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Theoretical Model Computations for Different Components of a Hot Box Type Solar Cooker Fabricated using polymeric and recyclable Materials

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***Abstract*— *Many countries having tremendous solar potentials are also the victim of the power crises since the available solar energy is not utilized efficiently. It has been recognized that the widespread use of solar thermal appliances (STA) for domestic work is being held back by excessive cost, low efficiency, high weight, and inconvenience of user and by lack of confidence in the long term durability of the material. In the present work, the limitations of materials used in various components of commercial available STA have been underlined and it has been shown that use of polymeric materials as specific component in solar thermal appliances can solve most of the existing limitations and may improve the efficiency of the existing appliances. In this paper theoretical model computations have been done for different components of a hot-box type solar cooker viz., glaze, insulation and casing material for the spectral transmittance, the solar flux absorbed and the optical efficiency, thermal efficiency, heat loses, weight, thermal profile and adjusted cooking power for several suitable materials, both conventional as well as new polymeric materials. Significant improvement in all the mentioned characteristic properties /figures of merit of the solar cooker can be achieved if right combination of polymeric materials is used in making glaze, insulation and casing. The present study offers that component improvements of a system results into cost reduction, extended lifetime and makes system easy to handle. This shall surely help in popularization of the solar appliances and enhancement of eco-friendly environment.*

Keywords*— *Solar Cooker, recyclable Materials, solar thermal appliances.

I. INTRODUCTION

In the current scenario of rapidly growing power crises, environmental pollution and ecological imbalances; the search of efficient and clean cooking fuel has become mandatory for the energy scientists. At present, the materials used in solar cooker are glass, metal or alloy which make them bulky, heavy, fragile, expensive, difficult to transport etc. Research work done during last decade about correlation in structure and properties of polymeric materials as well as development and study of light weight, low cost, portable solar cookers reveals that *some polymeric materials may prove to be highly promising candidates for improving most of the limitations of solar thermal appliances.* The selection of efficient materials for various components of a solar cooker is extremely important for the efficient use of the solar power. In literature several materials have been suggested for glaze viz. glass, acrylics, polycarbonate (PC), coated glass reinforced polyester (GRP), poly vinyl fluoride (PVF). In the present paper only three glaze materials- glass, polycarbonate (PC) and poly (methyl methacrylate) (PMMA)) have been considered. The most important attribute to justify the suitability of these materials for glaze option is transmittance and thus theoretical formalism for this has been done. The transmittance variations have been depicted for double glaze of each selected material. Besides this certain generally used insulation materials in the Solar Cooker have been selected for a comparative study.

II. DESIRED PROPERTIES OF MATERIALS OF VARIOUS COMPONENTS OF SOLAR COOKER

A solar cooker usually consists of the following components:-

(i) **Glaze**, which may be one or more sheets of glass or some other diathermanous material.

(ii)**Tubes**, fines or passage for conducting or directing the heat transfer fluid from the inlet to the outlet or containers to keep food load on absorber tray in case of solar cooker..

(iii)**Absorber plate**, which may be flat, corrugated or grooved with tubes, fines or passages attached to it.

(iv)**Insulation**, which minimizes heat loss from the back and sides of collector.

(v) Housing or **casing**, which surrounds the various components and protects them from dust, moisture etc.

(vi) **Concentrator**, focusing or non focusing type, which increases optical efficiency of absorber by directing large area radiation on small absorber area.

Materials of the transparent cover (glaze):- The work of a glaze is to transmit maximum solar energy to the absorber plate; to minimize upward heat losses from the absorber plate to the environment and to shield the absorber plate from direct exposure to weathering. In this context the properties required for glaze material cover are high transmittance for visible light and opacity to infrared and long wavelength radiations; poor thermal conductivity, high specific heat, low emissivity in the thermal radiation region. It should also posses' durability, which includes resistance to degradation due to ultraviolet radiations, moisture penetration, corrosion due to pollutants in the atmosphere. Low coefficient of expansion, high melting or softening temperatures, good impact strength, good scratch resistance and light weight are also desirable.

