Solar Cooker Carbon Mitigation Potential and Load Capacity: Identification, Analysis, and Utility of the Objective Parameters Derivable from Cooker Opto-Thermal Ratio (COR)

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ABSTRACT

Thermal performance parameters (TPPs) are used to rate the thermal performance of a solar cooker by researchers/developers and the objective parameters (OPs) to assist in the evaluation of the utility a solar cooker by users. Few researchers have utilised the correlation between TPP and OPs to facilitate the end users' decision-making with regard to the utility of a cooker for the intended purpose of successfully and satisfactorily completing cooking. In this review paper, some of the performance parameters and the related test procedures have been reviewed. Further an attempt has been made to identify and propose some new and useful objective parameters such as solar cooker load capacity (m_{max}) and solar cooker carbon mitigation potential (m_{CO2}), which will help the user in deciding about the load capacity (specific mass) limit and quantifying its contribution as a clean cooking device (one of the goals of UN, SDG2015), respectively.

Keywords: Caron mitigation, Optimum load, Solar boxcooker

1 Introduction

Cooking requires a substantial quantity of energy and effort. About two-thirds of the total energy is used for cooking in developing nations [1]. At the same time the lack of access to clean cooking for about one-third of the world's population results in the premature deaths of 4.3 million people each year as a result of indoor air pollution attributed to the burning of commercial fuels [2]. Also, with commercial cooking fuels becoming more expensive, supply-chain interruptions, and the resulting energy security and environmental sustainability issues, the use of solar cookers offers a viable solution. Solar cooking is one of the most practical and appealing possibilities for a healthy, environmentally friendly method of cooking [3]. In addition to being renewable, the sufficient availability of solar energy in most of the developing nations, including India, makes it a better choice for cooking energy [4]. Solar cookers contribute to a number of Sustainable Development Goals (SDGs) set by the United Nations, such as promoting clean energy, improving health, improving gender equality, combating climate change, and protecting natural resources. It is also in tune with the commitments made by India in COP 26 in the form of *Panchamrit*. All these will contribute to sustainable development and community welfare [5], [6].

In spite of substantial incremental improvements in the solar cookers of different types and designs and the aforementioned advantages; lower than expected propagation and adoption on a larger scale is a matter of concern. The limited adoption of solar cooking appears to be mainly due to the constraints of one design of existing cookers in different types of cooking, culture and culinary preferences, cooking time and capacity, and the communication gap between developers, researchers, and end users. Communication gaps are being tackle through interdependency of objectives. These constraints are being addressed and removed to a large extent by development of design hybrids and opting for a performance rating tool of these in the

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form of a single generalized TPPs and their correlation to OPs. TPPs are evaluating tools that are design-dependent, whereas OPs are need oriented and metrological factor-dependent tools. Figures of merit [7], standard cooking power [8], characteristic and specific boiling time [9], utilisable efficiency [10], effective concentration ratio [11] and cooker opto-thermal ratio (COR) [12] are a few TPPs; and maximum achievable temperature (T_{fx}), heat retention duration (τ_{hr}), and reference time (τ_r) [3] are OPs linked to thermal performance evaluation of major solar cookers (box type, concentrating type, and advanced type). COR is a generalized parameter which will be used herein to develop OPs as discussed ahead.

2 Methods of experimentation

2.1 Experimentation of COR

To determine COR, water was used as a standard load and loaded at 2.5 kg per square metre of cooker aperture area. The test load was put in a cylindrical shaped stainless steel cooking pot with a lid. The pot was coated with black paint. During the experiment, water temperature, solar insolation, and ambient temperature were measured using J-type thermocouple, solarimeter, and thermometer, respectively. The experiments were carried out around ± 90 min of the local solar noon [7], [11], [12] at the experimental location under the environmental conditions of $G_T \geq 700$ W/m^2; 20 °C ≤ T_a ≤ 40 °C and wind speed ≤ 1.5 m/s. Test procedure as reported in [3] was followed to conduct all the experiments.

Nomenclature

TPPs- Thermal performance parameters
Ops- Objective parameters
COR- Cooker Opto-thermal Ratio
η_0- Optical efficiency
U_L- Over all heat loss factor (W/ (m^2 °C))
T_a- Ambient temperature (°C)
M/m- Mass of load (Kg)
Cp- Specific heat capacity of load (J K^{-1} Kg^{-1})
(t_2-t_1)- Time interval during which water temperature rises from Tw1 to Tw2 (seconds)
Tw_1- initial water temperature (°C)
Tw_2- final water temperature (between 90-95°C)
$\bar{G}_T$- Average solar insolation during period of experimentation (W/m^2)

