Evaluating Low-Cost Reflective Material Alternatives for Solar Cookers

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Abstract- One reason that solar cookers have not gained widespread acceptance is because of unavailability of low cost good reflective material which can be used to make efficient solar cookers. Conventionally used reflective materials such as silvered glass mirror has drawback of higher cost, fragility and inflexibility which limits its application in solar cookers. A critical task in construction of domestic use solar cookers is to find a good cost-effective 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 solar cookers.

Index term: Solar cooker, low-cost, reflective material

I INTRODUCTION

A wide variety of cookers of different designs have been developed around the world. These designs of solar cookers have been classified based on their shapes, technique used for reflection of solar radiation or method of cooking. Further these solar cookers can be classified according to the method of cooking in to four main categories, these are the box type solar cookers or popularly known as solar ovens, concentrating or reflector type solar cookers, collector type solar cookers and panel type solar cookers. Almost all kind of solar cookers uses some kind of shiny reflective material that is used to reflect additional sun rays towards the cooking area [*1*] [*2*].

Reflectance of solar energy is used in almost all kind of solar thermal devices, these include solar cookers for cooking, space heating, water heating, space cooling, and heat generation process. Solar cookers can be built easily by using heat-reflecting surfaces [*3*].The principal use of reflectors is in concentrators which multiply the solar flux on a receiver. Concentrating solar power systems use large solar reflectors to concentrate sunlight to utilize solar energy. The widespread application of concentrating solar power generation depends on developing a durable, low-cost reflectors [*4*]. Polymer base concentrator is an alternative for obtaining flexible, light weight hubs. These concentrators consist of a very thin film (.1mm) UV-stabilized poly-methyl-methacrylate (PMMA) which is deposited by evaporating a reflective film of silver, and finally a protective layer of copper [*5*]. Polymer reflectors offer several advantages over glass mirror these include greater system design flexibility are lighter in weight, and have the potential for lower cost than glass reflectors. However, silvered polymer has several limitations, such as relatively higher cost, poor adhesion between the silver and the polymer on exposure to water. Silvered thin (1.0 mm thick) glass is durable but has relatively high cost, fragility in shipping and handling, and the availability is an issue [*6*]. Aluminized reflectors do not have the disadvantages of glass concentrators as they are lightweight, flexible so they can take curved shapes, thin and feature potential low cost [*5*].

II LITERATURE REVIEW

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. Then among several alternatives to choose the reflective materials, low cost rough-surface reflective aluminium paper was used which is commonly known as aluminium foil paper or simply aluminium foil. This material is easily available at low cost but its reflectiveness is not good compared to other available materials [*7*]. A test was conducted by **R. Meenakshi Reddy et al. (2015)**. In this test they have used different reflectors namely aluminium sheet, aluminium foil and glass mirror, to test the performance of the solar cooker. In this test parabolic dish collectors were fabricated using glass mirror, aluminium sheet and aluminium 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 [*8*]. A parabolic solar cooker was constructed by **J. Aidan (2014)** in which solar parabolic dish collector was made from Aluminium sheet to reduce heat loss. Manual sun tracking mechanism was used. Reflector surface was made using thin linings of Aluminium foil paper by gluing it to the outer surfaces of the dish. The optical efficiency of parabolic dish collector was found to be 17.86%; the low value could be attributed to the fact that the aluminium foil was not laid smoothly on the collector surface to offer a regular reflection on to the cooking utensil hence resulted into considerable radiation loss to the environment. This experiment clearly shows that it is difficult to attain higher efficiency using aluminium foil as a reflector material [*9*]. A test was

conducted by **S.M. Masum Ahmed et al (2019)**. In this test different reflecting materials were used for construction of parabolic solar cooker. The aim of the cooker constructed was to cook food with the lowest amount of energy and thus conserve food nutrients energy as well as gustatory qualities. This experiment illustrated the comparison of three different types of reflecting materials namely, Stainless Steel, Mylar tape and Aluminium Foil. By performing the test analysis of different reflecting materials, it was concluded that Mylar tape has the property to reflect the maximum amount of heat within a very short time [*10*].

IV MATERIAL SELECTION

Searching on internet we have come across various types of reflective materials which are made for other purposes, but can be used as reflective material for homemade solar cookers. These include reflective materials such as aluminum foil tape, Mylar, glass mirrors, mirror wall sticker, chrome vinyl, reflective paints and many others. Finding information about these materials on different websites, we find that four out of these many materials more suitable for the use in solar cooker. While choosing these materials we have taken care of the fact that the material is not much costly and is sold by different sellers and websites. Although different sellers name these materials little differently, we have given these materials names by which these can be easily found on the internet using Google search engine. These materials are 1) One-way solar reflective film 2) Vinyl car wrapper 3) Mirror wall sticker and 4) Aluminium foil tape. Following is the information about these materials from different sources.

Figure 1: A photo graph of different solar reflective films. From left 1) Aluminium foil tape 2) One-way solar reflective film 3) Mirror wall sticker 4) Vinyl car wrap.

