

DESIGN MODIFICATION OF PARABOLIC TROUGH SOLAR COOKER WITH HEAT STORAGE AND THERMOSYPHON SYSTEM

Saleh, L. *, Oluwole, F.O. and Shodiya, S.

Department of Mechanical Engineering, Faculty of Engineering, University of Maiduguri, Borno State, Nigeria

*Corresponding email: lawansaleh24@gmail.com

ABSTRACT

Energy access and sustainable cooking technologies represent critical challenges in developing regions, particularly in countries like Nigeria with abundant solar resources yet limited traditional energy infrastructure. This study aims to address the persistent limitations of solar cooking technologies by redesigning and constructing an enhanced parabolic trough solar cooker equipped with an innovative heat storage and thermosyphon system, specifically tailored for the climatic conditions of Maiduguri, Nigeria. The research responds to the urgent need for alternative cooking solutions that can mitigate environmental degradation, reduce reliance on fossil fuels, and provide sustainable energy access in rural and urban communities. The parabolic trough solar collector was designed with specific parameters, including a 1.27m length, 0.91m aperture width, and a concentration ratio of 82, optimized for the local latitude of 11.5°. The system incorporated key innovations such as a transparent glass cover, heat storage tank, and thermosyphon circulation system to enhance thermal performance and cooking capabilities during off-peak solar hours. Performance evaluation was conducted through standard stagnation and load tests, carried out from May to June 2024 at the University of Maiduguri Mechanical Engineering workshop, following the American Society of Agricultural Engineers (ASAE) standard testing protocol. Experimental results demonstrated that the cooker achieved a maximum absorber tube temperature of 138.4°C during stagnation tests and a thermal efficiency of 15% during load tests. The solar cooker consistently reached maximum water temperatures up to 66.9°C, with an average stagnation temperature of 77.0°C across seven days of testing. A linear regression analysis of the cooking power revealed a correlation between temperature difference and standardized cooking power, with a coefficient of determination (R^2) of 0.8177, validating the system's performance reliability.

Keywords: Sustainable cooking technologies, solar cooker, renewable energy, parabolic trough

1 INTRODUCTION

Energy access and sustainable cooking technologies are critical challenges in developing regions, particularly in countries like Nigeria with abundant solar resources yet limited traditional energy infrastructure [1, 2]. Solar cooking offers a cleaner and healthier alternative to conventional fossil fuel-based cooking methods such as kerosene and liquefied petroleum gas (LPG) stoves. By harnessing solar energy, a solar cooker converts sunlight into heat, which is then concentrated on a cooking vessel [3]. Solar energy is one of the most abundant renewable energy resources available globally and can be captured effectively through various technologies [4, 5]. Solar concentrators, which focus sunlight for enhanced energy utilization, have gained global recognition, particularly in regions with high solar radiation levels. Numerous solar concentrator designs have been developed and optimized over time, demonstrating their effectiveness across diverse applications, including cooking in areas with limited access to conventional energy resources [4]. Regions between latitudes 35°N and 35°S are ideal for solar energy harnessing due to their substantial annual solar radiation. Nigeria, located between latitudes 4°N and 14°N, falls within this favourable zone [6]. In Maiduguri, solar radiation

