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Design and Construction of a Parabolic Dish Solar Cooker

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ABSTRACT:
The use of renewable energy, particularly solar energy, is increasing day by day to promote its contribution to national economy. Solar energy can be used in heating, drying, cooking and also for generating electricity. In this paper the design, construction and performance test of a parabolic dish solar (PDS) cooker is discussed. The cooker having an aperture diameter of 106 cm and focal length of 54 cm was designed, constructed and the performance was tested. Plane mirror was used as reflecting material in the cooker. The maximum temperature inside the cooking pot was found to be 97°C.As performance test rice and dal were cooked in various amounts at different days and times. Experiments showed that the temperature inside the cooker varies with the available solar radiation. The cooker could cook 300 gm rice and 100 gm dal within 40 minutes at an available radiation level of 320 -390 W/m². An economic analysis of the cooker was performed and it showed a payback of 16 months, which is realistic and very promising.

Key Words: Solar cooker, parabolic dish, concentrating cooker, design and development of cooker.

1. Introduction

Energy crisis, at present is one of the major global challenges faced by mankind. Natural energy resources such as fossil fuel, oil, natural gas etc. are depleting in nature and will exhaust in one day. So, the need for conserving conventional energy and for developing energy alternatives has led to considerable research and development work in this direction and significant progress has been made. In a developing country like Bangladesh the crisis is more serious. The use of renewable energy, particularly solar energy, is increasing day by day to promote its contribution to national economy. Solar Home System (SHS) is now becoming popular in remote areas. The development of LED lights accelerated the use of solar home system. The initiation taken by Government through Infrastructure Development Company Limited (IDCOL) and different NGO's popularize this system within the country.

Cooking is one of the major energy consumption sectors is Bangladesh where mainly non-renewable sources (i.e. firewood, natural gas, LPGetc.) are used. As these sources are limited, their conservation is very important for future use and also for our next generation. There are three different ways of remedying suchan insufficient supply of non-renewable energy sources:(i) Increasing the treeplantation program of high yielding varieties, (ii)Introducing more and more energy efficient cooking stoves, (iii) Developing indigenous alternative sources of fuelor promoting green energies i.e. solar energy, which is efficient for cooking. Solar energy can be one of the most available and enormous sources of energy in Bangladesh, where the maximum and minimum day times are 12.5 and 10 hours respectively in the year round.The solar radiation level is in the range of 4 to 6.2 kW/m^2 per day. Using concentrating solar collectors the radiation level can be enhanced by capturing them from a larger area and directing them to a relatively smaller area. In concentrating type solar cooker usually a mirror or some type of reflective material is used to concentrate the incomingsolar radiation into a small cooking area. Some absorbing materials are used to absorb solar radiation and convert it into heat [1]. There are various types of solar cooker, among them parabolic dish solar cooker is a good solution for use of solar energy for cooking purpose because of its higher temperature. Parabolic dish solar cooker has the highest efficiency in terms of the utilization of the reflector area because there is no loss due to aperture projection effects. Also, radiation losses are small because of the small area of the absorber at the focus.

In the present study a parabolic dish solar (PDS) cooker was designed and constructed whose parabolic dish was madeusing small pieces ofplane mirror for better performance. It also caused more solar radiation to be concentrated into a smaller area for obtaining more heat. The radiation losses were also small because of smaller absorber area. Further in this paper the detailed design and construction of the cooker, performance test, data analysis and economic feasibility are discussed.

2.Geometry of ParabolicDish Solar (PDS) Cooker

In the proposed PDS cooker more solar radiation can be capturedby utilizinglarger reflector area. Also,there is less loss due to aperture projection effects andheat losses

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are small because of small absorber area which is situated at a distance from the center of the dish known as focal length.

The surface of revolution which formed by rotating a parabolic curve about its axis is called a paraboloid. Solar concentrators having a reflective surface in this shape are often called parabolic dish concentrators. Parabolic dish concentrators as shown in Fig. 1, uses a truncated portion of the surface generated by rotating the parabolic curve [2].