These considerations make glass a contender because it is inorganic, indicating a minimum effect from aging. In addition, glass is readily available from a very competitive market which should result in a minimum cost product. So far invariably glass glazes are used in solar thermal appliances. However, glass has some serious limitations such as relatively high brittleness and density which worsens the solar collector's unit weight index high density, and potential difficulties in fabricating very large think panels that might have to be covered or have a complex cross section such as in the linear fresnel lens. Presently, efforts are made to replace it by other suitable substitute. Polymers like PC, PTFE and PMMA are good candidates for this purpose. Of these polymeric materials, polymethyl methacrylate (PMMA) may prove to be very promising candidate as it has extraordinarily resistant to oxidative photodegraduation, there being no damaging u.v. absorption in the pure polymer down to 0.285μm.In addition to its good aging and optical characteristics, it is also adaptable to diverse processing techniques such as casting, extrusion, modeling the thermoforming. Therefore it is necessary to undertake research and experimental technological works on creating special plastics for the transparent covers of the collectors.

The insulation materials:- These materials should posses low thermal conductivity and must be heat resistant briefly to 180 C and for a long time to 80 C. They must not release volatile substances when heated, should have low moisture absorption, should not release dust particles, and should have good durability and rigidity, low density, ecological clean production and the cost effective. Materials likes Polystyrene, polyurethane, glass wool, sawdust, rock wool, cotton wool are the common commercially used material for insulation We have also done a comparative study of various polymeric insulation materials and the commercial used ones. The study clearly establishes that polymeric insulation materials are far more superior.

*Casing:-*The choice of materials for the casing of a solar collector is determined by the requirements of structural strength and longevity under all types of atmospheric action over the course of the collector's operating life and also on technical aesthetics. Such materials can be GI sheets, aluminum alloys with protective anode coating, radiation – and cold-resistant plastics and a combination of corrugated cardboard and aluminum alloys. Surprisingly, corrugated cardboard shows very impressive performance as done by our group in designing low cost solar cooker.

However, for creating a collector at the modern technical level the materials should be selected with considerations of all of the requirements imposed, some polymeric materials may prove to be promising candidates if cost considerations may be relaxed.

III. PARAMETERS OF INTEREST IN SOLAR THERMAL APPLIANCES WHICH MAY BE IMPROVED BY USE OF POLYMERIC MATERIALS

For the trapping of solar radiation in the collector, proper glazing of the trap is required. The most important property required for glaze material is high transmittance. Through a theoretical formalism of transmittance for glaze, a quantitative study has been done. The theoretical formalism is as follow:

In transient state of a STA the flux S absorbed by the collector plate can be written as:

$$S = I_b r_b\,(\tau\alpha)_b + \{I_d r_d + (I_b + I_d) r_r\}\,(\tau\alpha)_d \qquad (1)$$

and at any time the flux incident on a surface is given by:

$$I_s = I_b r_b + I_d r_d + (I_b + I_d) r_r \qquad (2)$$

where I_b is the beam radiation, I_d is the diffuse radiation, r_b, r_d are the tilt factors for beam and diffuse radiation respectively, and r_r is the radiation shape factor for a tilted surface with respect to the sky. For the horizontal upper

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glaze the value of r_b, r_d and r_r are found to be 1, 1 and 0, respectively.

In equation 1, τ is the transmissivity of the glaze material, α is the absorptivity of the collector plate, $(\tau\alpha)_b$ and $(\tau\alpha)_d$ are the transmissivity-absorptivity product for beam and diffuse radiation falling on the collector, respectively.