values range from 16.80403 MJ/m²/day to 25.03763 MJ/m²/day, with a mean value of 23.20437 MJ/m²/day, making the region highly suitable for solar energy applications [7]. Solar cookers, which rely on direct or indirect solar radiation for cooking, have been in existence since 1767, demonstrating their long-standing utility as a sustainable energy solution [3]. Nigeria, with a land area of approximately 924,000 km² and a population of over 218 million [8], is richly endowed with both conventional and renewable energy resources. Despite its abundance of energy resources, the country faces challenges of low electricity consumption per capita and reliance on expensive and scarce fossil fuels. This has led to unsustainable practices like deforestation for fuel wood, exacerbating environmental concerns. Solar energy, with its abundance, accessibility, and sustainability, presents a viable alternative, particularly in rural and remote areas. Nigeria experiences an average annual sunshine duration of 6.25 hours, with the northern region receiving up to 9.0 hours daily, further highlighting its solar energy potential [6]. Despite their benefits, solar cookers face limitations such as dependency on peak solar radiation periods and the need for frequent adjustments to align with the sun's trajectory. These constraints hinder their adoption for broader cooking applications, particularly during off-peak solar hours. Advanced solar concentrators, such as parabolic trough collectors, have been employed to address these challenges by achieving higher temperatures suitable for diverse applications [6]. International standards provide guidelines for assessing the performance of solar cookers, focusing on metrics like cooking power under specific environmental conditions [9]. These standards emphasize the importance of evaluating solar cookers in realistic scenarios to ensure their practical applicability. This study aims to address the limitations of solar cooking in Maiduguri by redesigning and constructing an enhanced parabolic trough solar cooker equipped with a heat storage and thermosyphon system. This innovative design seeks to optimize the cooker's performance for off-peak solar radiation periods, making it a more reliable and efficient solution for cooking needs in the region.

2 METHODS

2.1 Redesign for Parabolic Trough Solar Cooker

The first approach to the work was started by designing a parabolic trough solar concentrating collector in order to concentrate solar radiation into absorber tube so as to attain high temperature which in turn power the cooking coil. A storage system, designed as a tank, was constructed to temporarily hold the heat transfer fluid (oil) for cooking during off-sunshine hours. The orientation of the parabolic trough solar collector is a key design element that significantly impacts the system's ability to maximize solar energy collection [10]. According to the reviewed literature, parabolic trough solar collectors in the northern hemisphere should be aligned directly toward the south to optimize solar energy capture. Additionally, they should be tilted at an angle equal to the latitude of location where solar collector is installed. Therefore, since Maiduguri is on the northern hemisphere, therefore parabolic trough solar collector should face due south and tilted at an angle of 11.5° which is the latitude of Maiduguri. Parabolic trough solar cooker consists of a parabolic trough collector, absorber tube, transparent glass cover, liquid transfer pipes, storage tank, reflector sheet, heat transfer coil, cooking pot and supporting structure. The isometric view is shown in Figure 1.

