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DESIGN AND DEVELOPMENT OF A LARGE SIZE NON-TRACKING SOLAR COOKER

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Abstract

A large size novel non-tracking solar cooker has been designed, developed and tested. The cooker has been designed in such a way that the width to length ratio for reflector and glass window is about 4 so that maximum radiation falls on the glass window. This has helped in eliminating azimuthal tracking that is required in simple hot box solar cooker towards the Sun every hour because the width to length ratio of reflector is 1. It has been found that stagnation temperatures were 118.5^{o}C and 108^{o}C in large size non-tracking solar cooker and hot box solar cooker respectively. It takes about 2 h for soft food and 3 h for hard food. The cooker is capable of cooking 4.0 kg of food at a time. The efficiency of the large size non-tracking solar cooker has been found to be 27.5%. The cooker saves 5175 MJ of energy per year. The cost of the cooker is Rs. 10000.00 (1.0 US$ = Rs. 50.50). The payback period has been calculated by considering 10% annual interest, 5% maintenance cost and 5% inflation in fuel prices and maintenance cost. The payback period is least, i.e. 1.58 yr., with respect to electricity and maximum, i.e. 4.89 yr., with respect to kerosene. The payback periods are in increasing order with respect to fuel: electricity, coal, firewood, liquid petroleum gas, and kerosene. The shorter payback periods suggests that the use of large size non-tracking solar cooker is economical.

Keywords: Solar cooker, Solar energy, Energy conservation, Large size non-tracking solar cooker

1. Introduction

Energy consumption for cooking in developing countries is a major component of the total energy consumption including commercial and non-commercial energy sources [1]. The most of the energy requirement for cooking are met by non-commercial fuels such as firewood, agricultural waste and animal dung cake in

Nomenclatures

A	Absorber area, m^2
a	Compound interest rate per annum, %
B	Inflation rate in energy and maintenance per annum
C	Cost of the cooker, Rs.
c	Concentration ratio
c_p	Specific heat of cooking utensils, kJ/kg^{o}C
c_w	Specific heat of water, kJ/kg^{o}C
E	Energy savings per year, Rs
H	Solar radiation, kJ/m^2hr
M	Maintenance cost per annum, Rs.
m_1	Mass of water in cooking utensils, kg
m_2	Mass of cooking utensils, kg
N	Payback periods, yr
t_1	Initial temperature of water in the utensils, ^{o}C
t_2	Final temperature of water in the utensils, ^{o}C
Greek Symbols	
η	Efficiency of solar cooker, %
θ	Period of test, hr

rural areas and kerosene and liquid petroleum gas (LPG) in urban areas. The firewood requirement is 0.4 tons per person per year in India. In rural areas firewood crisis is far graver than that caused by a rise in oil prices. Poor villagers have to forage 8 to 10 hours a day in search of firewood as compared to 1 to 2 hours ten years ago. One third of India's fertilizer consumption can be met if animal dung is not burnt for cooking and instead is used as manure. The cutting of firewood causes deforestation that leads to desertification. Fortunately, India is blessed with ample amount of solar radiation [2]. The arid parts of India receive maximum radiation 7600-8000 MJ/m^2 per annum, followed by semi arid parts, 7200-7600 MJ/m^2 per annum and least on hilly areas where solar radiation is still appreciable i.e. 6000 MJ/m^2 per annum. Therefore, solar cookers seem to be a good substitute for cooking with firewood.

The first solar furnace was fabricated by naturalist George Louis Leclere Buffon (1707-1788). But Nicholas-de-Saussure (1740-1799) was first in the world to use the Sun for cooking. Augustin Mouchot, a French physicist, described a solar cooker in his book "La Chaleur Solaire" published in Paris, in 1869. He has also reported in the same book earlier work on solar cooking by English astronomer, Sir John Herschel, in South Africa, between 1834 and 1838.

Adams [3], an army officer, made India's first solar cooker in 1878 and he cooked food in it at Bombay. Since then many attempts were made to develop a suitable solar cooker. The reflector type solar cooker was developed in early 1950's [4] and was manufactured on a large scale in India [5]. Attempts were also made in 1960's and 70's to develop a reflector type solar cooker [6-9]. However a reflector type solar cooker did not become popular due to its inherent defects, e.g. it required tracking towards the Sun every ten minutes, cooking could be done only in the middle of the day and only in direct sunlight, its performance was greatly affected by dust and wind, there was a danger of the cook being burned as it was necessary to stand very close to the cooker when cooking and the design was complicated.

