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Maximum utilization of solar energy using various reflective materials for making economical solar cooker

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ABSTRACT: One of the main reason that solar cookers have not gained widespread acceptance over the world is because of unavailability of low cost good reflective material which can be used to make highly efficient solar cookers. Conventionally usable reflective materials like silvered glass mirror has a drawback of higher cost, fragility and inflexibility which limits its application in solar cookers. It will be a critical task in construction of household use solar cookers is to select a good low cost reflective material. Not only that, it is very difficult to guess which material is better than the other among different types of reflective material available in the market. In this work an attempt is made to search and evaluate best available reflective materials in the market which can be used for making domestic use solar cookers. During this work, a solar concentrator was made using a parabolic dish and was tested with four different types of reflective materials, namely One-way solar reflective film, Vinyl car wrap, Mirror wall sticker, and Aluminium foil tape. These reflective materials are compared with each other to find the best material on the basis of its reflectiveness, cost and ease of application. Experiment suggest that Vinyl car wrap and Mirror wall sticker are about 1.8 times better than Aluminium foil tape as far as reflectivity is considered. But since Vinyl car wrap is cheaper than Mirror wall sticker, we can say that it is the most suitable reflective material for application in domestic solarcookers.

I. INTRODUCTION

All types of solar cookers are influenced by the amount of solar radiation reaching on the earth's surface, more is the radiation reaching the earth's surface higher is the temperature achieved in cooking vessel. The average amount of solar radiation received on the earth is about 1.4 kW/m². However, the amount of solar radiation received is not uniform throughout the earth's surface and varies by latitude. Most of solar energy is available between latitudes 25°N and 25°S.

To utilize this solar energy several types of solar cookers have been developed. Almost all kind of solar cookers uses some sort of reflector material to reflect the solar radiation for additional heating. One of the most important tasks for making a solar cooker is to identify reflector materials that would be both suitable for this application as well as economical. We have conducted an extensive search for available reflective materials.

Solar cookers can be classified according to the method of cooking in to four main categories;

1. Box type solar cooker or popularly known as solar ovens
2. Concentrating or reflector cookers
3. Collector cookers
4. Concentrating or reflector cookers panel type solar cookers

II. LITERATURE SURVEY

Adil O M Omara (2020) work to provides a rich literature review of the applications of phase change materials (PCMs) as TES mediums to improve the SC performance. The paper indicates the feasibility of PCMs for improving the cooking performance and thermal parameters of SCs with lower cooking time in addition to the possibility of evening cooking. Furthermore, the review discusses the influence of thermal and geometric features of PCM on the cooking behavior. Additionally, the effect of the heat transfer fluids and the compatibility of the encapsulation materials are also included. Besides, the review also discusses the challenges of using PCMs with SCs related to optimal PCM quantity, PCM type, low exergetic efficiency, non-efficient thermal control, mechanical strength, and thermal conductivity limitations. Finally, the economic and

environmental aspects, and usage of solid-solid PCMs are recommended as future research for further studies.

In this study author (2019) studied about thermal performance of the solar box cooker, there is no significant improvement due to design modification of the solar box cooker. So, there is a need for development in terms of design of solar box cooker, reflector material and orientation, thermal storage and double glass cover. The thermal performance of the solar box cooker is based on the double glass cover. Hence there is a need to improve the performance of the double glass cover by adding some coating on the glass cover to increase the solar energy absorbing capacity. Also, we can use other PCM to increase the thermal storage timing and multiple cooking boxes to decrease the cooking timing. If we use these suggested things in solar box cooker with four reflectors and one base reflector, the thermal performance of the cooker will increase in better way.

