete three sets of experiments were conducted for each amount of rice and dal in various days. But it was not possible to conduct the experiments in a continuous interval because of weather condition and other constants. The uncertainty of the experiment depends on the weather as the radiation intensity changes with it. A total number of 36 experiments were conducted with three different reflecting materials. The typical recorded data obtained from the experiments are shown in Table 1 through Table 6. Table 7 and Table 8 are taken from the previous project report for comparison, although the time of experiment is different in two cases. The present study was carried out in the month of October-November, whereas, the previous work was in April-May when the radiation was maximum. Again, since one experimental setup is used throughout the work, so real comparison will not be possible to undertake under same condition or weather. One set of experiment was completed and then reflecting materials were changed with another one to complete other experiments.

Data with Glass as Reflecting Material

Table 1: Temperature within the cooking pot with load on 14.10.19

No. of obs.	Cooking item & quantity	Watch time	Radiation Intensity (W/m^2)	Energy (Whr/m^2)	Tempe -rature (°C)
1	Rice = 300g, Dal = 100g, Water = 800ml	12.50	345	00	26
2		1.00	323	78	34
3		1.10	395	125	48
4		1.20	315	193	54
5		1.30	356	256	65
6		1.40	378	315	73
7		1.50	306	389	81
8		2.00	357	451	88
9		2.10	386	497	90

Maximum Temperature: 90 °C
Started at: 12.50 pm Ended at: 2.10 pm
Remarks: 300g rice and 100g dal cooked properly within 80 minutes
Condition: Partly cloudy weather

Table 2: Temperature within the cooking pot with load on 17.10.19

No. of obs.	Cooking item & quantity	Watch time	Radiation Intensity (W/m^2)	Energy (Whr/m^2)	Tempe-rature (°C)
1	Rice = 300g, Dal = 100g, Water = 800ml	9.40	370	00	28
2		9.50	385	84	37
3		10.00	365	153	51
4		10.10	363	212	63
5		10.20	389	268	71
6		10.30	382	336	78
7		10.40	372	403	84
8		10.50	366	472	89

Maximum Temperature: 89 °C
Started at: 9.40 am Ended at: 10.50 am
Remarks: 250gm rice and 50gm dal cooked properly within 70 minutes
Condition: Partly cloudy weather

Data with Aluminum foil as Reflecting Material

Table 3: Temperature within the cooking pot with load on 30.11.19

No. of obs.	Cooking item & quantity	Watch time	Radiation Intensity (W/m^2)	Energy (Whr/m^2)	Tempe-rature (°C)
1	Rice = 300g, Dal = 100g, Water = 800ml	11.20	229	00	21
2		11.30	234	61	35
3		11.40	240	124	43
4		11.50	239	135	45
5		12.00	254	233	59
6		12.10	247	257	67
7		12.20	269	315	72
8		12.30	269	327	80
9		12.40	240	435	86
10		12.50	260	460	90

Maximum Temperature: 89°C
Started at: 11.20 am Ended at: 12.50 pm
Remarks: 300gm rice and 50gm dal cooked properly within 90 minutes
Condition: Partly cloudy weather

Table 4: Temperature within the cooking pot with load on 01.12.19

No. of obs.	Cooking item & quantity	Watch time	Radiation Intensity (W/m^2)	Energy (Whr/m^2)	Tempe -rature (°C)
1	Rice = 300g, Dal = 100g, Water = 800ml	09.30	240	00	22
2		09.40	229	62	34
3		09.50	232	99	45
4		10.00	237	116	56
5		10.10	235	224	59
6		10.20	248	247	64
7		10.30	250	317	77
8		10.40	269	325	82
9		10.50	246	433	85
10		11.00	244	469	88

Maximum Temperature: 88°C
Started at: 09.30 am Ended at: 11.00 am
Remarks: 300gm rice and 100gm dal cooked properly within 90 minutes
Condition: Partly cloudy weather

Data for SS sheet as Reflecting Material

Table 5: Temperature within the cooking pot with load on 09.03.2020

No. of obs.	Cooking item & quantity	Watch time	Radiation Intensity (W/m^2)	Energy (Whr/m^2)	Tempe-rature (°C)
1	Rice = 300g, Dal = 100g, Water = 800ml	10.30	323	00	29
2		10.40	320	37	53
3		10.50	269	61	71
4		11.00	379	104	86
5		11.10	348	163	94

Maximum Temperature: 94°C
Started at: 10.30 Ended at: 11.10
Remarks: 300gm rice and 100gm dal cooked properly within 40 minutes

Table 6: Temperature within the cooking pot with load on 09.03.2020

No. of obs.	Cooking item & quantity	Watch time	Radiation Intensity (W/m^2)	Energy (Whr/m^2)	Tempe-rature (°C)
1	Rice = 300g, Dal = 100g, Water = 800ml	11.30	324	00	29
2		11.40	321	35	59
3		11.50	268	66	75
4		12.00	377	114	88
5		12.10	343	175	95