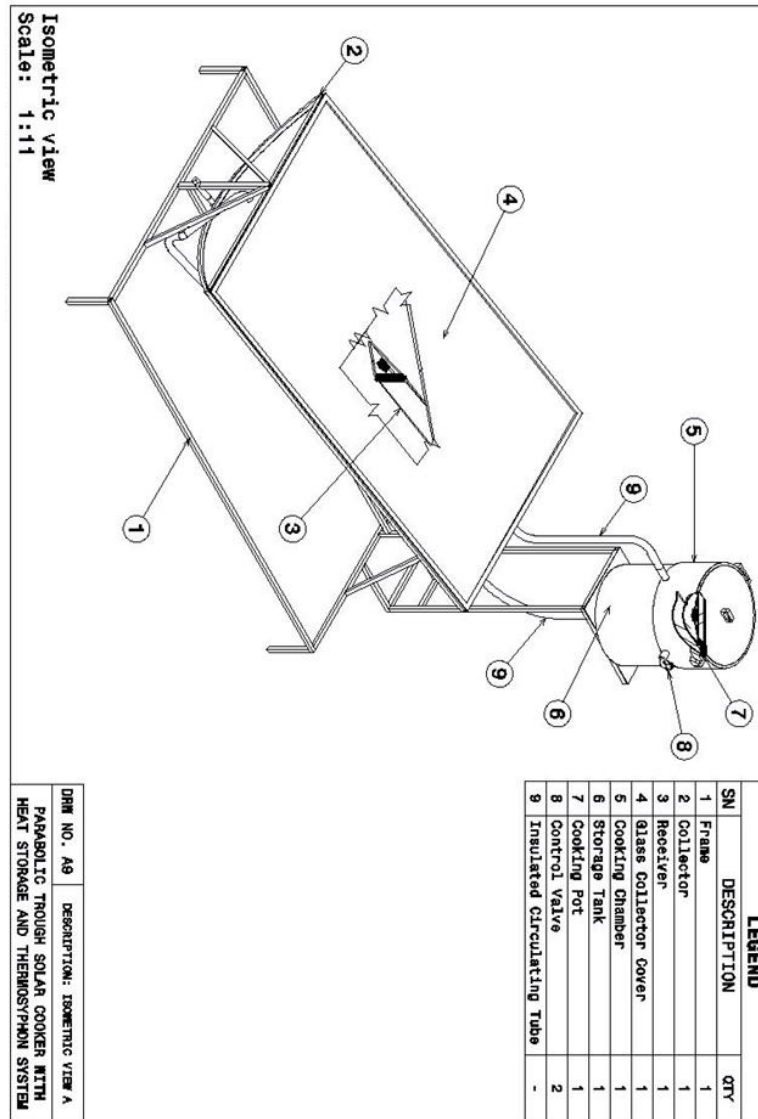


Figure 1 isometric view of parabolic trough solar cooker.

2.2 Sizing of the Parabolic Trough Solar Collector

Parabolic trough solar concentrator was designed considering necessary amount of radiation to be focused on the absorber area so as to fulfil the thermal energy demands for cooking. Key design elements include the size of the collector surface area and its geometry. The geometry of the solar parabolic trough is specifically crafted to collect and concentrate solar radiation onto the absorber tube, in accordance with the energy demand for cooking. According to [11], for optimum parabolic trough design, concentration ratio C_r should be equal to 82.

$$C_r = \frac{A_{ap}}{A_r} \quad (1)$$

Where A_{ap} = aperture area (m^2), A_r = receiver tube area (m^2), C_r = concentration ratio. Assuming the length of the parabolic trough solar collector to be the width of the available sheet metal size of mild steel at market (1.27m), diameter of receiver pipe is evaluated using Equation (2).

$$A_r = \pi d_o L \quad (2)$$

Where A_r = Receiver tube area (m^2), d_o = Receiver tube diameter (m), L = Length of receiver pipe (m). The parabolic trough collector aperture width (a) is determined using the following expression [12].

$$A_{ap} = aL \quad (3)$$

The effective area of the parabolic trough collector (A_{eff}) is determined using the following expression.

$$A_{eff} = (a - d_0)L \tag{4}$$

The height of the parabolic trough (H) is calculated using the following expressions.

$$H = 1.7f \tag{5}$$

$$f = \frac{a^2}{16 * H} \tag{6}$$

The rim radius r_r is calculated using the following Equation (7) [13].

$$r_r = \sqrt{4 * f * H} \tag{7}$$

The rim angle ϕ_r is evaluated using Equation 8.

$$\phi_r = \frac{\sin^{-1} a}{2r_r} \tag{8}$$

Table 1 presents the parameters of the developed parabolic trough solar collector.

Table 1. Parameters of the Developed Parabolic Trough Solar Collector

S/N	Parameter	Unit	Value
1	Trough height	<i>m</i>	0.29
2	Trough length	<i>m</i>	1.27
3	Aperture width	<i>m</i>	0.91
4	Focal length	<i>m</i>	0.17
5	Rim angle	°	82
6	Rim radius	<i>m</i>	0.44
7	Receiver pipe diameter	<i>m</i>	0.006
8	Receiver pipe area	<i>m</i> ²	0.0189
9	Collector aperture area	<i>m</i> ²	1.55
10	Glass cover thickness	<i>m</i>	0.005

