International Journal of Modern Trends in Engineering And Research
www.ijmter.com
e-ISSN No.:2349-9745, Date: 2-4 July, 2015

Development of Universal Test Standard for Concentrating Solar Cookers

Mahesh M. Rathore[1], Dr. Ravi M. Warkhedkar[2]

[1]Research Scholar, Dept of Mech. Engg. Govt. Engineering College Aurangabad, India,
[2]Department of Mechanical Engineering, Govt. College of Engineering, Karad, India,
Corresponding author: mmrathore@gmail.com

ABSTRACT . Different test standards are followed worldwide for testing of 'Solar Cookers'. Designs of solar cookers are evolving from low temperature solar panel cookers and ovens to high temperature solar concentrators. Most of the existing standards are developed for solar ovens. These test standards normally deliver technical information that may be useful only for the test centers. These test standards primarily report parameters like thermal efficiency; heating/cooling rates etc. under standard or normalized conditions. Concentrating solar cookers are gaining popularity because of their capability to deliver operations like frying, roasting and baking along with boiling. Also the cooking speeds are competing with conventional cook stoves. All these developments indicate that there is a need of designing different test standards for solar concentrating cookers.

Keywords: Solar Cooker Tests, Cooker Efficiency, cooking power, Standardization in Tests and Reporting.

Nomenclature

A_p = aperture area of dish concentrator, m^2
A_a = area of absorber surface, m^2
h_{fg} = enthalpy of vaporization of water, J/kg
I_{bn} = normal intensity of radiation, W/m^2
i_{av} = reference solar intensity, W/m^2
m_w = mass of water, kg
m_s = mass of steam, kg
Q_n = normalized useful energy rate, W
T_a = ambient temperature, °C
T_b = saturation temperature, °C

Greek symbols

η_{th} = Thermal efficiency of Concentrator
η_n = normalized efficiency of concentrator

I. INTRODUCTION

There are few test standards in use in different parts of the world for solar box cookers which are also termed as solar ovens. In solar ovens the pot is inside an insulated greenhouse and operating temperatures for cooking are low, mostly below 100°C for boiled food. When thermal performance tests are conducted for solar box cookers only sensible heat gain is recorded and used for calculations. This holds good as water does not change evaporate during the test period and even if it evaporates in small amount the steam condenses back inside the oven, releasing the latent heat. Hence all heat is still retained inside the insulated box. Losses because of radiation are negligible because of lower operating temperature as well as the fact that the cooking pot is inside the greenhouse which does arrests re-radiation from the cooking pot to atmosphere. Hence heat losses from the solar box cookers are primarily by way of conduction and to some extent convention. Conduction and convection losses are linear in nature and hence it is easy to establish performance characterization of solar box cookers. These test standards can also be applied for solar panel cookers as the pot in this case is also surrounded by greenhouse.

In case of concentrating solar cookers, the pot is exposed to atmosphere without a greenhouse. Such hot pot will have radiation losses in addition to convective losses. For this reason the loss characterization in case of concentrating solar cookers can't be treated as linear. Some quantity of water evaporates to steam that gets released to atmosphere. This steam takes away latent heat with it. As steam loss is because of latent heat gain, evaluating solar cooker performance only on sensible heat gain is not valid. For these two reasons authors recommend a separate test protocol for concentrating solar cookers.

II. REVIEW OF EXISTING TEST STANDARDS FOR CONCENTRATING COOKERS

A Draft of test procedure for testing of paraboloidal concentrating type solar cookers, had been laid down by center for energy studies of Indian Institute of Technology Delhi and Ministry of new and renewable energy, Government of India in 2006. This test protocol uses combination of test methods suggested by Mullick *et al.* [5] and further work done by Subodh Kumar *et al.* [9,10] in the area of heat losses due to reflector orientation and from the receiver of concentrator due to wind. This proposed test protocol was designed with the heating and cooling tests were recommended to evaluate characteristic performance parameters of the concentrator solar cooker. These parameters are, heat loss factor ($F'U_L$), optical efficiency factor ($F'\eta_o$), and standardized cooking power (P_s). Further, this test technique uses calculations for performance parameters in the sensible heating of working fluid that is transient heating mode and not in steady state. Such calculations lead to high error proneness.