In the present research work, V M Modi (2018) a thermal performance of box type solar cooker was analysed according to the American Society of Agricultural Engineers (ASAE) international test procedure and Bureau of Indian Standards (BIS). The experiments were conducted in order to determine the first figure of merit (F1), the second figure of merit (F2) and standard cooking power (Ps). It was observed that two figure of merits (F1, and F2), standard cooking power (Ps) and thermal efficiency of solar cooker were 0.1084, 0.31, 58.41 watt, and 37.76%, respectively. The economic feasibility was determined by comparing it with LPG and fuel wood. The payback period was found 1.08 years and 0.49 year, respectively when LPG and fuel wood was replaced by developed box type solar cooker. Finally, the results indicated that the cooker has a good reliability for cooking food and boiling water

An attempt was made by Pankaj K. Gupta (2016) for development and testing of a reflective panel type low cost solar cooker. In order to keep the cost as low as possible several alternatives were explored for the material to be used for the panel. It was decided to use the packaging card board material (used in making cartons) for the panel. Then among several alternatives to choose the reflective materials, low cost rough- surface reflective aluminum paper was used. This paper was glued to the base panel material using food grade adhesive. For cooking purposes, cylindrical aluminum boxes are used because aluminum has high thermal conductivity as compared to stainless steel. The outside of the box was painted black with epoxy black paint which can sustain high temperatures without chipping or leaving away from the surface. The cooker was found suitable for cooking once in winter and twice in summer for 1-2 persons with the estimated cost of Indian Rs. 200.00. As mentioned above he used rough surfaced aluminum paper as a reflective material.

A test was conducted by R. Meenakshi Reddy et al. (2015) In this test they have used different reflectors namely aluminum sheet, aluminum foil and glass mirror, to test the performance of the solar cooker. In this test parabolic dish collectors have been fabricated separately using glass mirror, aluminum sheet and aluminum foil reflectors. Manual sun tracking system was employed in which glass reflector was found efficient for cooking a food items compared to other two reflectors. In this experiment it was found that among the three reflectors mirror type reflector was more efficient for cooking and also aluminum sheet reflector was 10-15% less efficient compare to mirror type. But durability and handling of the total system is quite comfort by using aluminum sheet as reflector. It is a permanent and non-polluting type of energy source. The type of reflector material used can boost the performance of solar cooker.

Construction of Parabolic Solar Cookers was done by Aidan (2014), in which a solar parabolic dish collector was made from aluminum sheets to reduce heat loss. Iron bars were used to support the dish and utensils.

Manual sun tracking mechanisms were used that were made using iron bars to continuously adjust the cooker in the direction of the sun. The reflective surface was made using a thin lining of aluminum foil paper so that it could be affixed to the outer surfaces of the dish. A black colored cylindrical vessel was used as the receiver / absorber (cooking utensil) for experimental evaluation of the solar parabola dish collector. The optical efficiency of the parabolic dish collector was found to be 17.86%. The low value can be attributed to the fact that aluminum foil was not placed smoothly on the surface of the collector to offer regular reflections on the cooking vessel, hence causing considerable radiation damage to the environment. In addition there were other losses represented by the overall heat loss coefficient of 8.656 WK-1m-2 from all surfaces of the cooking vessel. The adjusted cooking power of 96.53 W measured the performance of the solar parabolic dish cooker.

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The adjusted cooking power of 96.53 W measured the performance of the solar parabolic dish cooker.

This value showed that the cooker offered 96.53 J of thermal energy over the water contained in the cooking vessel every second. This is for a heating period of 28 minutes (1680 seconds) between 60oC and 95oC, with water receiving about 162120 J of heat energy. This experiment clearly shows aluminium not a good reflector as efficiency was only 17.86, and therefore if available other reflective material options should be evaluated for solar cookers.

A test was conducted by S.M. Masum Ahmed et al (2019). In this test different reflective materials were used to manufacture the parabola solar cooker. The purpose of the manufactured cooker was to cook food with the lowest energy possible and thus conserve food nutrients energy as well as sensory properties and protect the environment by reducing CO_2 and other toxic emissions associated with all types of stoves or cookers. The experiment illustrated a comparison of three different types of reflective material. They are stainless steel, Mylar tape and aluminum foil. These three types of cookers were tested under different weather conditions and found a wide variety of temperature outputs. A maximum temperature of 93.7^{o}C was obtained using Mylar tape as a reflective material. In addition, the highest temperatures at 77.1^{o}C and 73.1^{o}C were obtained using aluminum foil and stainless steel, respectively. By performing test analysis of various reflectance materials, it was concluded that mylar tape has the property of reflecting the maximum amount of heat within a very short period of time. Although the purpose of this experiment was not to detect the best reflective material out of the tested materials. This experiment showed that mylar tape was the best reflector between stainless steel and aluminum foil in the other two test materials.

