

On-line recording of solar cooker use rate by a novel metering device: Prototype description and experimental verification of output data

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Abstract

A metering device for the determination of solar cooker use rate is presented. The device records food temperature, ambient temperature and irradiance. Automatic data evaluation yields the number of cooking cycles, cooking time, food “thermal mass”, as well as the impact on fuel consumption and GHG emission compared to other cooking techniques. Metering results are compared with actual conditions for box-type and concentrating solar cookers and found to be in agreement.

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1. Introduction

The amount of fuel saved by solar cooking in developing countries is still largely unknown. The mere fact that a household owns an energy saving cooking appliance does not allow any conclusions as to actual savings. The appliance has to be used in order to save fuel.

None of the current use rate monitoring methods work without the subjective participation of users and/or monitoring personnel. This limits the credibility of fuel saving figures, as the methodological discussion in the framework of the DME/BMZ/GTZ solar cooker field test in South Africa (GTZ and DME, 2002) has shown.

It would be interesting to have a mechanism through which actual use of fuel saving technologies such as solar cookers and heat retention devices can be monitored automatically, without the intervention of users or monitoring personnel. This information would be important for interested investors, manufacturers, distributors and users; it could also qualify these devices for the voluntary CDM market.

This paper presents prototype use meters for two solar cooker models (SunStove boxes and K10 concentrators), as well as a verification of the corresponding output data.

2. Use meter description

The Synopsis use meter (SUM) described here is an automatic recording and evaluation device for the use of solar cookers. Main outputs are use frequency, thermal

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mass of cooked food and cooking time. Results are cross-checked against cooker characteristics and environmental parameters.

In its present development stage, the SUM is a functional prototype, based on available components. Its purpose is the practical verification of the main functions. Improvements for future versions are discussed below.

The SUM prototype is based on a handheld 4-channel temperature data logger (Votcraft K204), measuring:

- ambient temperature via a shielded thermocouple sensor,
- pot bottom temperature as approximation of pot content temperature, via a specifically developed thermocouple set-up avoiding direct contact between sensor and food or fixed contact between pot and sensor,
- irradiance via a low-cost pyranometer-type temperature difference sensor, developed for this specific purpose.



Fig. 1. View of the SUM prototype for the K-10 cooker.

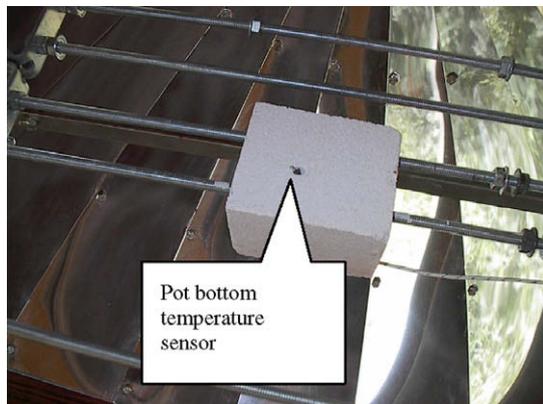


Fig. 2. The pot bottom sensor is protected against stray heat transfer.

Read-out and data evaluation take place with a laptop computer. Figs. 1 and 2 show the use meter for the K10 concentrating solar cooker.

3. Use rate indicators

For the determination of cooker use rate, the following parameters are used as indicators:

- Pot content temperature: this parameter defines when the cooking process sets in. The default value used here is 70 °C. The choice of this parameter is particularly important for cookers which reach boiling with difficulty – but which can however be used for cooking at sub-boiling temperatures.
- Pot content “thermal mass” (specific heat times mass), expressed in litre water equivalent; this parameter represents the amount of food prepared.

4. The determination of food mass and cooking time

In order to determine the quantity of food in the pot, the temperature rise ($T_{\text{final}} - T_{\text{initial}}$) can be related to the thermal energy input E_{th} to obtain the “thermal mass” (M_{th}) of the food in the pot, defined as mass times specific heat:

$$M_{\text{th}} = E_{\text{th}} / (T_{\text{final}} - T_{\text{initial}}) \quad (1)$$

The instantaneous thermal power $P_{\text{th}}(T)$ can be calculated by

$$P_{\text{th}}(T') = A * I * \eta(T') \quad (2)$$

with $T' = (T_{\text{pot}} - T_{\text{amb}}) / I$, T_{pot} the pot content temperature, T_{amb} ambient temperature, A the cooker aperture, I the irradiance, and $\eta(T')$ the linear collector efficiency:

$$\eta(T') = \eta_0 - K * T' \quad (3)$$

η_0 being the efficiency at ambient temperature, K the linear loss coefficient. Both η_0 and K are specifics of cooker models and can be measured directly with the use meter heating up a known quantity of water. Note that η_0 and K do not have to be measured for each individual cooker.

P_{th} can be determined by (2) and (3), and integrated to yield M_{th} by (1). The thermal mass is calculated for each one-minute interval, averages are formed for the temperature range between 50 and 70 °C. Unrealistically small or large values are discarded.

