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, which is required in a 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 108.0^{o} C in a large size non-tracking solar cooker and hot box solar cooker respectively. It takes about 2h for soft food and 3h 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. 6000.00 (1.0 US $ = Rs. 44.50). The payback periods are in increasing order with respect to fuel: electricity, charcoal, firewood, LPG, and kerosene. The shorter payback periods suggests that the use of large size non-tracking solar cooker is economical.

Key words: 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. All the energy consumed in India for various sectors such as industrial, agricultural, transport, households and others, about fifty per cent of this is used for cooking alone [1]. Most of the energy requirements for cooking are met by non-commercial fuels such as firewood, agricultural waste and cow dung cake in 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 the 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 cow 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 amounts of solar radiation [2]. The variation in the radiation is 4 to 6 kW $m^{-2}day^{-1}$. The arid parts of Western Rajasthan receive maximum solar radiation. In the month of December, solar radiation increases from 2.6 KWh/m^{2}day at Gulmarg to 3.7 KWh/m^{2}day at New Delhi, 4.1 KWh/m^{2}day at Calcutta, 4.5 KWh/m^{2}day at Jodhpur and 4.3 KWh/m^{2}day at Kodaikanal. During the period November to February, i.e. winter season, most of the Indian stations receive 4.0 to 6.3 KWh/m^2. During the summer season i.e. March to May, this value ranges from 5.0 to 7.4 KWh/m^2. The arid and semi-arid parts of the country receive much more radiation as compared to rest of the country with the mean annual daily solar radiation received at Jodhpur, i.e. 6.0 KWh/m^2.

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 & 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 cookers [10-16]. Different types of solar cookers have been tested and the solar oven [17-20] has been found best. 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 a subsidized cost by the Ministry of Non-conventional Energy Sources, Government of India and the state nodal agencies in India since 1981-82 and 580,000 solar cookers were sold up to December 31, 2004 [22] as against a 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. The hot box can meet cooking requirements for 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 novel non-tracking solar cooker has been designed and fabricated.

2. DESIGN

The cooker is based on a 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 cookers towards the sun every hour because the width to length ratio of the reflector is 1. This cooker is always kept fixed facing the equator.

The device consists of a double walled hot box. The outer box is made of a galvanised steel sheet (22 standard wire gauge, or swg) and inner of aluminium (22 swg). The space between them is filled with glass wool insulation. The inner tray is painted black with 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 415X405X75 mm^3 can be kept inside it for cooking four dishes simultaneously. Fig. 1 depicts an actual field installation of the large size non-tracking solar cooker.