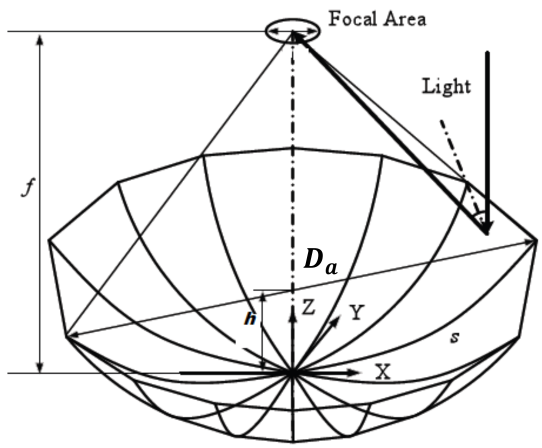

Fig. 1: Parabolic dish parameters and variables

The size of a parabolic dish is often specified in terms of linear dimension such as aperture diameter, D_a, or focal length, f. The height of the parabolic dish,h is defined as the maximum distance from the vertex to a line drawn across its aperture. In terms of focal length and aperture diameter, the height (h) of the dish is [2]:

$$h = \frac{D_a}{16f}$$

The parabolic dish aperture area,the most important parameter to solar energy designer, is simply the circular area defined by the aperture diameter D_a and is given by:

$$A_a = \frac{\pi D_a^2}{4}$$

The basic function of a parabolic dish solar cooker is to collect solar radiation over a large area and concentrate it onto a smaller area, the focal point, where the absorber containing food is located [2]. The temperature of the absorber as well as the food rises when more and more solar radiation concentrated and reflected onto the absorber and after some time the food is cooked.The incident solar radiation consists of direct and diffuse radiation. However, the majority of concentrating collectors can utilize only direct part of the radiation.

3. Design and Calculations
The heat demand of the cooker was assumed so that it could cook 400 gm rice at a time. Cooking of rice using conventional methods require5 volumes of water to one volume of rice, while cooking with a solar cooker requires two volume of water to one volume of rice[2]. In conventional methods about 25% of the water required for cooking is lost to the surrounding by evaporation whereas in solar cooking rate of evaporation is less.

Sizing of the solar cooker:

Assuming mass of water, m_w = 0.8kg, mass of rice, m_r=0.4kg with specific heat of water and rice as C_{pw} = 4.186 kJ/kg°C andC_{pr}= 1.76kJJ/kg°C; the density of water as ρ = 997.01kg/m^3 at 25°C, the energy requirement for cooking rice is –

$$Q = Q_r + Q_w = m_r C_{pr}(T_f - T_i) + m_w C_{pw}(T_f - T_i)$$
$$= 0.4\times 1.76(100-25) + 0.8\times 4.186(100-25)$$
$$= 303.96\ kJ$$

So, total energy required should be, $Q \approx 304\ kJ$
Again,it is known thatQ= $\eta_{th} I_b A_a t$. Assuming, average solar intensity, I_b = 485 W/m^2 andefficiency of the solar cooker as, η_{th} = 20% and time requiredfor cooking as, t = 1hr; then –

Q= $304\times 10^3 J = 0.20\times 485\times 3600\times A_a$

⇨ $A_a = 0.871\ m^2 = \frac{\pi D_a{}^2}{4}$

⇨ D_a = 1.06 m = 106 cm

Concentration ratio is defined as,C = $\frac{A_a}{A_{abs}}$;

Assuming, C=10;$A_{abs} = \frac{0.871}{10} = 0.0871 m^2$

Again, the cooking pot has a cylindrical part and a flat bottom part. Assuming, 2*L_{abs} = D_{abs}. So,

$$A_{abs} = \frac{\pi D_{abs}{}^2}{4} + \pi D_{abs} L_{abs} = \frac{\pi}{4} D_{abs}{}^2 + \pi D_{abs}\left(\frac{D_{abs}}{2}\right);$$