V EXPERIMENT AND RESULT ANALYSIS

5.1 Comparison on the basis of reflectiveness of material

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. In this experiment we constructed solar concentrator using parabolic dish and then different reflective materials were applied on it one by one on different days at approximately same time of the day. The concentrated solar radiation was focused on a black painted aluminum can of 250 ml filled with clean water in each case. The parabolic dish was adjusted manually several times to track the sun movement so that sun rays remain well focused on the can. A digital thermometer was submerged into the water. Initial temperature and consecutive rise in temperature for every one-minute interval was noted. The test for different materials was performed on four different days within 8 days from the start of first experiment. Based on rise of water temperature with time the different reflective materials are compared. The result of the experiment is tabulated below and then plotted on a temperature vs time graph.

Figure 2 : A photograph of setup.

	One-way solar reflective mirror Date: 28/11/18		Vinyl car wrap Date: 29/11/18		Mirror wall sticker Date: 30/11/18		Aluminium foil tape Date: 5/12/18	
Time	Temperature	Remark	Temperature	Remark	Temperature	Remark	Temperature	Remark
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 am
1	26.3		25.4		**25.5**		NA	Missed data
2	29.4		29.2		26.1		**24.8**	
3	33.3		35.6		28.9		26.6	
4	37.1		40.3		36.2		28.8	

5	40.4		43.9		45.2		31.1	
6	44.6		54.8		52.3		33.3	
7	48.7		68.6		56.9		35.6	
8	52.8		68.5		61.6		38	
9	56.6		74.3		66.2		40.4	
10	59.6		78.7		70.4		NA	Missed data
11	62.2		83.2		74.6		45.8	
12	65.7		87.8		78.4		48.6	
13	68.8		92.6		87.8		50.9	
14	71.2		96.7		86.8		52.8	
15	73.9		97.2		91.2		54.6	
16	76.9		97.4		95.1		56.5	
17	79.5		98.9		97.1		59.9	
18	**81.8**		**99.9**		97.9		61.8	
19	84.2		100.3		**99.4**		63.3	
20	86.6		100.4		99.5		**65.1**	
21	88.7		100.4		99.8		66.8	
22	91.2		100.5		100		68.4	
23	93		100.4	Time 11:41	100.6		69.7	
24	94.9				100.9	Time 11:59	71.1	
25	97.4						72.6	
26	97.9						73.8	
27	98						75.2	
28	98.1						76.5	
29	98.4						77.9	
30	99.1						79.5	
31	99.3						80.9	
32	99.5						82	
33	99.7						83.8	
34	99.9						85.1	
35	100.1						86.5	
36	100.4						87.8	
37	100.5						89.1	
38	100.2						90.4	
39	99.9						92	
40	99.4						92	
41	99.4						93.7	
42	99.9						95.9	
43	100.1						97.6	
44	100.1						98.3	
45	100.1	Time 11:50					98.7	Time 12:11

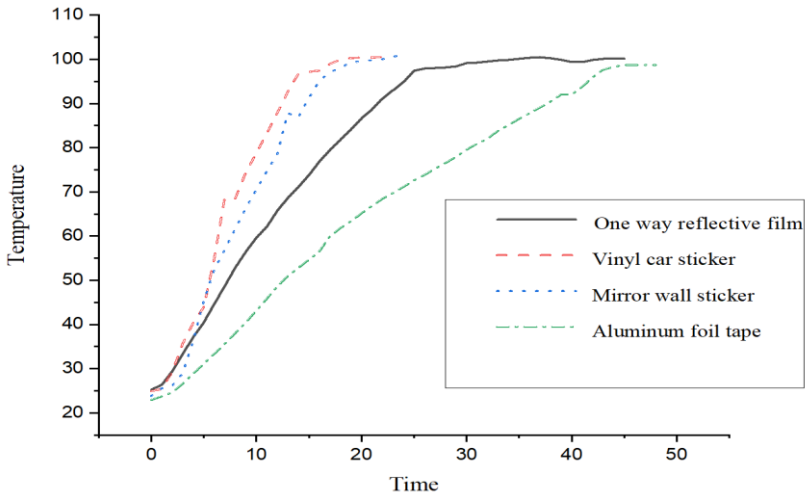

Figure 3: Time vs temperature graph for different materials.

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 100ºC mark for any of the material. The temperature of water in case of Vinyl car sticker takes shortest time to reach 100ºC, thus the time taken by water to reach the temperature just one minute before it reaches 100ºC (i.e. 99.9ºC) is taken as time interval for our analysis. This is maximum time interval which can be used in all the four cases without reaching the 100ºC. From the table 1, we find that this time interval is of 18 minutes. Thus, temperature after 18 minutes from the initial temperature is taken as the final temperature in each case. The chosen initial temperature and final temperature values are shown in bold in the table 1. Also, for comparison of different materials with each other we need to set a reference material. We take "Aluminum foil tape" as a reference material as it is one of the most popular reflective material.