A correction is made for the thermal mass of cooker parts, in particular the pot. Typical values of pot thermal mass are situated between 0.1 l water eq (for small steel pots) and 0.3 litre water eq (for big Al pots).

To obtain the number of meal portions (MP) corresponding to the resulting M_{th} , the average thermal mass per MP is used, under the assumption that the main part of thermal mass in water based food is water. A field visit in the use region can determine the local average M_{th} per

MP by studying the food volume per capita and meal. The default value is 0.5 l water eq per MP.

In order to determine whether the food has actually been cooked, the time the food has been held above a minimum cooking temperature (default value 70 °C) is recorded and can be compared with typical conventional cooking times and temperatures.

5. Use meter output verification

To verify SUM results, output data were compared with actual conditions. The SUM was switched on; the cooker



Fig. 3. K10 (right) and SunStove (left) during use meter tests at Synopsis.

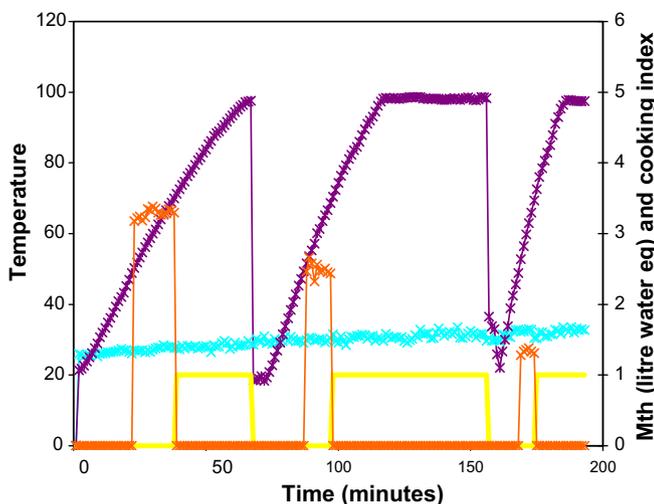


Fig. 4. SUM results for a K10 concentrating solar cooker: on the basis of measured pot bottom temperatures (violet), irradiance, and ambient temperature (light blue), SUM calculates instantaneous thermal mass (orange) and cooking index (yellow data points: 1 indicates cooking, 0 no cooking). The cooking time count is stopped when the temperature falls below an adjustable level (set here at 70 °C).

was exposed to the sun and loaded with a given quantity of water (controlled by an electronic scale). Single and multiple heat-up runs were recorded, with different loads and different tracking intervals, and under different environmental conditions. The experimental set-up is shown in Fig. 3.

Results (in terms of M_{th} , cooking time, number of successful cooking cycles) correspond to the actual cooking history. A result example is shown in Fig. 4: there were 3 heat-up cycles; the corresponding water masses were 3 l, 2 l and 1 l for the first, second and third heat-up cycle, respectively. Note that the calculated thermal masses correspond to water and pot (here, the pot thermal mass is 0.3 l water eq). With this correction, the precision in the determination of thermal mass for the K10 cooker is in the order of 10%.

6. Perspectives

The task of the solar cooker use meter prototypes presented here was the verification of the technical feasibility of the process. In order to become a widely distributed product, the use meter will need to be optimised for user friendliness, smaller size and lower cost. Dedicated components will have to replace the standard hardware which is presently employed. Handling will have to be improved at a later stage, when feed-back has shown the direction of changes to be made. Further perspectives include:

- Field testing of solar cookers fitted with use meters, with two different control groups, one without solar cookers and the other with solar cookers without user meters, in order to study the incitation effects of the use meter.
- Replacement of the handheld Thermologger by a dedicated low-cost device with fixed settings, without display, with start of the recording on “power on” by mini PV cells. In mass production, the meter could be based on a chip card.
- Wireless connection for meter read-out between logger and PC.
- Development of similar meters for other energy saving appliances. The use meter concept is not limited to solar cookers; it can be adapted to other fuel saving cooking appliances including heat retention cooking devices (“hot boxes”).

7. Conclusion

It can be concluded that the solar cooker use meter describes the actual cooking history in terms of quantity of food successfully cooked, allowing the assessment of fuel savings and GHG emission reduction, compared to other cooking options.

The validity of this conclusion should be checked for a wider variety of conditions.

Acknowledgement

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Appendix

Parameter values

Code	Value K10	Value SunStove	Explanation
S	0.79	0.34	Cooker aperture m ²
η_0	0.64	0.26	Cooker efficiency at ambient temperature
K	7.8	2.2	Cooker linear loss coefficient W/m ² K
T_{initial}	50	50	Start temperature for Mth evaluation
T_{final}	70	70	“Cooking” start temperature
M_{th} empty	0.3	0.1	Empty pot thermal mass litre water equivalent
M_{th} / MP	0.5	0.5	Thermal mass per meal portion

Reference

GTZ, DME, 2002. Solar Cooking Compendium, vol. 3: User acceptance. GTZ, Eschborn.