These defects were removed in hot box type solar cooker [10-16]. Different types of solar cookers have been tested and the solar oven [17-20] has been found best. Though the performance of the solar oven is very good but it also requires tracking towards the Sun every 30 minutes, it is too bulky and is costly. Therefore, the hot box solar cooker with a single reflector [21] is being promoted at subsidized cost by the Ministry of Non-conventional Energy Sources, Government of India and the state nodal agencies in India since 1981-82 and 637,000 solar cookers were sold up to September 30, 2008 [22] as against potential of 200 million solar cookers. The performance of the hot box solar cooker is very good but it also requires tracking towards the Sun every 60 minutes, therefore, its operation also becomes cumbersome. Considering this a two-reflector hot box solar cooker was developed and tested [23]. The cooker is kept in such a way that one reflector is facing south and other is facing east in the forenoon so that tracking is avoided for 180 minutes. In the afternoon, one reflector is facing south and other is facing west so that again tracking is avoided for 180 minutes.

To eliminate tracking completely a non-tracking solar cooker was developed [24]. These domestic solar cookers can meet cooking requirement of five people while family size in country side in India is large. To eliminate tracking completely and meet requirement of about 20 people, a large size non-tracking solar cooker has been designed and fabricated.

2. Design

The cooker is based on hot box principle having a single reflector. The cooker has been designed in such a way that the width to length ratio for reflector and glass window is about 4 so that maximum radiation falls on the glass window. This has helped in eliminating azimuthal tracking, which is required in simple hot box solar cooker towards the Sun every hour because the width to length ratio of reflector is 1. This cooker is always kept fixed facing equator.

The device consists of a double walled hot box. The outer box is made of galvanised steel sheet (22 SWG) and inner of aluminium (22 SWG). The space between them is filled with glass wool insulation. The inner tray is painted black by black board paint. Two clear window glass panes of 4-mm thickness have been fixed over it with an openable wooden frame. A 4-mm thick plane mirror is fixed over it. The tilt of the reflector can be varied from 0^o to 120^o depending upon the season and its tilt is fixed once in a fortnight. Four cooking utensils made of 22 SWG aluminium sheet and each having dimensions 415×405×75 mm^3 can be kept inside it for cooking four dishes simultaneously. Figure 1 depicts an actual field installation of the large size non-tracking solar cooker.

Fig. 1. Large Size Non-Tracking Solar Cooker.

3. Performance

The performance and testing of large size non-tracking solar cooker have been carried out by measuring stagnation temperatures inside cooking chambers, conducting cooking trials and comparing the performance with hot box solar cooker. It has been found that stagnation temperatures were 118.5ºC and 108 ºC in large size non-tracking solar cooker and hot box solar cooker respectively, the large size non-tracking solar cooker was kept fixed while the hot box solar cooker was tracked towards the Sun every hour. Cooking trials have also been conducted and rice, lentils, kidney beans, cauliflower, backing of *bati* (local preparation made of wheat flour) etc. have been cooked successfully. It takes about 2 h for soft food and 3 h for hard food. The cooker is capable of cooking 4.0 kg of food at a time. It has been found that performance of the large size non-tracking solar cooker is comparable with the hot box, though it is kept fixed while the hot box is tracked towards the Sun every hour. It has been made possible because the width to length ratio is 4 for the non-tracking solar cooker, while it is 1 for the hot box solar cooker.

The efficiency of solar cooker has been obtained by the following relation

$$\eta = \frac{(m_1 c_w + m_2 c_p)(t_2 - t_1)}{cA\int_0^\theta H d\theta} \quad (1)$$

Mass of cooking utensils was weighed and 1.0 kg of water was put in each cooking utensil. Initial and final temperatures of water were measured when water temperature was near to the boiling point. Duration was also measured. Solar radiation was measured by thermopile pyranometer and solar radiation was integrated using solar radiation integrator. The efficiency of the large size non-tracking solar cooker has been obtained from above relation for number of days in various season of the year and average efficiency has been found to be 27.5%.

4. Energy Consideration

Based on experience, it has been assumed that the cooker will cook both meals if the duration of bright sunshine hours exceeds 9 h/day, while it will cook only one meal if the duration of bright sunshine hours is less than 9 h/day but more than 6 h/day. It will not be able to cook on days when the bright sunshine hours are less than 6 h/day. By analysing 10 years data of the duration of bright sunshine hours measured at Jodhpur, it has been found that the cooker will cook both meals for about 254 days and one meal per day for about 67 days in a year at Jodhpur.

The energy for cooking per person is about 900 kJ of fuel equivalent per meal. The large size non-tracking solar cooker is capable of cooking for about 20 persons, and it will save 50% of cooking fuel per meal. Therefore, it will save 9 MJ of energy per meal and 5175 MJ of fuel equivalent per year.

The payback period has been computed by considering the equivalent savings in alternate fuels, viz. firewood, coal, kerosene, liquid petroleum gas (LPG) and electricity. The payback period has been calculated by considering the compound annual interest rate, maintenance cost and inflation in fuel prices and maintenance cost per year.