The overall transmissivity 'τ' of a transparent cover is given by:

$$\tau = \tau_r \tau_a \tag{3}$$

where τ_r is the transmissivity obtained by considering only reflection and refraction, τ_a is the transmissivity obtained by considering absorption.

$$\tau_r = \frac{1}{2}(\tau_{rI} + \tau_{rII}) \tag{4}$$

$$\tau_{rI} = \frac{1-\rho_I}{1+(2M-1)\rho_I} \tag{5}$$

$$\tau_{rII} = \frac{1-\rho_{II}}{1+(2M-1)\rho_{II}} \tag{6}$$

where τ_{rI} and τ_{rII} are transmissvities of the two components of polarization and M is the number of covers, which governs effect of number of covers on τr. ρI and ρII are the reflectivities of the two components of polarization and θi and θr are the angle of incidence and refraction, respectively, at the upper glaze surface. The direction of the incident and refracted beams are related to each other by Snell's law in which the refractive indices of the two media n1, n2 are related.

The transmissivity based the on absorption is given by:

$$\tau_a = \exp\left|KM\delta_c / \cos\theta_r\right| \tag{7}$$

where extinction coefficient K is a property of the cover material, M is the number of covers, δ_c is the thickness of the cover material and θ_r is the angle of refraction.

Further the optical efficiency of the trap of a STA is given as:

$$\eta = \frac{S}{I_s} \tag{8}$$

where S and I_s are defined in equation(1) and (2), respectively.

In most of the solar thermal appliances good insulation is mandatory to prevent the transmission of heat from inner part of the trap to outside environment. A study of different insulation materials has been done on the basis of (i) thermal conductivity (ii) density (iii) service temperature (iv) weather-ability and (v) cost. The heat transfer coefficient (U) value is a most powerful parameter for the comparison between different insulation materials. The U (heat transfer coefficient)-value of a flat insulation material, assuming the flow of heat transfer to be one dimensional and steady, and neglecting the convective resistance, can be computed by the following expression :

$$U = \frac{k}{L} \tag{9}$$

where L and k are thickness and thermal conductivity of the insulation material, respectively. As the thickness of insulation differs between 40 to 60 mm in most solar cookers, a common thickness of 50 mm the U-values of selected insulation materials are calculated.

IV. DISCUSSION OF RESULTS

Following results can be inferred from the theoretical model calculations done for the above mentioned characteristic properties:-

From study it is quite evident that transmittance based on absorption (□a)is almost independent of angle of incidence whereas that based on reflection refraction(□r) is a sensitive for of angle of incidence. It can be clearly seen in fig1 that the total transmittance (□) decreases with angle of incidence sharply beyond incident angle 50º. This is major reason for decrease in efficiency of Solar Thermal Appliances during winter. Thermal characteristics of glaze material play a crucial role in deciding the top heat losses and availability of solar radiation into the solar appliance.

Since we generally use double glaze illustrative number for total transmittance for different glazes are given in fig 1. It can be seen from this table that transmittance at all angle remain higher in order for PTFE, PMMA, PC and glass. All the polymeric materials studied here are more transparent than glass. From fig 2 it can be found that the total flux absorbed S for polymeric material glazes remain 10-13% higher than that for glass glaze. This aspect is also reflected in figure whereas spectral transmittance of PMMA and glass are shown. The comparative study of glass and transparent polymeric materials clearly establishes that polymeric glazes are far more superior to glass glaze on the basis of both, weight index as well as optical efficiency. Although conductive losses through top are small, these can be made negligible by the use of extruded polymer and designing glaze such that thickness of sheet remains perpendicular to the draw direction.