⇨ $0.0871 = \frac{\pi D_{abs}{}^2}{4} + \pi D_{abs}\frac{D_{abs}}{2}$

⇨ D_{abs} = 0.1926 m = 19.26 cm

⇨ L_{abs} = 9.63cm

Assuming thickness of cooking pot as 2mm

⇨ l_{abs} = 9.43cm, D_{abs} = 19.06 cm ,

⇨ Assuming h = 13 cm, then the focal length,

⇨ $f = \frac{D_a{}^2}{16h}$ = 54 cm

4. MaterialSelection for Construction of PDS Cooker
Apart from the design and construction of parabolic dish solar cooker the materials used in its construction of different components should be carefully selected to achieve best results so that the proposed cooker can reflect more solar radiation to heat up the cooking

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element in the cooking pot thus consumeless time and also ensure long life of the cooker.The cooking pot holder and the reflector weremounted on a structure called frame. MS flat bar was used for this. The whole frame was supported by another structure constructed from MS angle and flat bar. The frame could be rotated to direct the dish towards the sun. In this project commercially available dish could not be used because of cost and also it was not available in local market. So,the reflector was made by several pieces plane mirror by attaching them to a plastic mold. The plastic mold was supported by the MS flat bar as mentioned before.

In this cooker, absorber works as the cooking pot.Aluminum is selected as absorber material because it has high thermal conductivity, good corrosion resistance,high absorbing capability of heat and light weight. Also, it iseasily available in the local market and most importantly can be colored dark to its external surface easily.

For reflecting systems, materials of high quality and good specular reflectance properties are required. A light glass mirror of high surface quality and good specular reflectance was selected. The glass mirror of 2 mm thickness was chosen to reduce the overall weight. Glass mirror was selected over polished aluminum surface because of its reflectivity of 95% is better than that of aluminum (85%).Finally the cooking pot was painted with a mixture of black oxide and varnish. This mixture has the property to increase the absorption capability of the material on which it is coated.

5. Data Collection

After completion of the construction works, it was placed under open sky directing towards the sun. For the assurance of the fact that the reflector surface is fully directed to the sun it has to be observed that the surface of the cooking pot has enlightened by all side of its outer periphery. After every 15 minute the cooker was manually tracked for perfect focusing all the time to get the highest solar intensity at every time. Temperature of the cooking elements was recorded from the digital temperature collector with 10 minutes time interval. At the same time the solar intensity was also recorded from a solarimeter. According to the measurement water is taken into the cooking pot and when temperature of water was raised to 75º to 80ºC the rice and dal was added.

Different amount of rice and dal were used at different observations. For a fixed amount of rice and dal five observations were taken at different time of the day at different days. Total 20 observations weremade for various amounts of rice and dal. The typical results obtained are shown in Table 1 and Table 2 respectively,for (200 gm rice+50 gm dal) and (300 gm rice+50 gm dal)

Figure4.1: Photographic view of PDS Cooker

Table 1: Experimental data on 22.5.14

No. of obs	Cooking item with quantity	Watch time	Inten-sity W/m²	Energy Wh/m²	Temp ºC
Started at: 11.40 am End at: 12.15 pm					
1	Rice = 200 gm Dal = 50 gm Water = 500 ml	11.40	376	00	29
2		11.50	387	103	82
3		12.00	394	367	97
4		12.10	401	536	97
5		12.15	370	689	97
Remarks: 200 gm rice and 50 gm dal boiled properly at 35 mins. Stagnation temperature: 97°C					

Table 2: Experimental data on 12.5.14

No. of obs	Cooking item with quantity	Watch time	Inten-sity W/m^2	Energy Wh/m^2	Temp ºC
Started at: 09.50 am End at: 10.30 am					
1	Rice= 300 gm Dal=50 gm Water=	09.50	317	00	33
2		10.00	331	114	68
3		10.10	346	278	82
4		10.20	392	385	96
5		10.30	402	584	96

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	700 ml					
Remarks: 300 gm rice and 50 gm dal boiled properly at 40 mins. Stagnation temperature: 96°C						

6. Result & Discussion

The variation of temperature of water and cooking element inside the cooking pot with time plotted and are shown in Figure 1 to Figure 4.