Now as we know heat absorbed (Q) in time (t) is given by

$$Q = MC_p t(T_f - T_i)$$

Where,

- Q is heat absorbed by water in time t
- t is time interval in consideration
- C_p is specific heat constant for water at constant pressure
- M is mass of water in container
- T_f is final temperature of water
- T_i is initial temperature of water

We can define a term relative effectiveness E of a reflective material as a ratio of heat absorbed by water when using a particular reflective material to the heat absorbed by the water when using Aluminum foil tape. This will give us an idea that how good or bad a reflective material is as compared to "Aluminum foil tape". This can be expressed mathematically as follows.

$$E = \frac{MC_p(T_f - T_i) \times t}{MC_p(T_{f4} - T_{f4}) \times t} = \frac{(T_f - T_i)}{(T_{f4} - T_{f4})}$$

For "One-way solar reflective film (OWSRF)" $E_{OWSRF} = \frac{(T_{f1} - T_{i1})}{(T_{f4} - T_{i4})} = \frac{(81.8 - 25.2)}{(65.1 - 24.8)} = \frac{56.6}{40.3} = 1.4$

For "Vinyl car sticker (VCS) $E_{VCS} = \frac{(T_{f2} - T_{i2})}{(T_{f4} - T_{i4})} = \frac{(99.9 - 24.9)}{(65.1 - 24.8)} = \frac{75}{40.3} = 1.86$

For "Mirror wall sticker (MWS)" $E_{MWS} = \frac{(T_{f3} - T_{i3})}{(T_{f4} - T_{i4})} = \frac{(99.4 - 25.5)}{(65.1 - 24.8)} = \frac{73.9}{40.3} = 1.83$

And for "Aluminum foil tape (AFT)" $E_{AFT} = \frac{(T_{f4} - T_{i4})}{(T_{f4} - T_{i4})} = \frac{(65.1 - 24.8)}{(65.1 - 24.8)} = \frac{40.3}{40.3} = 1$

Where subscript 1, 2, 3 and 4 refers to One-way solar reflective film, Vinyl car sticker, Mirror wall sticker and Aluminum foil tape respectively. Comparing values of E_{OWSRF}, E_{VCS}, E_{MWS}, E_{AFT} we observe that value of E_{VCS} is highest followed by E_{MWS}, E_{OWSRF} and E_{AFT}. Although Vinyl car wrapper and Mirror wall sticker relative effectiveness is i.e. E_{VCS} and E_{MWS} values are nearly same. Therefore, we can say that as far as reflectiveness is considered the "Vinyl car sticker" and "Mirror wall sticker" are the best performers. On the other hand, "Aluminum foil tape" which is one of the most commonly used reflective material is the worst performer among the four material in consideration.

5.2 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.

Table 2

Material	Website	Size (Length × Breadth)	Cost as on 20/02/2019	Cost per m^2	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 sticker	www.amazon.in	50inch×24inch (1.27m×.61m)	Rs 349.00 + 40(Delivery charges) = Rs 389	Rs 502	Sold By INDIASHOPERS

Mirror wall sticker	www.aliexpress.com	0.15m×0.15m (9PCS/Set Square about15cm×15cm 1pice size)	Rs 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

From the above data we can see that "Aluminum foil tape" has the lowest price per square meter followed by "One-way solar reflective material", "Vinyl car sticker", and then "Mirror wall sticker". Note that these materials are offered by different sellers on these websites, we have purchased material from the lowest price seller to our knowledge.

5.3 Comparison on The Basis of Ease of Application

The comparison of ease of application the materials in consideration is done on the basis of our experience during the experiment.

One-way solar reflective film: Easily applicable.
Vinyl car sticker: Easily applicable.
Mirror wall sticker: Easily applicable.
Aluminum 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.

VI CONCLUSION

1. From the first experiment to find the best material on the basis of its reflectiveness we find that "Vinyl car sticker" and "Mirror wall sticker" have performed almost equally well with relative reflectiveness of about 1.8 and are the best performers.
2. When compared on the basis of cost we find that "Aluminum foil tape" has lowest price per square meter.
3. Finally, when compared on the ease of application of the material. We can say that all three materials except "Aluminium foil tape" were easy to apply. On the other hand, it was very difficult to handle "Aluminium foil tape" and fair amount of tape was wasted due to crease formation.

Although cost of aluminium foil tape is lowest compared to other materials but it is the worst performer when reflectivity is considered among other materials. Giving preference to reflectiveness over cost we find that "Vinyl car wrapper" and "Mirror wall sticker" has performed almost equally in reflectiveness test and are about 1.8 times better than "Aluminium foil tape". Since cost of the "Vinyl car sticker" is considerably lower per square meter. We can say that "Vinyl car sticker" is the most suitable material among the four commonly used reflective materials used for making parabolic solar cooker for domestic and experiment purpose which can be easily found in the market. On the other hand, Aluminium foil, which is widely used as reflective material for making of solar concentrators is worst among the all four materials tested.

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