Similarly from table1 it can be inferred easily that PS expanded insulation is good enough to be used in solar cookers. Table 2 indicates that by just replacing glass glaze by PMMA glaze, 50% reduction in weight can be obtained. Interestingly if plastic material is used for casing also the thickness of insulation may be decreased considerably for small bottom loss. In fact a major component of cost of solar appliances is due to insulation. Thus reduction insulation thickness would decrease cost

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considerably and would make appliance economically viable. Similarly the combination F and B, listed in table 3 and which are of polymeric materials are used for casing and insulation, the weight as well as bottom loss coefficients are significantly reduced. In Table 4 Comparison of total body weight of commercial available solar cooker and novel design light weight solar cooker has been done The study confirms that the overall body weight of the LSC designed using polymeric materials is significantly less than the commercially available solar cooker. This reduction in weight will ease the small scale and large scale transportation.

To further stress on the superiority of LSC (low weight low cost solar cooker) designed using polymeric material and light weight insulation, a comparison of thermal profile of LSC and CSC is shown in Figure 4. This is a representative temperature profile of solar cooker with bare plate with reflector. The initial rise is higher in case of LSC which is enough for two meal cooking. It clearly indicates that optical efficiency with acrylic plate is much better than CSC.An important parameter of solar cookers is the adjusted cooking power is shown in Figure5 . The adjusted cooking power of LSC obtained is higher than the reported ones.[Funk P.A(2000).] In the fig 5 where comparision of adjusted cooking power of LSC and CSC with excess of temperature is shown, the slope of LSC are less than CSC indicating better cooking performance of LSC .

It can be concluded that selection of suitanble polymeric material for each components of solar cooker would lead to its significant improvemnt and popularity.

REFERENCE

[1] Lenel U R & Mudd P R, *Sol. Energy*, 32 (1984) 109.
[2] Mcqueen H J, Shapiro M M & Feldman D, *J Matls Energy Systems*, 2 (1980) 65.
[3] Hommam P S, Hilleargy & Darnall K R, *Solar Heating Materials Handbook*, Anachem, (1981).
[4] Sexena A, Varun, Pandey S P & Srivastav G, *Renew Sust Energ Rev*, 15 (2011) 3301.
[5] Garg H P & Rani U, *Sol Energy*, 29 (1982) 467.
[6] Nahar N M, *Energy Convers Mgmt*, 23 (1983) 91.
[7] Jubran B A & Alsaad M A, *Energy Convers Mgmt*, 32 (1991) 223.
[8] Nahar N M, *Renew Energ*, 23 (2001) 167.
[9] Nandwani S S, *Renew Energ*, 32 (2007) 427.
[10] Kumar S, *Renew Energ*, 30 (2008) 1117.
[11] Harmim A, Belhamel M, Boukar M & Amar M , *Energy*, 35 (2010) 3799.
[12] Sengar N, Dashora P & Mahavar S, Indian J Sci Technol, 3 (2010), 1038.
[13] Dashora,P., Bafna M, Bhargava A, *2007* Synthesis of PMMA sheets from regenerated monomer and their characterization for use as glaze in solar appliances, in Journal of solar energy society of india, 16(1), 33-43, (2007).
[14] Sukhatme S P, Solar Energy: *Principles of Thermal Collection and Storage*, Tata McGraw-Hill Book Co. (2007)
[15] Goswami D Y, Kreith F & Kreider J F, *Principle of solar engineering*, Taylor & Francis, USA, (2000).
[16] Minal B, *A Study of Thermal Properties of Potential Polymeric Materials and their use in Solar Thermal Appliances*, Thesis , University of Rajasthan, Jaipur, (2009)

Table.1: Comparison of the heat loss for different insulation material,, with different thickness of insulation materials and no. of glaze = 2

Insulation material	thermal conductivity (□) W/mK	heat loss in (W/m^{2}K) when thickness (m) of insulation is used		
		0.04	0.05	0.1
Sawdust	0.08	2	1.6	0.8
Polywool	0.065	1.625	1.3	0.65
rock wool	0.045	1.125	0.9	0.45
Glass wool	0.04	1	0.8	0.4
PS expanded	0.03	0.75	0.6	0.3
Cotton Wool	0.029	0.725	0.58	0.29

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Table.2: Comparison of weight between different glaze material when no. of glaze = 2