2.3 Performance Evaluation

2.3.1 Standard Stagnation Test

During the stagnation test experiment the developed parabolic trough solar cooker was exposed to solar radiation at University of Maiduguri Mechanical Engineering workshop without any loading for seven days. The stagnation test was carried out daily from 26th May 2024 to 2nd June 2024, also, each day stagnation test experiment began at 09:00am and were continued until 16:00pm. During the experiment, the radiation intensity on a horizontal surface was recorded by using digital pyrometer, model number SPM-1116SD, which has an accuracy of 0.1 W/m². A digital thermometer, model number MTM-380SD, with an accuracy of 0.1°C, was utilized to measure temperatures at various locations within the solar cooker. The said thermometer also contained three (3) channel contact thermocouples. During the stagnation test, the temperatures measured at different locations of the solar cooker included the inlet fluid temperature, outlet fluid temperature, and mid-absorber temperature. Wind speed and ambient temperature were recorded using a Cup vane anemometer, model number ABH-4224, which has an accuracy of 0.1 m/s. Wind speed, ambient temperature, inlet, outlet fluid temperature and mid absorber temperature were measured and recorded at each day of the experiment at 10 minutes intervals as recommended by American Society of Agricultural Engineers (ASAE) standard testing protocol. The manual tracking of the parabolic trough solar collector was carried out with the aid of inclinometer. The tracking was adjusted 15⁰ at every one hour along east-west direction as recommended in the literature. The recorded data was used to evaluate the stagnation temperature of the developed parabolic trough solar cooker using Equation 9 [14].

$$SST = \left(\frac{T_s - T_a}{I_{measured}} \right) \times \left(\frac{850W}{m^2} \right) \tag{9}$$

Where SST = standard stagnation temperature ($^{\circ}C$), T_s = mid absorber pipe maximum temperature ($^{\circ}C$), T_a = Ambient temperature ($^{\circ}C$) and $I_{measured}$ = Solar radiation that corresponds to the maximum temperature (W/m^2).

2.3.2 Load Test Experiment

Load test experiment was also conducted at University of Maiduguri Mechanical Engineering workshop during which the constructed parabolic trough solar cooker was exposed to solar radiation with full load of water at the said location for another seven days. The load test was carried out for the dates 3rd June 2024 to 6th June 2024, and 13th June 2024, 24th June 2024 and 25th June 2024, also, each day the experiment began at 09:00am and were continued until 16:00pm. The solar cooker was tested with load of water. In the course of the experiment, the radiation intensity on a horizontal surface was measured using a digital pyrometer, model number SPM-1116SD, with an accuracy of $0.1 W/m^2$. Also, digital thermometer with model number (MTM-380SD) and accuracy of $0.1^{\circ}C$ was used to measure temperatures at different locations of the solar cooker. The said thermometer also contained three (3) channel contact thermocouples. Various location of the solar cooker was measured are; the inlet fluid temperature, outlet fluid temperature, the mid absorber temperature and water contained in the cooking chamber temperature. The wind speed and ambient temperature were measured using Cup vane anemometer with model number (ABH-4224) and accuracy of $0.1m/s$. Wind speed, ambient temperature, water temperature, inlet and outlet fluid temperature were measured and recorded at each day of the experiment at 10 minutes intervals as recommended by American Society of Agricultural Engineers (ASAE) standard testing protocols. The manual tracking of the parabolic trough solar collector was carried out with the aid of inclinometer. The tracking is adjusted 15° at every one hour along east-west direction as recommended by the literature. The recorded data was used to evaluate the thermal efficiency, interval cooking power and standardised cooking power using Equations (10), (11) and (12) [15].

$$\eta_{th} = \frac{M_w * C_p * \Delta T}{I_b * A_{ap} * 600} \quad (10)$$

$$P_i = \frac{(T_2 - T_1) M C_v}{600} \quad (11)$$

$$P_s = P_i \frac{(700)}{I_i} \quad (12)$$

Where η_{th} = thermal efficiency of the solar cooker, M_w = Mass of water in the cooking pot (kg), C_p = Specific heat capacity of water ($J/kg k$), I_b = Solar power (W/m^2), A_{ap} = Aperture area of the collector (m^2), ΔT = increase in water temperature (k), P_i = Cooking power (W) for interval I , T_2 = Final temperature of water ($^{\circ}C$), T_1 = Initial temperature of water ($^{\circ}C$), C_v = Specific heat capacity of water ($4186 J / [kg^{\circ}C]$), P_s = standardized cooking power (W), and I_i = interval average of solar insolation (W/m^2).

