STM JOURNALS

International Journal of
Machine Systems and
Manufacturing Technology

Volume 2, Issue 1, 2024
January—June
DOI (Journal): 10.37591/IJMSMT

https://journals.stmjournals.com/ijmsmt

Research IJMSMT

Comparative Energy and Exergy Performance of Box-Type Solar Cookers Using Various Pot Materials

Harshita Swarnkar[1], Ritu Jain[2], Amit Tiwari[3,*]

Abstract

This research presents a laboratory study of a box-type solar cooker for two types of pot materials. Under the climate conditions of Jaipur, experiments were carried out on a standard box-type solar cooker using steel and aluminum vessels, either with or without a load. It is estimated what the merit figure (F1 and F2) is. The obtained F1 values show that the cooker, when used with steel and aluminum containers, is of A quality. Energy and exertion analysis is the basis for performance evaluation. The solar-powered cooker with aluminum vessels has a greater energy and effectiveness than the solar oven with titanium dishes.

Keywords: Solar cookers, first figure of merit F_1, second figure of merit F_2, energy and exergy efficiency

INTRODUCTION

A practical substitute for the fuel wood, kerosene, and other fuels that are customarily utilized in Ethiopia is the use of solar energy for cooking. It has been demonstrated that, when done correctly, solar cooking can be an effective mitigation technique for global climate change, deforestation, and the economic deprivation of the world's poorest people [1]. Of course, solar cookers cannot completely eliminate the usage of combust fuels. The disadvantage of solar collectors is that grilling must take place when and where the sun is shining. Despite this, solar collectors are not as commonly used as they could be because they depend upon a free, abundant, and renewable power source to transform solar radiation into heat [2–3]. Ethiopia relies more on fossil fuels to meet its energy needs since environmentally friendly energy technologies are less well-known and utilized there [4]. With more than 275 bright days annually, most poor nations, including Ethiopia, have global horizontal insolation in the range of 5-7 kWh/m2 [5]. Of all sustainable sources of energy, solar energy has the largest potential, and even if it is only partially utilized, it will rank among the most significant energy sources [6]. Since energy and its consumption have a direct impact on living, studies to address energy-related issues is very important [7]. The solar rice cooker is an amazing environmentally friendly device that uses solar energy to transport heat for food preparation, pasteurization, sterilization, and other purposes. It works by focusing sun rays on an impermeable pot wall. High-nutrient meals, a one-time subsidies cost, nearly no maintenance and running costs, long-term use, etc. are only a few benefits of box-type solar cookers [8]. Therefore, the research for this study has concentrated on the aforementioned topics. A solar cooker is a basic

***Author for Correspondence**
Amit Tiwari
E-mail: amittiwari992@gmail.com

[1]M. Tech Scholar, Department of Electrical Engineering, Suresh Gyan Vihar University, Jaipur, Rajasthan, India
[2]Assistant Professor, Department of Electrical Engineering, Suresh Gyan Vihar University, Jaipur, Rajasthan, India
[3]Assistant Professor, Department of Mechanical Engineering, Suresh Gyan Vihar University, Jaipur, Rajasthan, India

Received Date: June 20, 2024
Accepted Date: June 25, 2024
Published Date: July 02, 2024

Citation: Harshita Swarnkar, Ritu Jain, Amit Tiwari. Comparative Energy and Exergy Performance of Box-Type Solar Cookers Using Various Pot Materialst. International Journal of Machine Systems and Manufacturing Technology. 2024; 2(1): 9–0p15.

appliance that cooks food using sun energy. It is usually used for cooking that involves scorching [9]. It is a known truth that there are many different types of solar cookers available today, and producers and researchers are always working to enhance them. Additionally, it is more appropriate for places with lots of sunlight, and its inexpensive price makes it very appealing from a business standpoint, particularly for the rural populace in developing nations. A. Harmim et al. [10] tested the box type solar cooker under both full and no load conditions, and they recommended two figures of merit (F 1 and F2) to gauge the cooker's thermal performance for two distinct pot materials. Funk, Larsor, and Funk suggested additional metrics for estimating the solar energy cooker's functionality [11].

Determination of F_1 and F_2

A freezing test conducted in the absence of load yields the value of F1, which may be stated analytically as

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

whereby˘ is the heat loss factor at stagnation and the optical effectiveness while which is the percentage of incident solar energy that reaches the absorber and is absorbed. Once a steady state is established, the receiving plate's stagnation temperature (Tps), the ambient temperature (Tas), and the solar insolation temperature (Hs) are measured [12].

