RESEARCH ARTICLE OPEN ACCESS

Optimization of Thermal Performance of Solar radiation for Optimum Geometrical Shape of Box Type Solar Cooker

Jatin Shringi*, Dharmendra Kumar Jain**
* (Post-Graduate Student, Department of Thermal Engineering, Career Point University Kota, India)
** (Assistant Professer and Guide, Départment of Thermal Engineering, Kota, India)

ABSTRACT
The objective of paper is to carry out the study of optimization of thermal performance of solar radiation for optimum geometrical shape of a box type solar cooker. The study involves fabrication of different geometries for on field evaluation in region. In observation temperature profiles are plotted against equal time intervals and then figure of merit is calculated. In solar cooking heat transfer modes i.e. conduction, convection and radiation plays a dominant role. The solar technologies for cooking are highly useful in developing countries like India which is enriched with sunshine. The results show that trapezoidal shape is better than other geometrical shapes made and the information will likely impact on design of future solar cookers.
Keywords – Box type solar cooker, figure of merit, geometrical shapes, heat transfer, temperature Profiles

I. INTRODUCTION

The solar radiation in India is 5 to 7 KWh/m^2 for 300 to 330 days in a year. Solar cooking presents an alternative energy source for cooking. It is simple, safe and convenient way to cook food without consuming fuels, heating up the kitchen and polluting the environment. Solar cookers have an advantage on health, time and income of the users and on the environment. In tropical countries like India the solar energy have widespread scope and therefore it becomes reliable and sustainable source of energy. [1]

II. PRINCIPLES OF OPERATION OF SOLAR COOKER

The principle of solar cooking is that rays of sun are converted to heat and conducted into the cooking pot. The ability of a solar cooker to collect sunlight is directly related to the projected area of the collector perpendicular to the incident radiation. In this regard, the geometric concentration ratio is defined as

$$CR = A_t/Ar_c \qquad (1)$$

Where A_t is the total collector area and Ar_c is the area of the receiver/absorber surface. In the case of the simple box with no reflectors, The energy entering the aperture can be given simply as:

$$Qc = Ap\ \tau g\ I \qquad (2)$$

Where Aa is the area of the surface of glazing material facing the sun (assumed perpendicular), τg is the transmissivity of the glazing material, and I is the value of the global solar radiation perpendicular to the collector. Equation (2) assumes that the collector is normal to the incident radiation. The variation of the apparent area of the collector with the angle of the sun is given by equation (3).

$$Aap = Ap \cos(\theta) \cos(\varphi) \qquad (3)$$

Where Aap is the apparent area of the collector; Ap is the area of the collector assuming the solar radiation is perpendicular to the surface; θ is the solar azimuth angle, and φ is the difference between the solar elevation angle and the collector tilt angle. [2]

III. GEOMETRICAL DETAILS

The three geometrical shapes have been fabricate i.e. square, rectangle and trapezoidal with same aperture area of 40 cm.The boxes are made of 2.5 cm bamboo commercial plywood sheet at base as they have good absorbing property, walls of cooker is made of commercial plywood of 2.5 cm, 4mm glass, aluminum as a reflector (no reflector mirror is used), insulating material. The box and cooking pot are painted black inside and outside for better capture of Insolation. Walls of square and rectangular type cooker is straight i.e. 0 degree and trapezoidal have inclined walls as standard angle 45 degree. The rim system is made to stable a glass on the walls of cooker and the glass is open through vacuumed rubber arrangement.