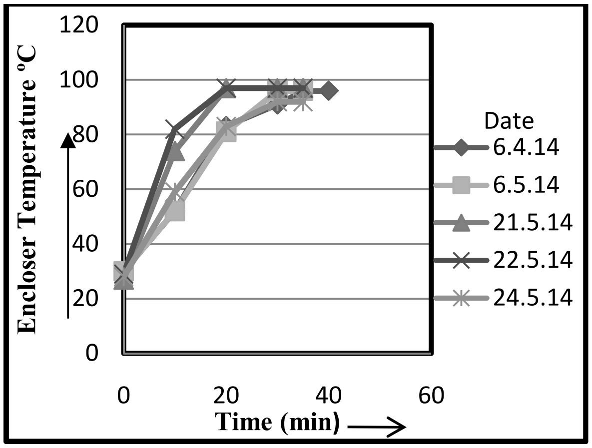

Figure 1: Temperature vs time curve for 250 gm load for different days

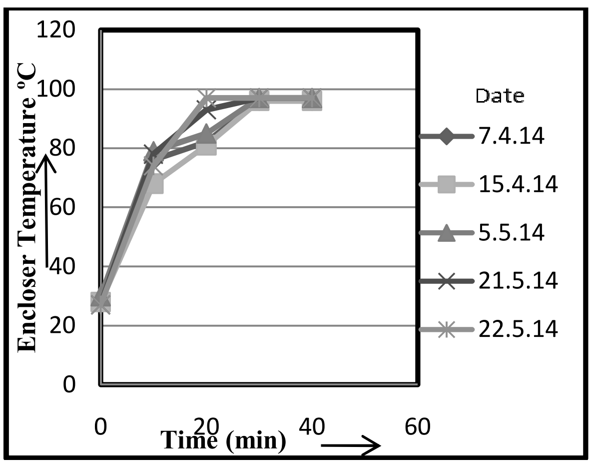

Figure2: Temperature vs time curve for 300gm load for different days

From Figures 1 to 4 it was seen that the temperature within the cooking pot increased with time. It was also seen that on different dates the increasing of temperature with time varies. It was because of the variation of intensity. The higher the radiation the higher the temperature obtained.

From Figure 1, it was seen that among all the data for 250 gm rice and dal, the highest time was taken on 6.4.14. It was because the average intensity was 301 W/m² on that day which was the lowest. The highest temperature recorded was 97° C.