Maximum Temperature: 95°C
Started at: 11.30 am Ended at: 12.10 pm
Remarks: 300gm rice and 100gm dal cooked properly within 40 minutes

Table 7: Experimental data on 15.04.14 from earlier work

No. of obs.	Cooking item & quantity	Watch time	Radiation Intensity (W/m^2)	Energy (Whr/m^2)	Tempe-rature (°C)
1	Rice = 300g, Dal = 100g, Water = 800ml	11.15	320	00	30
2		11.25	326	130	64
3		11.35	335	280	84
4		12.45	338	375	96
5		12.55	372	483	97
6		12.05	392	667	97

Maximum Temperature: 97°C
Started at: 11.30 am Ended at: 12.10 pm
Remarks: 300gm rice and 100gm dal cooked properly within 40 minutes

Table 8: Experimental data on 16.04.14 from earlier work

No. of obs.	Cooking item & quantity	Watch time	Radiation Intensity (W/m^2)	Energy (Whr/m^2)	Tempe-rature (°C)
1	Rice = 300g, Dal = 100g, Water = 800ml	09.50	276	00	30
2		10.00	288	116	62
3		10.10	294	211	73
4		10.20	307	348	92
5		10.30	314	377	95
6		10.35	322	468	95

Maximum Temperature: 97°C
Started at: 09.50 am Ended at: 10.35 am
Remarks: 300gm rice and 100gm dal cooked properly within 45 minutes

6. Results and Discussion

The variation of water temperature inside the cooking pot against cooking time are plotted for some typical experimental results for different reflecting materials and various loading and they are shown in Fig. 3 to Fig. 6.

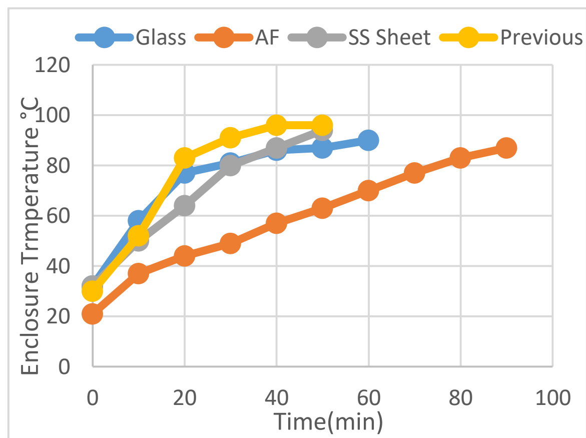

Fig.3: Temperature vs. time curve for 200g rice and 50g dal

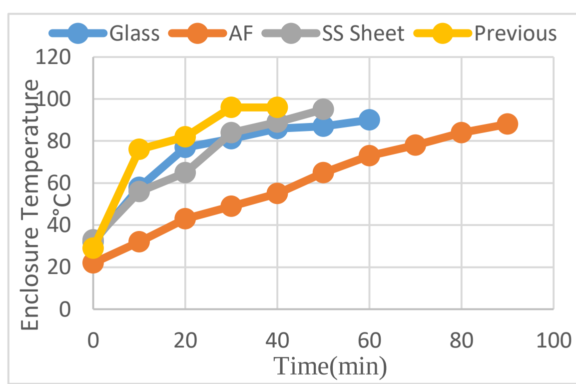

Fig.4: Temperature vs. time curve for 250g rice and 50g dal

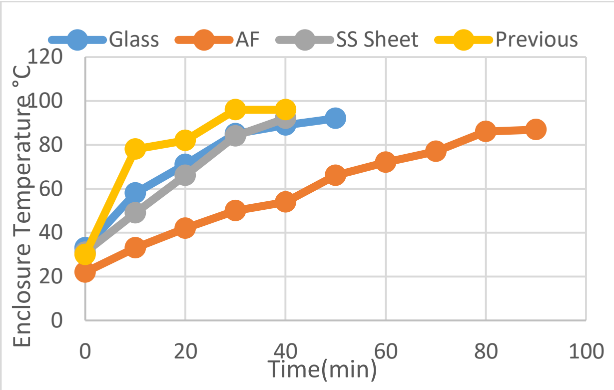

Fig.5: Temperature vs. time curve for 300g rice and 50g dal

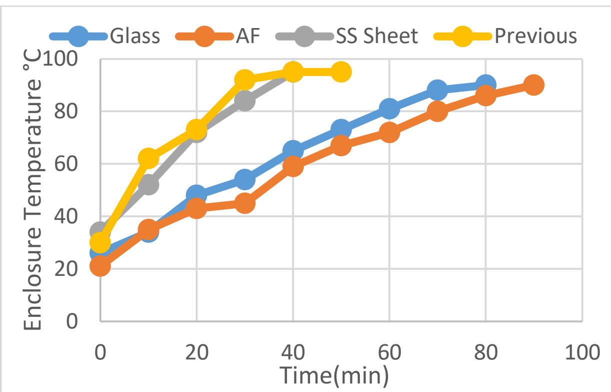

Fig.6: Temperature vs. time curve for 300g rice and 100g dal

From Figs. 3 to 6, it was noticed that the temperature inside the cooking pot increases as the time increases and also radiation intensity increases with time since most experiments were conducted in the morning time. The total cumulative radiation energy is also increasing, because of continuous incidence of solar radiation. The rate of increase is different in different time and different days. The reason is the radiation level and also the amount of load is different in different days. With the change in reflecting materials the rate of increase is different in different days and time. It was observed that in all cases the rate of temperature increase is very similar for glass and SS sheet as reflecting material. The higher the radiation intensity, the higher is the temperature rise and lesser is the time requirement.