Material	Density (g/cm^3)	Weight of single glaze (kg)	Weight of double glaze (kg)
Glass	2.235	1.67	3.34
PTFE	2.3	1.72	3.44
PC	1.2	0.9	1.8
PMMA	1.19	0.89	1.78

Table.3: Model calculation of weight of the combination of materials for casing and insulation

Combination of materials selected	Casing				insulation				Weight of combination (kg)	Bottom loss coefficient for combination (W/m^2K)
	Material	thickness (mm)	density (gcm^{-3})	λ W/mK	Material	thickness (cm)	density (gcm^{-3})	λ W/mK		
A	Aluminium	2	2.7	235	Glass wool	5	0.024	0.04	2.97	0.769
B	PMMA	3	1.18	0.282	PS expanded	5	0.012	0.03	1.863	0.512
C	PMMA	3	1.18	0.282	Felt	5	0.5	0.04	12.84	0.755
D	PMMA	3	1.18	0.282	Poly wool	5	0.02	0.065	2.04	0.997
E	GI sheet	0.5	7.85	71.8	Glass wool	5	0.024	0.04	2.3	0.792
F	Corrugated Card board		0.085 g/cm^2	0.21	PS expanded	5	0.012	0.03	0.652	0.525

Table.4: Comparision of Overall body weight of CSC and LSC

Component	Material used in CSC	Weight of component (kg)	Material used in LSC	Weight of component (kg)
Casing	GI sheet (.5mm)	1.98	Corrugated cardboard	0.38
Glaze (Double)	Toughened glass (4 mm)	2.62	PMMA (3mm)	1.16
Insulation	Felt (5 cm)	4.02	PS Expanded (10 cm) & 1 layer of Cor.Crd. brd.	0.96
Reflector	Plain glass (4mm)	1.45	PMMA (4mm)	0.77
Accessories		3		1.5
Total weight		≈ 13		≈ 4.8

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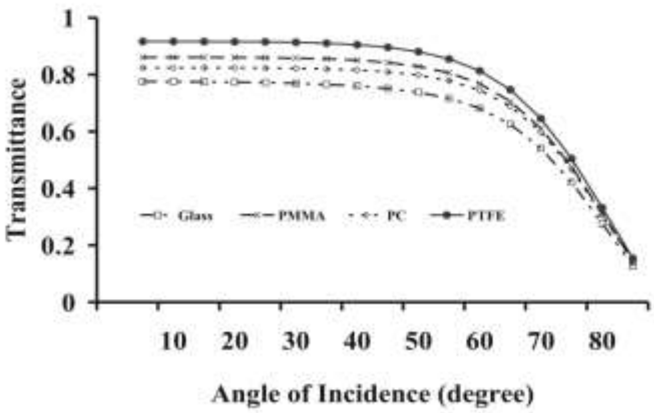

Fig.1: Curves for total transmittance of beam radiation for (———)PTFE,

(¯ ¯ ¯ ¯) PMMA , (------) PC and (— ¯ ¯ ¯ —)glass when number of glaze = 2.□□$_a$ is transmittance due to absorbtance, □$_r$ is transmittance due to reflection-refraction, □ =□□□$_a$ ×□□$_r$ is total transmittance