Shaw [8] worked extensively to analyze the development of a comparative framework for evaluating the performance of solar cookers and compared test standards proposed by various researchers. He reported that no test standard protocol fulfill all the criteria that a user expects and for this reason he proposed a new standard that accounts for technical parameters like efficiency along with other parameters like reproducibility, understandability and objectivity. Kundapur and Sudhir [4] have also proposed new world standard for testing solar cookers which has consideration of nine parameters including ergonomics, cooking test, user interaction and cost.

Sardeshpande *et al.* [7] have developed a procedure to examine the performance of a 25 sqm solar concentrator. Their results appeared to be reasonable, consistent and satisfactory. Pillai *et al.*[6] have also used above procedure for evaluation performance of a Scheffler concentrator of 16 sqm and got realistic results. These both the trials were conducted with latent heat exchange only; not with sensible heat exchange.

III. PROPOSAL FOR TEST PROTOCOL

Proposed test standard deviates from conservative philosophy of recording heat gain in sensible heat regimes only. Instead authors propose a test protocol, that should use latent heat interactions as in most of practical situations. Latent heat exchange allows solar cooking at saturation temperature. At given pressure, the saturation temperature is constant; it makes sense to record it.

Further, it is recommended that the experimentation for evaluation of thermal performance must be carried out when sky is clear and solar radiation intensity I_{bn} is above 550 W/m^2 and average wind speed during test duration should be less than 3 m/sec.

Principle of operation

The proposed method is based on Latent heat gain by water to document performance of solar cooker near boiling point. As cooking is expected to be performed near boiling point of water, it makes sense to record and report performance near boiling point.

Test Setup

a. The proposed experimental setup consists of a 4 sqm. parabolide Scheffler Reflector dish fitted with anodised aluminium reflector as shown in Fig. 1. A mild steel structure supports the reflector dish. Its sun tracking mechanism is manual.
b. Eight kg of water in 25 litre cooker is heated for test. Mass of the water say $m_{w.}$
c. Pot is to be blackened from outside with blackboard paint. Mass of the pot and its lid is say m_p.
d. Put lid on the pot and weigh water on weighing machine and record composite weight. Weighing machine has least count of 1 gramme.
e. Remove the lid and put the pot with water on the solar cooker focus. Pot is open to atmosphere. Water level in the pot is kept at least 100 mm below the rim. This care is taken as during bubble burst and surface evaporation of water particles splashed should return back to the pot.
f. Record time, water temperature, ambient temperature, T_a, and normal beam radiation, I_{bn}, till the water reaches boiling point. I_{bn} should be recorded using solarimeter.
g. Track the solar cooker as and when required. Record time to boil in hours as T_{boil}.
h. As the water reaches boiling temperature, now put the lid on the pot and shift the pot on the weighing machine and again record composite weight of pot, water and lid together. Say this mass is m_1
i. Put the pot back on solar cooker and remove lid. Focus the solar cooker and track as and when required. Now take the test for one hour and again record composite weight of pot, water and lid together, after one hour. Say this weight is m_2

Calculations:

Actual mass of water evaporated during test period, $m_e = m_1 - m_2$ (1.1)

Heat gain, $Q_1 = m_e \times h_{fg}$ kJ (1.2)

Where h_{fg} is latent heat of evaporation for water at boiling point, in kJ/kg.

Calculate average of beam normal radiation over one hour test period as I_{bn}

Heat input, $$Q_1 = \frac{A_a \times I_{bn}}{1000} \times 3600\,\text{s/h} = 3.6 \times A_a \times I_{bn} \text{ kJ/h} \quad (1.3)$$

Where I_{bn} is average of beam normal radiation over one hour test period.