Of the three test materials, aluminum foil and mylar tape are readily available and can be purchased easily but there are many more reflective materials that are readily available and need to be tested.

III. METHODOLOGY

By searching on internet reading reviews and from seller's description we have purchased different reflective materials and chosen to test four of these. After purchasing these materials from different sellers, first we do preliminary examination of the materials and observations have been noted down. This is because of the fact that we could not rely on seller's description of the product because he may be exaggerating the cons of the product for marketing purposes. Also, we purchase a dish from local hardware store. We clean and smoothen the dish by sanding it with sandpaper. After this we apply white paint on this surface. The white paint will help in reflecting some of the light back if any light gets transmitted through the reflective film. Then we apply different reflective materials on its surface for test of reflectiveness.

Preliminary examination of the reflective material

One-way solar reflective film

This is a thin film of plastic. This film is not intended to reflect all of the sun rays, it reflects sun rays partially. One can easily see through the film standing on the darker side towards the brighter side. The specularity of this film appears to be as good as glass mirror, but the image of the object kept in front of it appears to be some fainted if observed carefully. The film has transparent adhesive coating on one side. The plastic material appears to be stiff and durable.

Vinyl car wrap

This is thin film of plastic relatively softer then one-way-solar-reflective-film. This film appears opaque unless some very bright object like sun is viewed through it. This may be due to improper metallization in manufacturing process. The specularity of this film is not as good as glass mirror but is fairly good. The material appears to be durable. We had bought this film from two seller and found no difference in the quality of the film.

Mirror wall sticker

This is thin film of plastic which appears to be stiffer then both one-way-solar-reflective-film and vinyl-car-wrap. We have bought this material from two sellers, the quality of the film in both the case differed in case of its opaqueness. The one which was pricier appeared to be fully opaque when sun was viewed from its one side while the cheaper one allowed some of the sun light to be transmitted. The specularity of this film is appears to be as good as glass mirror.

Aluminium foil tape

This aluminium foil is similar to the aluminium foil used in packing food items except that it has adhesive coating on one side. The film is completely opaque. The specularity of the film

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appears to be far lower than glass mirror. It is very soft and malleable; wrinkles are formed very easily and hence care should be taken while applying this on the surface.

Experimental setup

Parabolic dish arrangement

A parabolic dish which is used as antenna, was used as a parabolic surface for applying different types of reflective films on its surface.

Test for reflectiveness comparison

A test was conducted in which four different types of reflective materials namely One-way- solar-reflective-film, Vinyl-car-wrap, Mirror-wall-sticker, and Aluminium-foil-tape were tested to find best material. The test for different materials was performed on four different days within 8 days.

A photograph of Mirror wall sticker on parabolic surface

Time	One-way reflective mirror Date: 21/01/20	Vinyl wrapper car sticker Date: 24/01/20	Mirror wall sticker Date: 05/02/20	Aluminium foil tape Date: 09/02/20
0	25.2 (Start time 11:15)	24.9 (Start time 11:18)	23.8(Start time 11:35)	22.9(Start time 11:26)
1	26.3	25.4	25.5	NA
2	29.4	29.2	26.1	24.8
3	33.3	35.6	28.9	26.6
4	40.4	43.9	45.2	31.1

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5	48.7	68.6	56.9	35.6
6	59.6	78.7	70.4	NA
7	73.9	97.2	91.2	54.6
8	86.6	100.4	99.5	65.1
9	91.2	100.5 (Time 11:41)	100.1	68.4
10	97.9		100.8 (Time 11:59)	72.6
11	98			80.9
12	98.1			86.5
13	98.4			98.7 (Time 12:14)
14	99.1			
15	100.1 (Time 11:50)			