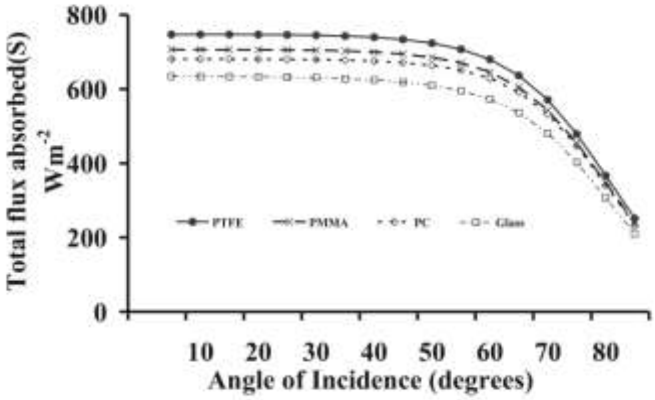

Fig.2: Comparison of total flux absorbed (S) for (———)PTFE,

(¯ ¯ ¯ ¯) PMMA , (------) PC and (— ¯ ¯ ¯ —)glass, when number of glaze = 2

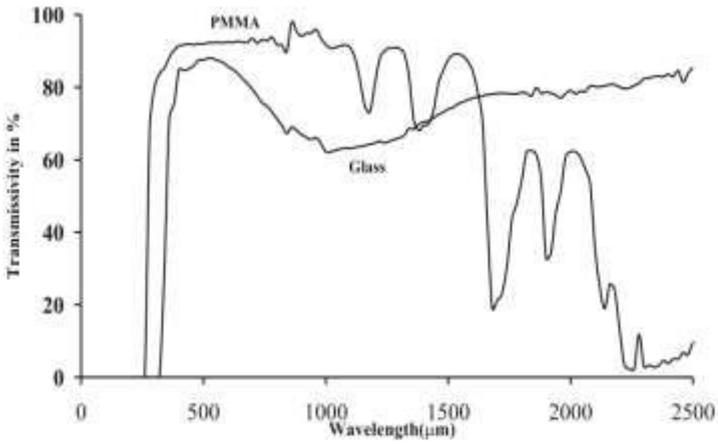

Fig.3: Transmittance of the commercially available toughened glass and PMMA over the entire solar spectrum.

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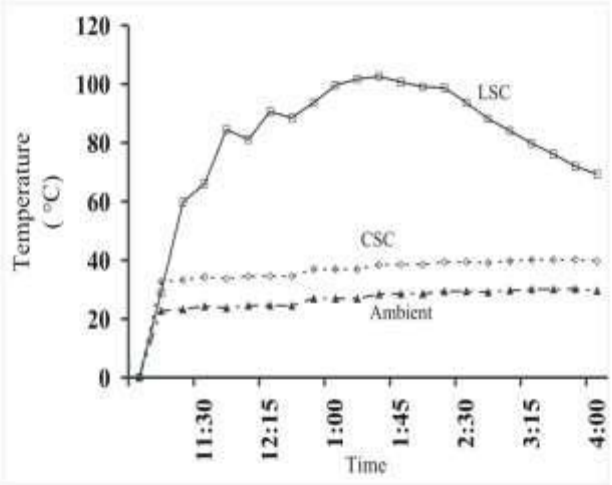

Fig.4: A comparison of thermal profile for CSC and LSC

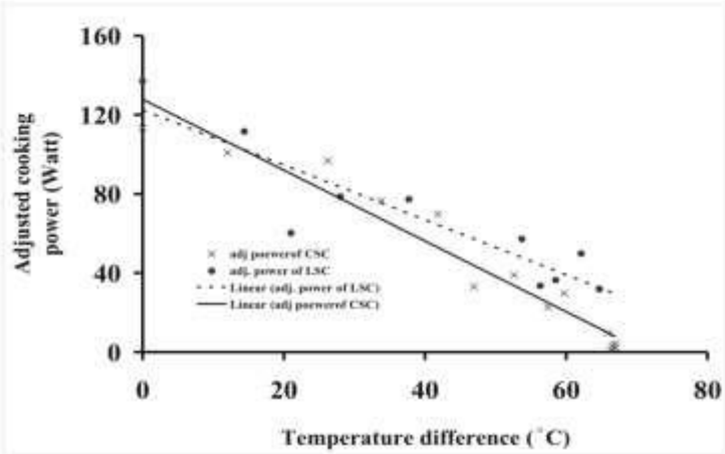

Fig. 5: A comparison of cooking power curves for CSC and LSC