2.2 Determination of COR

Experimental value of tests performed were used to calculate $\dot{Q}''$ using eq. (1) [12] as follows:

$$\dot{Q}'' = \frac{(M_f C_{pf})'_f (T_{w2} - T_{w1})}{A_p \Delta T} \tag{1}$$

where $\dot{Q}''$is the rate of useful heat gain by the test load/fluid per unit cooker aperture area (A_p); $(M_f C_{pf})'_f$ is the sum of the heat capacities of the test load (in this case, water) and the cooking pot; T_{w1} and T_{w2} are the initial and final temperatures (fitted values) of the test load, respectively; and t is the time interval in seconds. Furthermore, these experimental data of cooker was used to plot exponential fit of temperature of the test load (T_w) vs. Time plot (fig.1) and the linear fit plot of $\dot{Q}''/\bar{G}_T$vs.$(T_{wm} - \bar{T}_a)/\bar{G}_T$(fig.2) From the linear plot of$\dot{Q}''/\bar{G}_T$ vs.$(T_{wm} - \bar{T}_a)/\bar{G}_T$set of two parameters, $F'\eta_o$and$F'U_L/C$ were calculated. Their ratio yields the value of COR for a solar cooker.

$$COR = \frac{F'\eta_o}{F'U_L/C} = \frac{\eta_o C}{U_L} \tag{2}$$

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where η_o is the optical efficiency, C is the concentration ratio and U_L is the overall heat loss factor of the test cooker.

2.3 Relation between COR and the OP maximum potential energy output

Experimentally derived value of COR is used to calculate one of the OP maximum achievable temperatures, T_{fmax} derivable from COR. It gives the maximum possible temperature that could be achieved for a typical solar cooker having a value of COR.

$$T_{fmax} = COR(\bar{G}_T) + \bar{T}_a \tag{3}$$

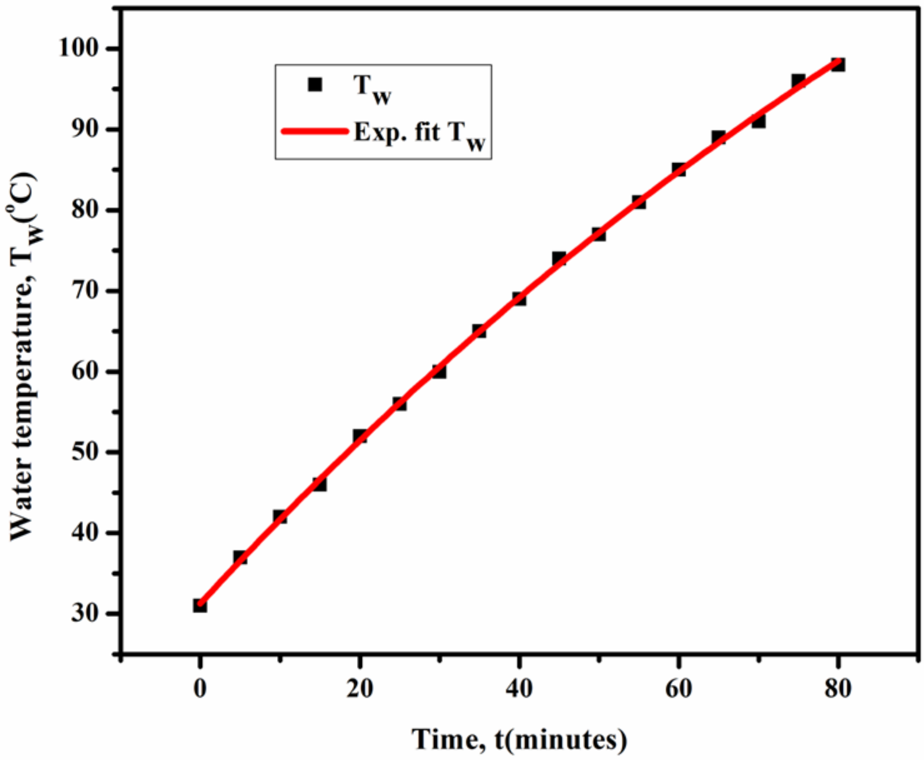

Figure1: *Plot of water temperature and time (the line is a least square fitted)*

Through the relationship of T_{fmax} and COR, the equation (4) for the maximum potential energy produced by the solar cooker is derived.

$$\dot{Q} = mc_p\bar{G}_T \times COR \tag{4}$$

Energy required for accomplishment of cooking per loading is calculated using this equation (eq.4) and typical value of COR, for given $\bar{G}_T$.