The F2 is calculated mathematically as follows: it can be obtained by melting the jars that are positioned on the absorbing plate, i.e., at the entire weight.

$$F_2 = \frac{F_1 (mC_p)_w}{A(t_2 - t_1)} \, ln\left[\frac{1-(T_{w1} - T_{as})/F_1 H_s}{1-(T_{w2} - T_{as})/F_1 H_s}\right] \text{Eq.} \quad (2)$$

Where t1 is the point in temperature at which the water reached Tw1 in (°C), and t2 is the amount of time (in seconds) needed to heat the water from Tw1 to Tw2. The average room temperature (Tas) between time period t1 to time period t2, the average solar radiation (Hs) throughout time period t1 to time period t2, and the culmination of the mass that is water and specific heat (J/kg 0C) are all expressed in units of W/m².

Energy and Exergy Efficiencies

Energy Efficiency

The overall energy balance equation for the solar box cooker for the steady-state flow process within a finite time period (Δt) is as follows: [Energy obtained by water in the vessel] = [Energy given to water in the vessel] – [Energy lost from water in the vessel] Equation [3]

The energy that the water in the container within the cooker gains can be regarded as the system's output energy (E0), which is expressed in KJ.

$$E_O = mC_p (T_{w2} - T_{w1}) \text{ Eq.} \quad (4)$$

In this case, m and CP stand for the water's mass (kg) and specific heat capacity (J/kgK), respectively. During the entire load test, Tw1 and Tw2 represent the water's instantaneous final and beginning temperatures (K) [13]. The output energy in the above expression is solely dependent on the difference between the initial and final temperatures (Tw1 - Tw2). However, in real-world applications, the ambient temperature and the values of the initial and final temperatures also affect the system's efficiency, and the energy-based approach is unable to account for this kind of qualitative effect.

The input energy (Ei) of the system (in kJ) can be defined as the energy delivered to the fluid in the vessel that is kept inside the cooker.

$$E_1 = H_s A \Delta t \text{ Eq.} \quad (5)$$

Where A is the total volume (m2) of the glazing surface and HS is the instantaneous solar in solution (W/m2) measured during the test period over a time interval Δt.

As a result, the system's simultaneous energy efficiency (η_E), which is represented as follows, can be defined as the product of the energy that water supplies to itself and the energy that it gains.

$$\eta_E = \frac{E_0}{E_i} = \frac{mC_P(T_{W2} - T_{W1})}{H_S A \Delta t} \text{ Eq.} \tag{6}$$

Energy Efficiency

For the solar powered box cooker, the overall energy balance equation for the constant state flow procedure over an extended period of time can be expressed as

[Input Energy to SBC] - [Energy lost from SBC] equals [Output Energy from SBC]. Equation (7)

The current solar energy flow (HS A Δt) can be used to compute the energy of solar radiation, or the energy input EXi to the solar cooker. This can be expressed using the formula shown below, which has the broadest acceptability [14].

$$E_{xi} = H_S \left[1 + \frac{1}{3}\left(\frac{T_a}{T_S}\right)^4 - \frac{4T_a}{3T_S}\right] A\Delta t \text{ Eq.} \tag{8}$$

where Ts is the sun's surface temperature. With a black body temperature of 5762 K, the sun's spectrum is mainly concentrated in the wavelength range of 0.3–3.0 µm. The spectral distribution of solar radiation on the earth's surface causes variations in the sun's surface warmth (TS), however for the sake of computations, a value of 5800K has been taken into account [14–15].

The output exergy (EXO) of the system is the energy gained by the water in the vessels inside the fryer as a result of temperature rise, and it is stated as

$$\mathrm{E_{X0}} = E_0 - \mathrm{mC_P T_a} \ln \frac{\mathrm{T_{W2}}}{\mathrm{T_{W1}}} \text{ Eq.} \tag{9}$$

The instantaneous energy efficiency (ηA) of the system can be defined as the ratio of the energy gained by water to the ratio of the energy supplied to water an disdepicted as

$$\eta_X = \frac{E_0 - mC_P T_a \ln\frac{T_{W2}}{T_{W1}}}{H_S\left[1+\frac{1}{3}\left(\frac{T_a}{T_S}\right)^4 - \frac{4T_a}{3T_S}\right]A\Delta t} \text{ Eq} \tag{10}$$

Experimental Setup and Procedure

Two distinct types of pot ingredients have been used in the current experiment with the standard-size box-type solar cooker. The photograph perspective of the box-style solar cooker utilized in the trials is displayed in Figure 1. There are four pots in the solar cooker—two large and two mini. A layer of styrofoam was used as insulation and a GI sheet was used to build box-type solar cookers (thermal conductivity = 0.033W/m-K). The plate that surrounds the for the box-style solar cooker is made of black-painted GI sheet with an inner surface area measuring 47.5 cm by 47.5 cm and a height of 8.75 cm, and an outside surface area measuring 57.5 cm by 57.5 cm and a thickness of 17.5 cm. The alloy of aluminum big pot has a volume of 1.5 liters and the little pot has a volume of 0.750 liters; the steel big pot has a capacity of 2.5 liters and the small pot is 1 liter.