Cost Comparison

All the four materials used in the experiment are available on online shopping websites "Amazon.in" and "Alixpress.com". These materials are available online and can be shipped almost anywhere in India. The cost and other details of the purchased materials are listed below

Material	Website	Size (Length × Breadth)	Cost as on 18/01/2020	Cost per m2	Seller
One-way solar reflective material	www.aliexpress.com	2m ×0.4m	US $4.05 (Approximately Rs. 250.9)	Rs 313.7	Sold By TL Colourful Life Store (China)
Vinyl car wrap	www.amazon.in	50 inch×24 inch (1.27m×.61m)	Rs 349.00 + 40(Delivery charges) = Rs 389	Rs 502	Sold By INDIASHOPERS

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Mirror wall sticker	www.aliexpress.com	0.15m×0.15 m (9PCS/Set Square about 15cm×15cm 1 piece size)	US $2.01 (Approximately Rs. 143.35)	Rs 707.9	Sold By Tie Ler Official Store China (Shanghai)
Aluminum foil tape	www.amazon.in	.072m×20m	Rs 179 + 76 (Delivery charge) = 255	Rs 177	Sold by Sri sai enterprises

Comparison on the basis of ease of application

One-way solar reflective film:

For applying on the surface this film has to be cut into small strips so that its bulging on the surface can be avoided

Vinyl car wrap:

Similar to "One-way solar reflective film" this film has to be cut into small strips so that its bulging on the surface can be avoided. As its one side has adhesive coating no additional glue is needed to be applied. The film is easily applicable on the concentrator's surface and easy to maintain.

Mirror wall sticker:

The film is thicker and stiffer than other films and due to its stiffness, any unwanted small particles on the surface of the dish causes relatively large bulge on the film thus reducing the effective surface area.

Aluminium foil tape:

Application of aluminum foil tape was very difficult because creases are formed very easily and once formed it is permanent and cannot be removed. Also, it is very fragile and tears very easily.

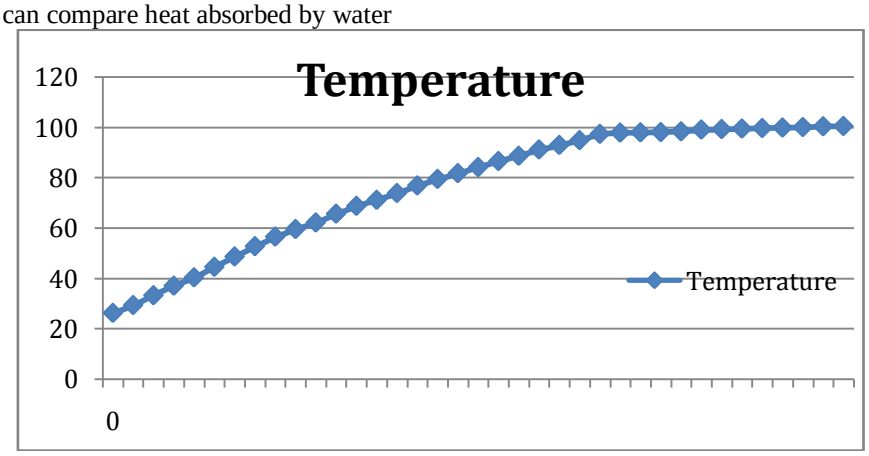
IV. RESULT

Setting reference temperature and material

From the data collected from the experiment we can compare heat absorbed by water in same amount of time for different reflective material. For the further analysis of the data collected we need to decide an initial temperature and a time range for which temperature rise has to be taken into consideration. Ideally initial temperature in all four cases should be same but due to practical limitations we do not have such value. Therefore, we choose initial temperature for different material so that values are close to each other. The time interval is taken in such a way that we do not cross 100˚C mark for any of the material. The temperature of water in case of Vinyl car wrap takes shortest time to reach 100˚C, thus the time taken by water to reach the temperature just one minute before it reaches 100˚C (i.e. 99.9˚C) is taken as time interval for our analysis.