From Fig. 3, it is evident that among all the data for 200g rice and 50g dal the highest time required for cooking was recorded for Aluminum foil. It is because Aluminum foil has lowest reflectivity among the three reflective materials used and also the data for Aluminum foil as reflecting material were taken in the month of November, when the radiation intensity was relatively low.

From Fig. 4, it can be noted that among all the data for 250g rice and 50g dal the highest time needed for cooking was also with the Aluminum foil. This might be because of its poor reflectivity.

From Fig. 5, it is envisioned that among all the data for 300g rice and 50g dal the highest time was also taken for Aluminum foil. But in this case the time taken for glass is also more compared to the time taken for stainless steel sheet as shown in the graph. In this case, the solar radiation intensity was also less for cloudy weather.

Fig. 6, also shows similar behavior as it is seen from other cases. From all the figures, one thing is evident that the time for cooking with glass is relatively longer in this study. The reasons might be (i) the radiation intensity is different in the two studies and (ii) deterioration in the reflecting property of glass because of time. The cooker was left for long time and after cleaning it was used in the present study.

7. Conclusion

Solar energy will be one of the most promising environment friendly renewable energy in future. Utilization of solar energy for cooking in developing countries may play a significant role. The parabolic dish solar cooker represents a possible alternative for cooking. After experiments with the three different reflecting materials the following comments could be made:

1. Glass and stainless steel sheet performance are very close to each other. But the reflecting property of SS sheet might be reduced in course time.
2. The maximum temperature inside the cooking pot with glass reflecting material was 92°C in September at a radiation level of 331 W/m^2. The values with other reflecting materials are: with aluminum foil 90°C in October at a radiation level of 303 W/m^2 and with SS sheet 95°C in March at a radiation level of 387 W/m^2.
3. Due to different time of the year the solar radiation varied and different cooking times were needed for completion of cooking for a particular type of reflecting material.
4. From the report of 2014, the maximum temperature inside the cooking pot was found as high as 97°C in April at a radiation level of 389 W/m^2.
5. Comparing these results it can concluded that glass is the best as reflective material for parabolic dish solar cooker, but its construction is bit complex. As it is feasible with other reflecting materials available in local market so they can also be promoted in Bangladesh.

References:

[1] Erina Baynojir Joyee, ‘Design and Construction of a Parabolic Dish Type Solar Cooker’, UG Project Report, Department of Mechanical Engineering, KUET, 2014.

[2] Johansson T. B., Kelly H, Burnham L, Williams R, Reddy A. K. N, ‘Renewable Energy Sources for Fuels and Electricity, Earth Scan Publications Ltd. and Island Press; 1993.

[3] Honsy Z. Abou-Ziyan, Experimental Investigation of Tracking Paraboloid and Box Solar Cookers under Egyptian Environment, Applied Thermal Engineering Vol. 18, pp.1375-1394, 1998.

[4] J. L. Pranab, K. B. Rajesh, S. K. Samdarshi, Enabling Inter-cooker Thermal Performance Comparison based on Cooker Opto-thermal Ratio (COR), Applied Energy, vol. 99, pp.491-495, 2012.

[5] Jose M. Arenas, Design, Development and Testing of a Portable Parabolic Solar Kitchen; Renewable Energy, Science Direct, vol., 32, pp.257-266, 2007.

[6] J. Aidan, Performance Evaluation of a Parabolic Solar Dish Cooker in Yola, Nigeria, Journal of Applied Physics, vol. 6 pp. 46-50, 2014.

[7] G. Avilés, J. Juan, G. A. Mauricio, Thermal Model of a Solar Cooker Jorhejpataranskua, Energy Proceedia, ScienceDirect, vol. 57, pp.1623-1631, 2014.

[8] S. M. Masum Ahmed, Md. Rahmatullah, S. Ahmed, A. M. Saleque, Md. Abdur Rahman, Design, Construction and Testing of Parabolic Solar Cooker for Rural Households and Refugee Camp, Solar Energy, Elsevier, vol. 205, pp.230, 2020.

[9] E. O. Akoy, A. I. Ahmed, Design, Construction and Performance Evaluation of Solar Cookers. Vol. 1, pp. 75-82, 2015

[10] S. B. Joshi, A. R. Jani, Design, Development and Testing of a Small Scale Hybrid Solar Cooker; Solar Energy 1 (122), pp. 148–155, 2015.