January 2024 saw the conduct of experiments in the Energy Laboratory of the Electrical Engineering Department of Suresh Gyan Vihar University in Jaipur, Rajasthan, India. The experiments commenced at 8:30 AM and ran until 5:30 PM. Using a solarimeter (suryamapi) with a minimum count of 20 (W/m2), the intensity of sunshine on the surface of the horizontal was monitored during all of the trials. Temperatures at several points on the box-style solar cooker, such as the absorber plate, cooking pots, cooking fluid, and ambient temperature, were measured using copper-constantan thermocouples to function.

RESULT AND DISCUSSIONS

a combination of energy and energy analysis, a comparison study of the solar cooker using two distinct kinds of pot materials—aluminum and steel—has been conducted. The fluctuation in solar intensity with respect to the time of day is depicted in Figure 2. Before noon, solar intensity increases steadily until it reaches its greatest level, at which point it rapidly decreases. At about 2:00 PM, a maximum value of 920W/m2 is achieved.

The time-temperature charts for aluminum and steel pot materials with and without load conditions are displayed in Figures 3 and 4.

Figure.1. Photographic view of box-type solar cooker.

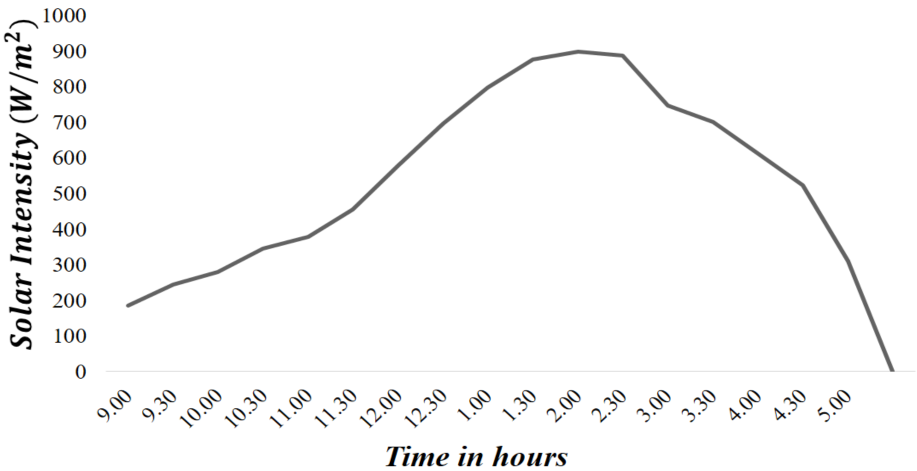

Figure 2. Variation of solar intensity with time of the day.

It can be observed from Figures 3 and 4 that the maximum value of the aluminum pot is greater than that of the steel pot. Mullicket al. (1987) reported that the first figure of merit (F1) exhibits variability ranging from 0.12 to 0.16. Good optical efficiency and a low heat loss factor are indicated by a high F1 value. After then, their prototype will be rated as Grade A. Using the aforementioned equation 1, the figure of merit F1 for the experimental stagnation test for steel and aluminum is determined to be 0.13645 and 0.14661, respectfully. For both aluminum and steel pots, the second Figure of Merit (F2) is 0.694 and 0.727, respectively. In conclusion, the outcomes derived from the worldwide cooking power test protocol unequivocally demonstrate that the current cooker meets the required standards.

Eqs. [6] and [10] were used to compute the energy and energy efficiency. A solar cooker's efficiency of energy with an aluminum pot is 21.37%, while with a steel pot, it is estimated to be 20.78%. An aluminum-pot solar cooker has an exergy efficiency of 6.08%, whereas a steel-pot solar cooker has an exergy efficiency of 5.17%. The aluminum pot in the rooftop solar cooker has an energy efficiency of 17.59% higher than that of the stainless steel pot.