The economic evaluation and payback periods have been computed by the following relation [25,26]

$$N = \frac{\log\{(E-M)/(a-b)\} - \log\{(E-M)/(a-b) - C\}}{\log\{(1+a)/(1+b)\}} \quad (2)$$

The economic evaluation and payback periods have been computed by considering the following annual cost

Interest rate $a = 10\%$

Maintenance $M = 5\%$ of the cost of solar cooker

Inflation rate $b = 5\%$.

Cost of the cooker is Rs. 10,000 (1.0 US $ =Rs. 50.50). The cash flow of the cooker with respect to different fuels has been carried out and is shown in Table 1. From Table 1, it is clear that the cash flow is more with respect to fuel electricity and least with respect to kerosene.

Table 1. Economic Analysis of Large Size Non-Tracking Solar Cooker.

Year 1	Cash flow (Rs.) 2	Interest (Rs.) 3	Maintenance (Rs.) 4	Energy savings (Rs.) 5	Net savings (Rs.) 6=5-4-3
(a) Alternate fuel firewood					
0	-10,000.00	-	-	-	-
1	-5484.25	1000.00	500.00	6015.75	4515.75
2	-241.13	548.42	525.00	6316.54	5243.12
3	5815.88	24.11	551.25	6632.37	6057.01
(b) Alternate fuel coal					
0	-10,000.00	-	-	-	-
1	-4708.00	1000.00	500.00	6792.00	5292.00
2	1851.52	47.08	525.00	7131.60	6559.52
(c) Alternate fuel kerosene					
0	-10,000.00	-	-	-	-
1	-8541.37	1000.00	500.00	2958.63	1458.63
2	-6813.95	854.14	525.00	3106.56	1727.42
3	-4794.71	681.40	551.25	3261.89	2029.24
4	-2428.01	479.47	578.81	3424.98	2366.70
5	317.67	242.80	607.75	3596.23	2745.68
(d) Alternate fuel LPG					
0	-10,000.00	-	-	-	-
1	-7317.09	1000.00	500.00	4182.91	2682.91
2	-4181.74	731.71	525.00	4392.06	3135.35
3	-539.50	418.17	551.25	4611.66	3642.24
4	3669.98	53.95	578.81	4842.24	4209.48
(e) Alternate fuel electricity					
0	-10,000.00	-	-	-	-
1	-3934.21	1000.00	500.00	7565.79	6065.79
2	3445.53	39.34	525.00	7944.08	7379.74

The exact payback period has been computed from Eq. (2) with respect to different fuels and is shown in Table 2. The payback period is least, i.e. 1.58 yr, with respect to electricity and maximum, i.e. 4.89 yr, with respect to kerosene. The payback periods are in increasing order with respect to fuel: electricity, charcoal, firewood, LPG, and kerosene. The estimated life of this solar cooker is more than 15 years. The shorter payback period suggests that the use of large size non-tracking solar cooker is economical.

Table 2. Payback Periods of Large Size Non-Tracking Solar Cooker.

Ser. No.	Type of Fuel	Calorific Value	Efficiency (%)	Cost (Rs.)	Payback periods (yr.)
1	Firewood	19.89 MJ kg^{-1}	17.3	4.00 kg^{-1}	2.04
2	Coal	27.21 MJ kg^{-1}	28.0	10.00 kg^{-1}	1.78
3	Kerosene	45.55 MJ kg^{-1}	48.0	10.00 L^{-1}	4.89
4	LPG	45.59 MJ kg^{-1}	60.0	22.11 kg^{-1}	3.13
5	Electricity	3.6 MJ kWh^{-1}	76.0	4.00 kWh^{-1}	1.58

The use of large size non-tracking solar cooker would help in conservation of conventional fuels, such as firewood, animal dung cake and agricultural waste in rural areas of India, and LPG, kerosene, electricity and coal in the urban districts. Conservation of firewood help in preserving the ecosystems and animal dung cake could be used as fertiliser, which could aid in the increase of production of agricultural products. Moreover, the use of the non-tracking storage solar cooker would result on the reduction of the release of CO_2 to the environment.

5. Conclusions

The performance and testing of large size non-tracking solar cooker have been carried out by measuring stagnation temperatures inside cooking chambers, conducting cooking trials and comparing the performance with hot box solar cooker. It has been found that stagnation temperatures were 118.5°C and 108°C in large size non-tracking solar cooker and hot box solar cooker respectively. Cooking trials have also been conducted and rice, lentils, kidney beans, cauliflower, backing of *bati* (local preparation made of wheat flour) etc. have been cooked successfully. It takes about 2 h for soft food and 3 h for hard food. The cooker is capable of cooking 4.0 kg of food at a time. The efficiency of the large size non-tracking solar cooker has been found to be 27.5%.