First graph plotted between One-way solar reflective film time vs temperature

The starting temperature was measured 25.2. From graph 5.1, we observe that temperature normally rises up to 55 ^{O}C. After this rate of temperature rise is decreased slightly and after the temperature of about 95 ^{O}C the rate of temperature rise is reduced. Water attains 100 ^{O}C at about 34-35 minutes



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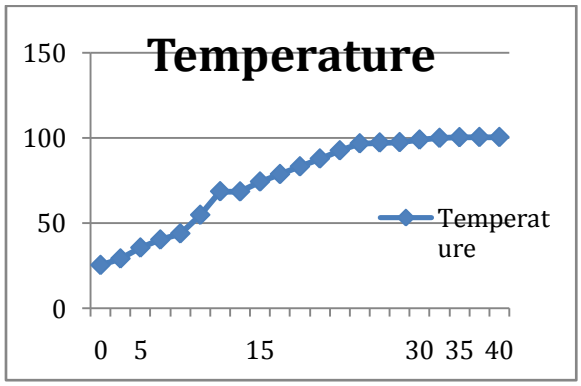
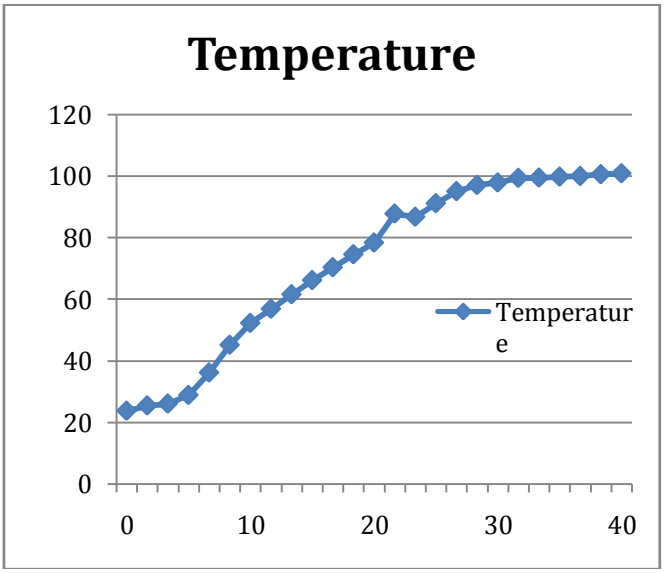
Second graph plotted between Vinyl car wrap time vs temperature

The starting temperature was measured 24.9. From graph 5.2, It can be seen that temperature reaches increases at very high rate up to 70 ^{O}C in about 7 minutes. After this rate of temperature rise is decreased slightly and temperature reaches up to 95 ^{O}C in less than 14 minutes. After this the rate of temperature rise is considerably reduced and it take more 5 minutes to reach



Third graph plotted between Mirror wall sticker time vs temperature

In Mirror wall sticker case starting temperature was measured to be 23.8. From graph 5.3, temperature increase is relatively slow at beginning from temperature 23.8^{O}C to about 30 ^{O}C. After this temperature rises very quickly to about 55 ^{O}C. Water in this case attains 100 ^{O}C in less than 22 minutes which is 4 minutes more than Vinyl car sticker



Fouth graph plotted between Aluminium foil tape time vs temperature

The starting temperature was 22.9. From graph 5.4, It can be seen that temperature rise is relatively slow. The temperature will not reaches 100 ^{O}C in case of aluminum foil tape. Maximum temperature reached is 98.7 ^{O}C and time taken is 48 minutes