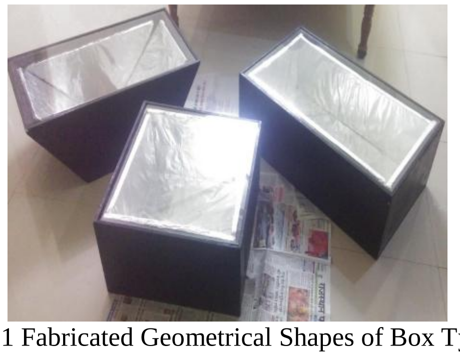

Fig.1 Fabricated Geometrical Shapes of Box Type Solar Cooker

IV. ON FIELD STUDY

Thermal Performance

For studying the thermal performance of the cookers the on field study is done. The cookers were placed in Sun and observations have been taken. During the experiment, the cookers were loaded with water in containers. The diameter of a container is 16.5 cm. The containers are filled with 1700 ml of water in total as per the bureau of standards during the experiment. The temperature profiles of the base plate and the water loaded in the containers have been recorded through the thermocouples and digital temperature indicator. The ambient temperatures have also been noted down. One similar container is kept outside with 850 ml of water. Though the observations have been taken for various days, here one representative observation is presented. The temperature profiles for the water corresponding to the cookers have been shown in Fig 2-3.

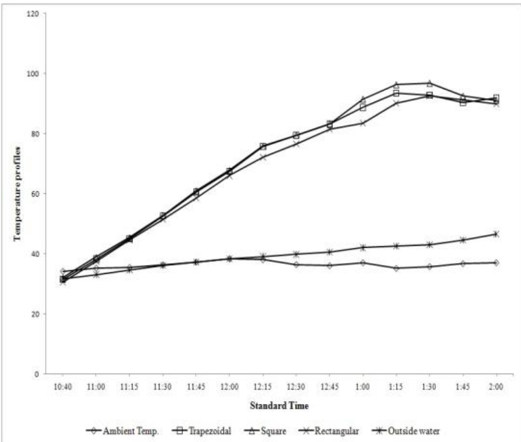

Fig .2 Temperature Profile (i)

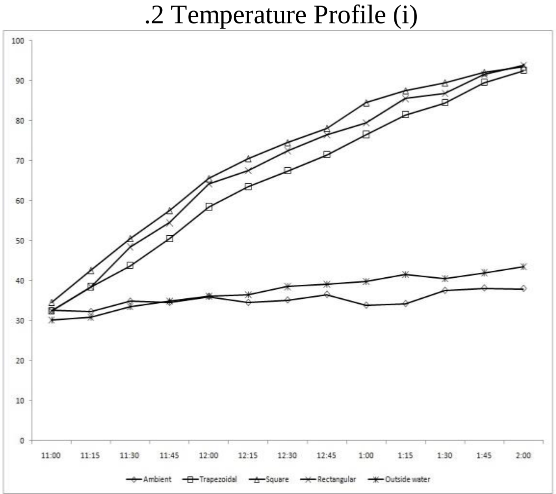

Fig.3 Temperature Profile (ii)

Figures of Merit

For the evaluation of the thermal performance of the solar cookers and to compare and quantify the performance of the different solar cookers, test procedures have been described by the Bureau of Indian Standards [10-11] which have been further revised [12].The first test is a stagnation test without load and through it the first figure of merit is obtained. The second test involves the sensible heating of full load of water (8 kg/sq.m.) in the containers and through this test the second figure of merit is obtained.

The first figure of merit (F_1) for thermal performance of the solar cookers is the ratio of the optical efficiency to the heat loss factor. It is mathematically defined as

$$F_1 = \frac{T_{ps} - T_{as}}{H_s} \quad (1)$$

Where T_{ps} is the plate stagnation temperature (°C), T_{as} is the ambient temperature at stagnation (°C) and $H_s$is the solar insolation at stagnation (W/m^2).The second figure of merit (F_2) takes into account the heat exchange efficiency of cookers and is obtained through the sensible heating test of specified load of water. The second figure of merit is evaluated through the following relation

$$F_2 = \frac{F_1 (MC)_w}{A\tau_m} ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{H}\right)} \right] \quad (2)$$

where F_1 is the first figure of merit, $(MC)_w$ is the heat capacity of the water in the containers, τ is the measured time for the sensible heating of water between the two known temperatures T_{w1} and T_{w2} of water, $T_a$is the average ambient temperature over the time period τ_m and H is the average insolation over the horizontal surface for the time period τ_m.