The cooker saves 5175 MJ of energy per year. The cost of the cooker is Rs. 10000 (1.0 US $ = Rs. 50.50). The payback period has been calculated by considering 10% annual interest, 5% maintenance cost and 5% inflation in fuel prices and maintenance cost. The payback period is least, i.e. 1.58 yr, with respect to electricity and maximum, i.e. 4.89 yr, with respect to kerosene. The payback periods are in increasing order with respect to fuel: electricity, coal, firewood, LPG, and kerosene. The estimated life of this solar cooker is more than 15 years. The shorter payback periods suggests that the use of large size non-tracking solar cooker is economical.

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References

1. Fritz, M. (1981). *Future energy consumption*. Pergamon Press, New York.
2. Mani, A. (1981). *Handbook of solar radiation*. Allied Publisher, New Delhi.
3. Adams W. (1878). Cooking by solar heat. *Scientific American*, 38, 376.
4. Ghai, M.L. (1953). Design of reflector type direct solar cooker. *Journal of Scientific and Industrial Research*, 12 A, 165-175.
5. Ghai, M.L.; Pandhar, B.S.; and Dass, Harikishan (1953). Manufacture of reflector type direct solar cooker. *Journal of Scientific and Industrial Research*, 12A, 212-216.
6. Duffie, J.A.; Löf, G.O.G.; and Beck, B. (1961). Laboratories and field studies of plastic reflector solar cookers. *Proceedings of UN conference on New Sources of Energy*, Rome, Paper S/87, 5, 339-346.
7. Löf, G.O.G.; and Fester, D.A. (1961). Design and performance of folding umbrella type solar cooker. *Proceedings of U N conference on new sources of Energy*, Rome, Paper S/100, 5, 347-352.
8. Tabor, H. (1966). A solar cooker for developing countries. *Solar Energy*, 10, 153-157.
9. Von Oppen, M. (1977). The Sun basket. *Appropriate Technology*, 4, 8-10.
10. Ghosh, M.K. (1856).Utilisation of solar energy. *Science & Culture*, 22, 304-312.
11. Telkes, M. (1959). Solar cooking ovens. *Solar Energy*, 3, 1-11.
12. Garg, H.P. (1976). A solar oven for cooking. *Indian Farming*, 27, 7-9.
13. Nahar, N.M. (1990). Performance and testing of an improved hot box solar cooker. *Energy Conversion & Management*, 30, 9-16.
14. Grupp, M.; Montagne, P.; and Wackernagel, M. (1991). A novel advanced box-type solar cooker. *Solar Energy*, 47,107-113.
15. Nahar, N.M.; Marshall, R.H.; and Brinkworth, B.J. (1994). Studies on a hot box solar cooker with transparent insulating materials. *Energy conversion and Management*, 35, 784-791.

16. Nahar, N.M. (1996). Studies on solar cooker with tilted absorber. In *Towards Clean Energy Proc. National Solar Energy Convention*, 1996 Eds. Ghosh, B., Saha, S. K., and Basu, S., held at Jadavpur University Calcutta, during Dec. 27-29, 1996. Tata Mcgraw- Hill Publishing Company Ltd., New Delhi, 41-44.
17. Garg, H.P.; Mann, H.S.; and Thanvi, K.P. (1978). Performance evaluation of five solar cookers. *Proc. ISES Congress*, New Delhi (Eds. F de Winter and M. Cox) Pergamon Press New York SUN 2, 1491-1496.
18. Malhotra, K.S; Nahar, N.M.; and Ramana Rao B.V. (1983). Optimization factor of solar ovens. *Solar Energy*, 31, 235-237.
19. Nahar, N.M. (1986). Performance studies on different models of solar cookers in arid zone conditions of India. *Proc. 7th International conf. on Alternative Energy Sources.* Miami, Hemisphere Publishing Corporation, New York, 1:431-439.
20. Olwi. I.A.; and Khalifa, A.H. (1988). Computer simulation of solar pressure cooker. *Solar Energy*, 40, 259-268.
21. Parikh, M.; and Parikh, R. (1978). Design of flat plate solar cooker for rural applications. *Proc National Solar Energy Convention of India*, Bhavnagar, Central Salts and Marine Chemical Research Institute, Bhavnagar, India, 257-261.
22. MNRE (2008). *Akshay Urja*, Ministry of Non-conventional Energy Sources, Government of India, New Delhi, 2, 48.
23. Nahar, N.M. (2001). Design, Development and testing of a double reflector hot box solar cooker with a transparent insulation material. *Renewable Energy*, 23, 167-179.
24. Nahar, N.M. (1998). Design, development and testing of a novel nontracking solar cooker. *International Journal of Energy Research*, 22, 1191-1198.
25. Boer K.W. (1978). Payback of solar systems. *Solar energy*, 20, 225-232.
26. Duffie, J.A.; and Beckman, W.A. (1980). *Solar engineering of thermal processes*. Wiley, New York.