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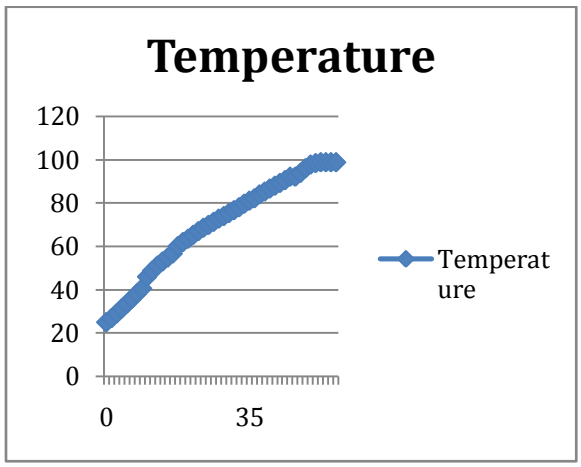
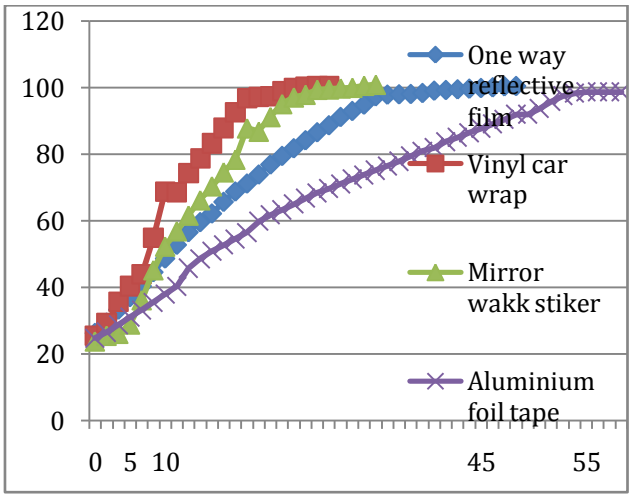


Time vs temperature comparison graph representing for different materials

The comparison of different material is shown in figure 5.7. This graph shows that the temperature rise curve of Vinyl car wrap is steeper than the curves of other reflective material. For all materials curve is steep at the beginning suggesting higher temperature rise rate. At the middle the curve is more or less constant and at end the curve is getting flattened which suggest slow rate of temperature rise.



V. CONCLUSION

1. From the primary experiment to seek out the most effective material on the premise of its reflectiveness we discover that relative effectiveness of the Vinyl automobile wrap is one.86 and relative effectiveness of Mirror wall sticker is 1.83. The distinction being little (i.e. 0.03), say that each materials performed nearly equally and are the most effective performers. whereas the second- best entertainer is unidirectional star reflective film with relative effectiveness of 1.4. As none of the fabric have relative effectiveness less then reference material that's aluminum foil tape, aluminum foil tape is worst entertainer.
2. In comparison on the idea of price we discover that aluminium foil tape has lowest value per square metre followed by Vinyl automotive wrap, unidirectional reflective film and Mirror wall sticker. However as reflectiveness of the aluminium foil tape is lowest among the compared with other reflective material
3. As Vinyl automotive wrap and Mirror wall sticker has performed nearly equally as way as reflectivity is taken into account and price of Vinyl automotive wrap is concerning twenty nine percent cheaper than Mirror wall sticker, We advocate mistreatment Vinyl automotive wrap as a reflectivematerial.

4. From our expertise we will say that aluminium foil tape is most promptly obtainable on- line further more as in offline market. On the other hand different material area unit simply.

Finally, in comparison on the convenience of application of the fabric. we will say that each one 3 materials except "Aluminum foil tape" were simple to use. On the opposite hand, it had been terribly troublesome to handle "Aluminum foil tape"and honest quantity of tape crease formation.

As "Vinyl automotive wrapper" and "Mirror wall sticker" has performed nearly equally in reflectiveness check and price of the "Vinyl automotive wrap" is significantly lower per square metre. "Vinyl automotive wrap" is that the most fitted reflective material among all the four normally used reflective materials used for creating parabolic star cooking utensilfor domestic and test experiment purpose simply found on many e-commerce websites. Aluminium foil tape that is wide used as reflective material for creating of star concentrators is worst among the all four materials tested as way as reflectivity cares. Thus, we have to advocate mistreatment aluminium foil tape for creating domestric solar cooker utensil. Our recommendation is vinyl automotive wrap for construction of inexpensive star cookers for daily need domestic use now a days

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