The value of the first figure of merit F_1should be equal to or greater than 0.12 as per the BIS standards for the efficient working of the cooker. The minimum required value of F_2should be 0.4 for cookers loaded with all the pots. The standard load of water for the full load test has been specified as 8 kg of water equally distributed in the pots per square metre aperture area. The water to be loaded in the pots should be at the ambient temperature and the values of $T_{w1}$and T_{w2} have been fixed at 60°C and 90°C respectively. The average figures of merit for the boxes have been found to be as: Trapezoidal F_1=0.11, F_2 = 0.46; Square F_1=0.11, F_2 = 0.46; Rectangular F_1= 0.11, F_2 = 0.45, respectively.

V. RESULT AND DISCUSSION

The Fig. 2-3 present the experimental temperature profiles of the three systems. It can be seen that the temperature of the water kept in the square system is slightly more, followed by the trapezoidal and rectangular systems respectively.

The performance of all the three systems is almost same initially with slight change in the later period. This is expected as all the three systems are same in aperture area and total energy absorption, but the difference in later stage suggests that square and trapezoidal systems are better than the rectangular one.

The average value of the figure of merit F_1 is almost same for the three systems, whereas F_2 is higher for square and trapezoidal as compared to rectangular.

VI. CONCLUSION

For the study different geometrical shape of box type solar cooker is fabricated. A figure of merit is calculated and Temperature profiles are drawn with respect to equal time intervals. It is concluded that for improving the thermal performance of the cooker the inclined walls are preferable in fabrication of solar box type cooker due to inclination shadowing effect is less on cooking pot.

REFERENCES

[1] Bansal M, Saini RP, Khatod DK, Development of cooking sector in rural areas in India- A review, Renewable and Sustainable Energy Reviews,17, 2013, 44-53.

[2] Cuce, E., Cuce, P.M.: A comprehensive review on solar cookers. Applied. Energy 102, 1399-1421,.

[3] Mahavar, S., Sengar, N., Rajawat, P., Verma, M., Dashora, P.: Design development and performance studies of a novel single family solar cooker. Renewable Energy; 2012, 47, 67-76.

[4] Rao AVN, Rao TLS, Subramanyam S, Mirror boosters for solar cookers-III, Energy Converse Mgmt 1991,32, 51-58.

[5] C Z M Kimambo, development and performance of solar cooker. August 2007, Journal of Energy in southern Africa, Vol 18 N,.

[6] NaharN.M, “Design Development and Testing of a Double Reflector Hot Box Solar Cooker with Transparent Insulation Material”. Renewable Energy, Elsevier, Amsterdam, vol. 23, 2001, pp. 167-179.

[7] Eardem Cuce, Pinar Mert Cuce, A Comprehensive review on solar cookers, Applied Energy 102 (2013)1399-1421.

[8] John A. Duffie, William A. Beckman, Solar Engineering of Thermal Processes, Wiley – interscience publication.

[9] Sukhatme SP. Solar Energy: Principles of Thermal Collection and Storage. New Delhi: 1996 Tata McGraw Hill.

[10] Bureau of Indian Standards (BIS) IS 13429:1992.

[11] Mullick SC, Kandpal TC and Saxena AK, Thermal Test Procedure for Box Type Solar Cookers. 1987 Solar Energy 39(4), 353-360,.

[12] Mullick SC (2002) Evaluation of Solar Cooker Performance – An Overview. In: Proceedings. of International Conference on Recent Advances in Solar Energy Conversion Systems (eds. Nema RK and Bhagoria JL), pp. 45-47. MANIT, Bhopal.

[13] Namrata Sengar and Sachin Jain, A Comparative and Experimental study of Hot Box Solar Cooker, 2015 International Journal of Science, environment and technology. Vol 4.

[14] Abhishek Saxena, Varun, S.P.Pandey, G.Srivastav, A thermodynamic review on solar cooker, (2011), Renewable and sustainable energy Reviews 15