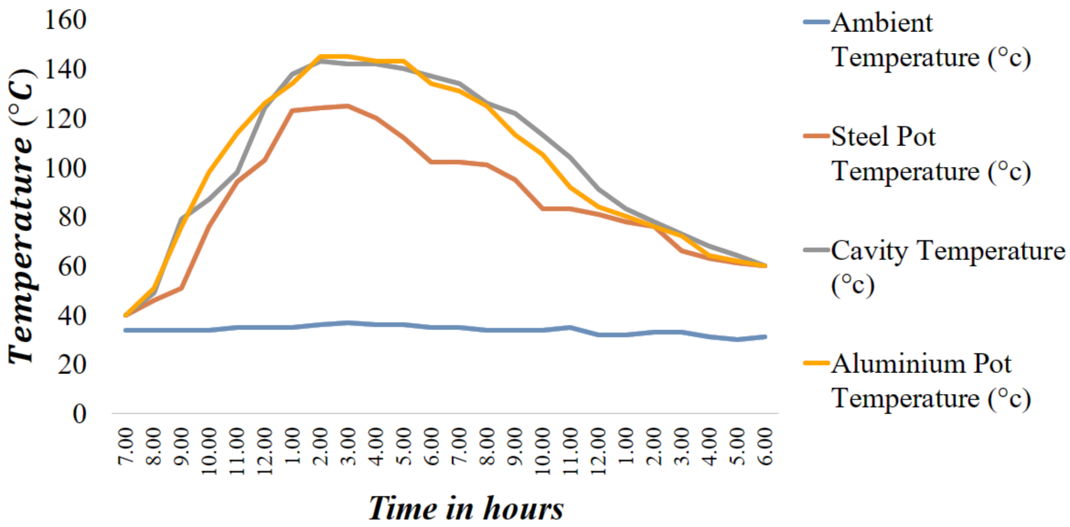

Figure 3. Variation of temperature of cooker components without load.

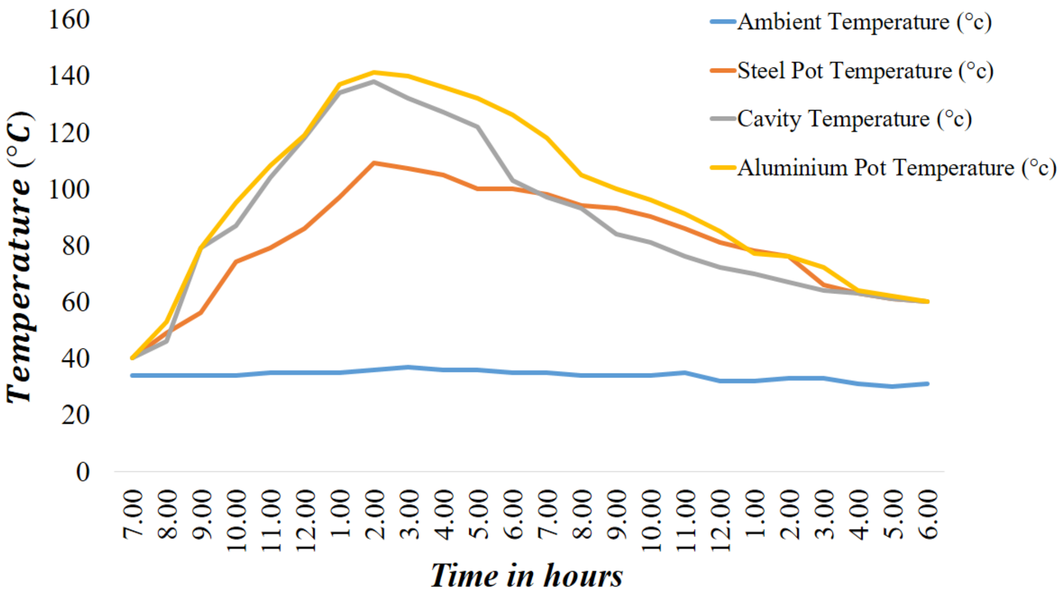

Figure 4. Variation of the temperature of cooker components with load.

CONCLUSION

In the current study, the two distinct types of pot material are examined for cooker performance in the Jaipur, India, climate. The conclusion reached is as follows: For solar cookers with aluminum pots, the first figure of merit (F1) is determined to be 0.14661, while for solar cookers with steel pots, it is 0.13645. The BIS states that the solar pressure cooker, with its two distinct pot materials, belongs in the A Grade category. The solar cooker's second figure of merit (F2) is 0.694 when using aluminum pots and 0.727 when using steel pots. The findings suggest that pots made of steel and aluminum work better when cooked by boiling. Steel pots can be used for evening cooking, whereas aluminum pots are utilized for quick cooking throughout the day. Aluminum pots have an energy efficiency of 17.59% higher than steel pots. When using an aluminum pot, the solar cooker's energy use is 21.37%; when using a metallic pot, the rate is 20.78%.