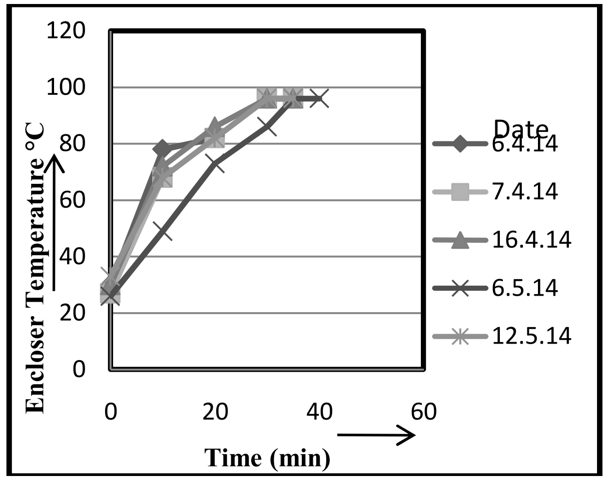

Figure3: Temperature vs time curve for 350gm load for different days

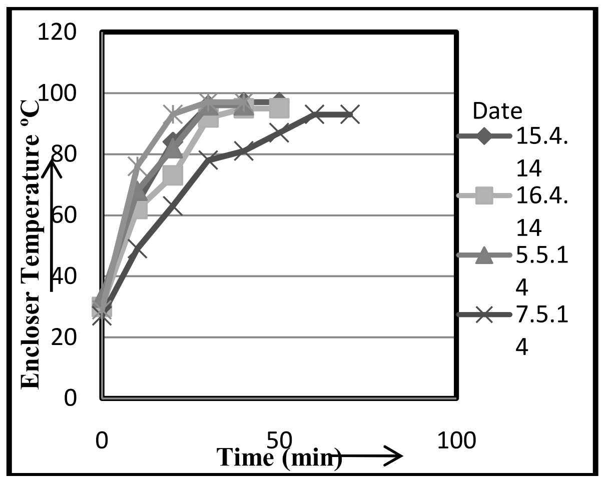

Figure4: Temperature vs time curve for 400 gm load for different days

From Figure2, it was seen that, for 300 gm rice and dal almost same time was taken for cooking on various days. But on 15.4.14 the temperature was relatively less than the other day's after 10 minutes. It was because of intensity at that time was fallen to a very low value of 285 W/m² compared to other days values. The highest temperature recorded was 97° C.

From Figure3, it was seen that all the data for 350 gm rice and dal were almost same. On 6.5.14 it was seen that the time taken for cooking was 50 minutes. It was the highest time taken among all the data for cooking 350 gm rice and dal because, it was a cloudy day. So, the

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intensity varies randomly. The highest temperature recorded was 96° C.

From Figure4, it was seen that on 7.5.14 the time taken for cooking was about 70 minutes. It was the highest time among all the data for cooking 400 gm rice and dal because, it was a cloudy day. So, theintensity varies randomly as on 6.5.14. The highest temperature recorded was 97° C.

7. Economic Analysis

The cost analysis of the constructed solar cooker wasperformed on the basis of present market price of various materials used. The material quantity and their cost are shown in Table 1.

Table 1: Shows construction cost of the solar cooker

Materials	Quantity	Cost in Tk
Angle bar	12 kg	750
Flat bar	3 kg	175
Glass (3 mm)	2 piece(96× 42 sq. in)	1000
Glue	600 ml	140
Black oxide	20 gm	50
Hardware		50
Total cost		2165

For the economic analysis of the constructed cooker the main approaches were calculating the annual cost and calculating the life cycle cost. This is summarized in Table 2.

Table 2: Life cycle cost of the constructed cooker

Type of Cost		Annual cost Tk.	Life cycle costTk.
Fixed cost	1.Construction cost	2165	2165
Total fixed cost		2165	2165
Variable cost	1.Maintenance cost a. Paint required for cooking pot b. Washing chemical	50 80	250 400
Total variable cost		130	650
Total cost		2295	2815

Assuming the constructed solar cooker can cook about 800 gm per day and about 200 days per year [3]. From experience the cost for cooking 800 gm rice in household Chula by using wood as cooking fuel is 5 Tk. [4].

Table 3: Cost benefit comparison of parabolic dish type solar cooker

Cooker	Annual cost	Life cycle cost(5 yrs)in Tk	Remarks
Solar Cooker	563	2815	Saving by Parabolic dish type solar cooker is Tk.437 annually
Household chula	1000	5000	

From the Table 3, the cost benefit ratio [5] for 5 years is,2815/5000 =0.563.

Pay Back Analysis:

Total construction cost = 563.00 Tk.From Table 3, net saving = Tk.437.00. So, Payback period is total investment to net saving = 563/437= 1.3 yr. =16 months.

8. Conclusion

In near future solar energy will contribute a major share in energy sector. So, proactive utilization of solar power is important.Energy consumption for cooking in developing countries like Bangladesh is a major component of the total energy consumption. The parabolic dish solar cookerrepresents a potential subsidiary way of cooking upon the conventional ways. According to the design the cooker was constructed with the materials which are available in the local market. After construction it was tested with different operating conditions and the cooker can cook 300 gm rice and 100 gm dal within 40 minutes at an available radiation level of 322-390 W/m². So, the efficiency of cooking of the cooker found satisfactory. Though its construction and operational cost is low, so this type of solar cooker can be promotes in remote and rural areas.

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