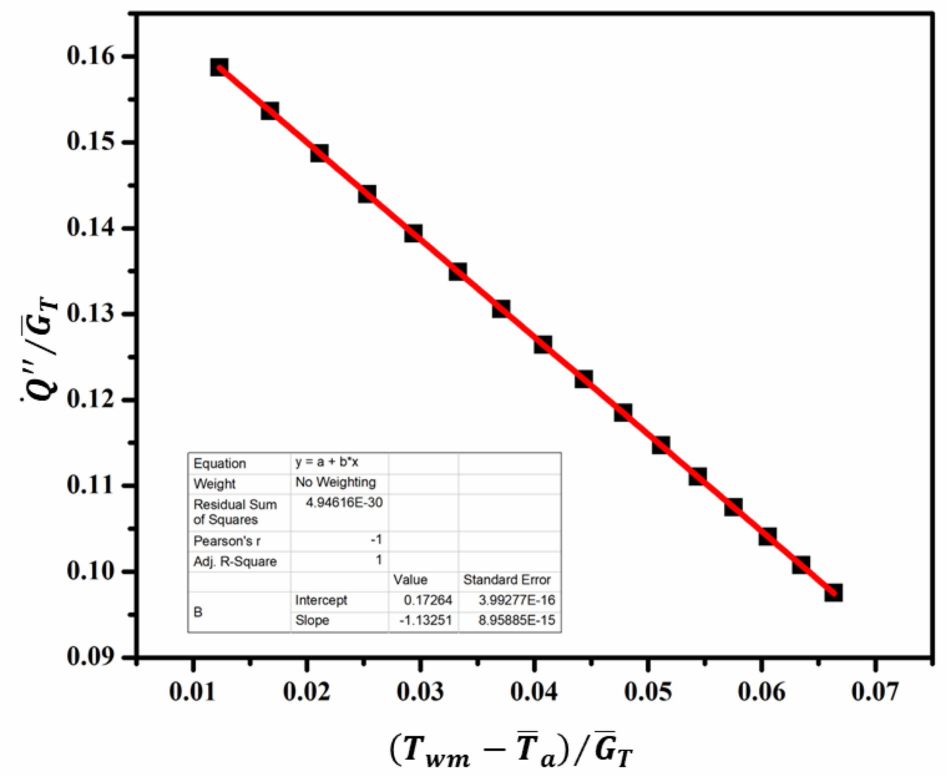

Figure 2: *Plot of* $\dot{Q}''/\bar{G}_T$vs.$(T_{wm} - \bar{T}_a)/\bar{G}_T$*(linear fit)*

3 Result and Discussion

3.1 Determination of carbon mitigation potential

To determine carbon mitigation potential of a solar cooker,the carbon dioxide emission in terms of oil equivalent to generate the required amount of energy (eq. (4)) is calculated using eq. (6). Carbon dioxide emission factor of 263.88kgCO_2 per MWh (oil) energy produced is taken for derivation [13] and COR=0.15, calculated experimentally has been taken for calculating mass of potential CO_2emission for different solar insolation in present case (Table 1).

$$m_{CO2} = \dot{Q} \times CO_2 \ emission \ factor \ of \ replacing \ fuel \tag{5}$$

$$m_{CO2} = mC_p\bar{G}_T \times COR \times CO_2 \ emission \ factor \ of \ replacing \ fuel \tag{6}$$

Table1: *Carbon mitigation potential for different solar insolation for testing cooker when replaces crude oil*

m(kg)	$\bar{G}_T$(W/m^2)	$mc_p\bar{G}_T \times COR$ (J°Cm^2/w^2)	Energy (MWh)	CO_2 Emission factor (oil) (kg/MWh)	m_{CO2} (kg)	m_{CO2}per month(kg)
0.9	800	455101.92	0.000126	263.88	0.034	1
0.9	900	511989.66	0.000142		0.037	1.11
0.9	1000	568877.40	0.000158		0.042	1.26

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0.9	1100	625765.14	0.000174		0.046	1.38

3.2 Determination of potential load capacity

A potential objective parameter has also been identified in the process and termedas "specific load capacity" (m_{CO2}). Once defined, the user will be able to select the optimal amount of food that can be cooked under ideal conditions. A theoretical attempt was made to realise it using COR-defined objective parameters such as heat retention duration and reference cooking time, but no desired result was found. To achieve the desired result, a combination of theoretical and experimental approaches is currently being developed. Somepositive results are anticipated in the near future.

4 Conclusions

A relationship between COR and amount of CO_2 emission saving for completion of cooking per loading has been established for calculation of carbon saving. It will help in determination of the carbon credit to be claimed under the specified condition.No direct relationship between τ_{hr} and time τ_r has been established. More of these OP's relationships are being studied theoretically and experimentally in order to optimise the load limit.

5 Declarations

5.1 Competing Interests

We, the authors hereby declare that there is no conflict of interest involved in this work.

5.2 Informed Consent

All the writers all well informed and have given their consent for publication.

5.3 Publisher's Note

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