REFERENCES

1. X. Apaolaza-Pagoaga, A. Carrillo-Andr´es, C.R. Ruivo, Experimental characterization of the thermal performance of the Haines 2 solar cooker, Energy 257 (2022), https://doi.org/10.1016/j.energy.2022.124730.
2. X. Apaolaza-Pagoaga, A. Carrillo-Andr´es, C. Ruivo, Experimental thermal performance evaluation of different configurations of Copenhagen solar cooker, Renew. Energy 184 (2022) 604–618, https://doi.org/10.1016/j. renene.2021.11.105.
3. C. Ruivo, A. Carrillo-Andr´es, X. Apaolaza-Pagoaga, Experimental determination of the standardised power of a solar funnel cooker for low sun elevations, Renew. Energy 170 (2021) 364–374, https://doi.org/10.1016/j.renene.2021.01.146.
4. X. Apaolaza-Pagoaga, A. Carrillo-Andr´es, C. Ruivo, New approach for analysing the effect of minor and major solar cooker design changes: influence of height trivet on the power of a funnel cooker, Renew. Energy 179 (2021) 2071–2085, https://doi. org/10.1016/j.renene.2021.08.025.
5. A. Carrillo-Andr´es, X. Apaolaza-Pagoaga, C. Rodrigues Ruivo, E. Rodríguez-García, F. Fern´andez-Hern´andez, Optical characterization of a funnel solar cooker with azimuthal sun tracking through ray-tracing simulation, Sol. Energy 233 (2022) 84–95, https://doi.org/10.1016/j.solener.2021.12.027.
6. A. Kumar, A. Saxena, S.D. Pandey, A. Gupta, Cooking performance assessment of a phase change material integrated hot box cooker, Environ. Sci. Pollut. Res. (2023), https://doi.org/10.1007/s11356-023-25340-x.
7. S.S. Ghosh, P.K. Biswas, S. Neogi, Thermal performance of solar cooker with special cover glass of low-e antimony doped indium oxide (IAO) coating, Appl. Therm. Eng. 113 (2017) 103–111, https://doi.org/10.1016/j. applthermaleng.2016.10.185.
8. Harshita Swarnkar, Ritu Jain, Amit Tiwari, Role of Phase Change Materials in Solar Cooking for Thermal Energy Storage Applications: A Review, International Journal of Convergence of Technology and Management, Vol.10 Issue 1 Page No 05-18, ISSN: 2455-7528, https://www.gyanvihar.org/journals/wp-content/uploads/2024/Page_5_to_18.pdf
9. P.K. Devan, Chidambaranathan Bibin, S. Gowtham, G. Hariharan, R. Hariharan, A comprehensive review on solar cooker with sun tracking system, Materials Today: Proceedings, Volume 33, Part 1, 2020, Pages 771-777, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2020.06.124.
10. A. Harmim, M. Merzouk, M. Boukar, M. Amar, Solar cooking development in Algerian Sahara: Towards a socially suitable solar cooker, Renewable and Sustainable Energy Reviews, Volume 37, 2014, Pages 207-214, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2014.05.028
11. Harshita Swarnkar, Ritu Jain, Amit Tiwari, Himanshu Vasnani, Phase change material application in solar cooking for performance enhancement through storage of thermal energy: A future demand, World Journal of Advanced Engineering Technology and Sciences, 2024, 12(01), 306–330, https://doi.org/10.30574/wjaets.2024.12.1.0239
12. Chang Zhou, Yinfeng Wang, Jing Li, Xiaoli Ma, Qiyuan Li, Moucun Yang, Xudong Zhao, Yuezhao Zhu, Simulation and economic analysis of an innovative indoor solar cooking system with energy storage, Solar Energy, Volume 263, 2023, 111816, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2023.111816.

13. Ramalingam Senthil, Enhancement of productivity of parabolic dish solar cooker using integrated phase change material, Materials Today: Proceedings, Volume 34, Part 2, 2021, Pages 386-388, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2020.02.197.
14. Gawande, T.K., Ingole, D.S. Comparative study of heat storage and transfer system for solar cooking. SN Appl. Sci. 1, 1676 (2019). https://doi.org/10.1007/s42452-019-1753-0.
15. K. Varun, U.C. Arunachala, P.K. Vijayan, Sustainable mechanism to popularise round the clock indoor solar cooking – Part I: Global status, Journal of Energy Storage, Volume 54, 2022, 105361, ISSN 2352-152X, https://doi.org/10.1016/j.est.2022.105361.