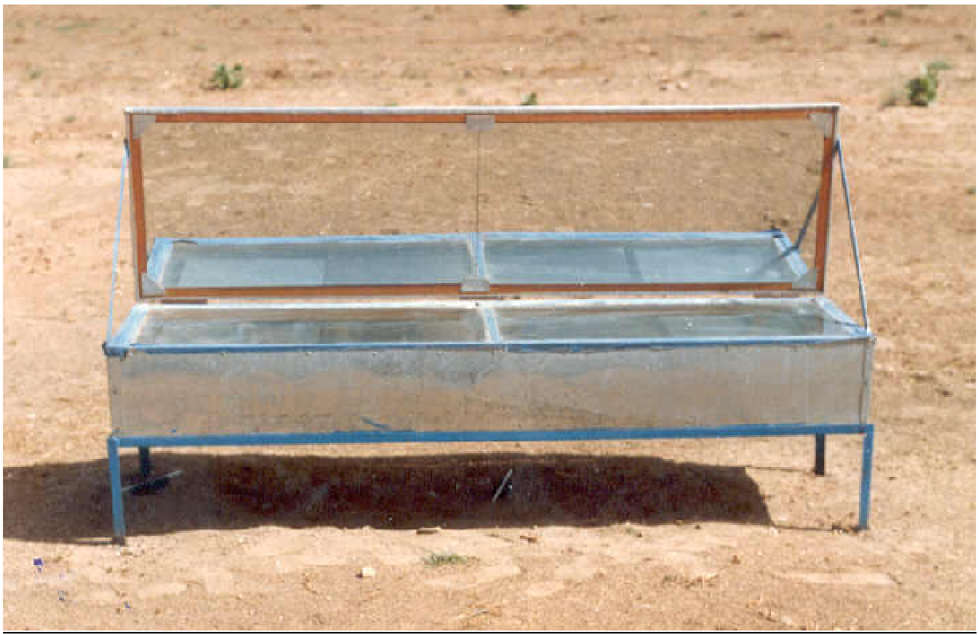

Fig. 1. Large size non-tracking solar cooker

3. PERFORMANCE

The performance and testing of a 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 a hot box solar cooker. It has been found that stagnation temperatures were 118.5^{O} C and 108.0^{o} C in a large size, non-tracking solar cooker and a hot box solar cooker respectively. The 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 hours (h) for soft food and 3h 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 the solar cooker has been obtained by the following relation.

$$\eta = \frac{(m_1 + m_2 c_p)(t_2 - t_1)}{c A \int^{\theta} H \, d\theta} \quad (1)$$

Where,

A	Absorber area, m^2
c_p	Specific heat of cooking utensils, K Cal.Kg^{-1} ^oC
H	Solar radiation, KCal m^{-2} hr^{-1}
m_1	Mass of water in cooking utensils, kg
m_2	Mass of cooking utensils, kg
t_1	Initial temperature of water in the utensils, ^oC
t_2	Final temperature of water in the utensils, ^oC
θ	Period of test, hr
η	Efficiency of solar cooker

The efficiency of the large size non-tracking solar cooker has been found to be 27.5 %.

4. ENERGY CONSERVATION

Based on experience, it has been assumed that the cooker will cook both meals if the duration of bright sunshine hours exceeds 9h/day, while it will cook only one meal if the duration of bright sunshine hours is less than 9h but more than 6h. It will not be able cook on days when the bright sunshine hours are less than 6h. By analysing the duration of bright sunshine hours, 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 9.00 MJ of energy per meal and 5175.00 MJ of fuel equivalent per year.

The payback periods have been computed by considering the equivalent savings in alternate fuels, viz. firewood, coal, kerosene, liquid petroleum gas (LPG) and electricity. The payback periods have 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 [24,25]

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

Where,

a	Compound interest rate per annum
b	Inflation rate in energy and maintenance per annum
C	Cost of the cooker, Rs.
E	Energy savings per year, Rs
M	Maintenance cost per annum, Rs.
N	Payback periods, yr

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 %.

The cost of the cooker is Rs. 6000.00 (1.0 US $ = Rs. 44.50). 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. 1.09 yr., with respect to electricity and maximum, i.e. 2.20 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 periods suggests that the use of large size non-tracking solar cooker is economical. The use of large size non-tracking solar cooker would help in conservation of conventional fuels, such as firewood, cow dung cakes 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 cow dung cakes 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. CONCLUSION

The performance and testing of a large size non-tracking solar cooker has been carried out by measuring stagnation temperatures inside cooking chambers, conducting cooking trials and comparing the performance with a hot box solar cooker. It has been found that stagnation temperatures were 118.5^{O} C and 108.0^{o} C in a 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 2h for soft food and 3h 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. 6000.00 (1.0 US $ = Rs. 44.00). 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. 1.09 yr., with respect to electricity and maximum, i.e. 2.20 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 periods suggest that the use of large size non-tracking solar cookers is economical. The use of a large size non-tracking solar cooker would help in conservation of conventional fuels, such as firewood, cow dung cake and agricultural waste in rural areas of India, and LPG, kerosene, electricity and coal in the urban districts. Conservation of firewood helps in preserving the ecosystems and cow 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 in the reduction of the release of CO_2 to the environment.

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