Now heat gain rate during test period, $Q_2 = m_e \times h_{fg}$ kJ/h (1.4)

Thermal efficiency during test period

$$\eta_{th} = \frac{\text{Heat gain rate}}{\text{Heat input rate}} = \frac{m_e \times h_{fg}}{3.6 I_a \times I_{bn}} \times 100 \quad (1.5)$$

Heat gain and losses for solar cooker depends on the difference of temperature of the load with ambient temperature as well as on I_{bn}. To report uniformity in tests in different regions and in different seasons with reference to ambient temperature and I_{bn} normalized values are to be reported. Authors recommend temperature difference of 75°C (boiling point around temperature 100°C & ambient temperature around 25°C) and I_{bn} of 700 Watts/sqm as standard operating conditions and all results are to be normalized to these values.

Normalised heat rate

$$Q_n = \frac{m_e \times h_{fg}}{3.6} \times \frac{(T_b - T_a)}{75} \times \frac{700}{I_{bn}} \text{ in watts} \quad (1.6)$$

Normalised Thermal efficiency

$$\eta_n = \frac{m_e \times h_{fg} \times 100}{3.6 A_a \times I_{bn}} \times \frac{(T_b - T_a)}{75} \times \frac{700}{I_{bn}} \quad (1.7)$$

Q_n and η_n are the most important parameters to be reported.

CONCLUSIONS

Proposed test standard provides useful information to be reported to all stakeholders. Thermal performance test provides important technical parameters which can be used for certification of the solar concentrating cookers. Q_n & η_n are the most important parameters to be reported. These normalized parameters will bring in uniformity for comparing different solar concentrating cookers tested at different test centers in different climatic conditions.

REFERENCES

[1]. ASTM International (2007), "Standard Test Method for Determining Thermal Performance of Tracking Concentrating Solar Collectors" Designation: E 905 – 87, Reapproved 2007, PP. 1-14

[2]. Centre of Energy Studies, Ministry of Non-conventional Energy Sources (2006), "Draft Test Procedure Solar Cooker – Paraboloid Concentrator Type" August 2006, PP. 1-12.

[3]. Chandak Ajay (2009), 'Apparatus For Testing Solar Concentrators' Patent application no 2377/MUM/2009. filed with Controller of Patents, Mumbai.

[4]. Kundapur Dr.Ashok , Prof. Sudhir C V, (2009), "Proposal for New World Standard for Testing Solar Cookers" PP 1-5

[5]. Mullick S.C., Kandpal T.C. and Subodh Kumar (1991), "Thermal Test Procedure for a Paraboloid Concentrator Solar Cooker", Solar Energy Volume 46, Issue 3, 1991, PP. 139-144.

[6]. Pillai Indu R., Chandak Ajay G., Sardeshpande Vishal and Somani Sunil K. (2010), "Methodology for Performance Evaluation of Fixed Focus Moving Solar Concentrators" World Renewable Energy Congress XI, 25-30 September 2010, Abu Dhabi, UAE, PP 1-6.

[7]. Sardeshpande Vishal R, Ajay G. Chandak, Indu R. Pillai (2011): Procedure for Thermal Performance Evaluation of Steam Generating Point-Focus Solar Concentrators. Solar Energy (2011), Volume 85, Issue 7, July 2011, Pages 1390-1398

[8]. Shaw Shawn (2006), "Development of a Comparative Framework for Evaluating the Performance of Solar Cooking Devices" Report PP 1-63.

[9]. Subodh Kumar, Kandpal T.C., Mullick S. C. (1994), "Effect of Wind on the Thermal Performance of a Paraboloid Concentrator Solar Cookers", Renewable Energy, Vol.4 No.3, 1994, PP. 333-337.