3 RESULTS AND DISCUSSION

3.1 Machine Assembly

The design of the parabolic trough solar cooker with heat storage and thermosyphon system was initiated by knowing the approximate required value of energy demand for cooking per capita in Nigeria from the literature [16]. The sizing of the parabolic trough solar collector and thermal energy storage tank was carried out based on energy required for cooking of family of four (4) and using the upsized concentration ratio of parabolic trough solar collector of 82° as obtained in the literature. The parameters of the parabolic trough solar collector are presented in Table 1. In order to improve energy collection and to reduce energy loss to minimum, both the parabolic trough collector aperture and the receiver tube are insulated using 5mm transparent flat glass as shown in Figure 2.

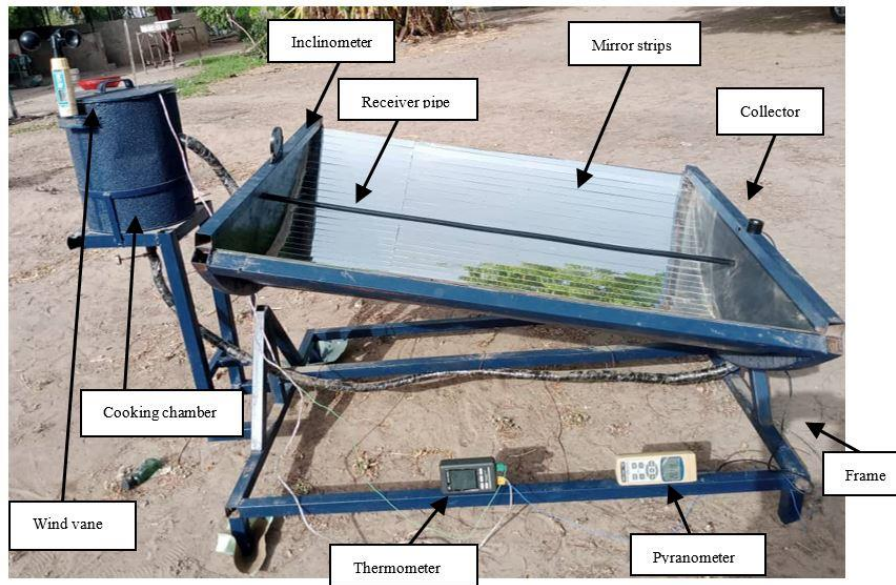


Figure 2. Fabricated machine assembly

3.2 Performance Evaluation

3.2.1 Stagnation Test Results

The seven-day standard stagnation temperature (SST) test results provide insights into the performance of the developed parabolic trough solar cooker under varying solar and environmental conditions (see Figure 3). The maximum absorber tube temperature recorded during the test was 138.4°C on 26-May-2024, achieved at 13:10 PM when solar radiation intensity peaked at 847.4 W/m². This demonstrates the peak efficiency of the solar cooker during clear weather conditions with strong solar radiation. Variations in solar radiation intensity and ambient temperature had a significant impact on the stagnation temperature across the test days. For instance, on 27-May-2024, high solar intensity of 921.8 W/m² was observed; however, sudden cloud cover reduced the stagnation temperature to 84.3°C. On 28-May-2024, partial cloud cover further lowered the SST to 59.3°C, emphasizing the impact of weather changes on the cooker's thermal performance. Conversely, on 02-June-2024, stable solar radiation led to a higher SST of 87.5°C, even under relatively high ambient temperatures. The influence of cloud cover was evident on days such as 28-May, 29-May, and 01-June, where reduced solar radiation limited the maximum absorber tube temperatures. However, the solar cooker demonstrated resilience due to its glass cover protection, which helped mitigate the effects of sudden changes in solar intensity. This feature ensured consistent performance, as seen on 27-May-2024, when the absorber temperature remained relatively unaffected by the afternoon drop in solar radiation. Daily trends in the test results showed that the maximum absorber temperatures were consistently reached around midday, typically between 12:10 PM and 01:50 PM. This corresponds to the period of peak solar radiation, which highlights the importance of optimal solar tracking in achieving high thermal performance. Overall, the parabolic trough solar cooker achieved an average SST of 77.0°C over the seven days.

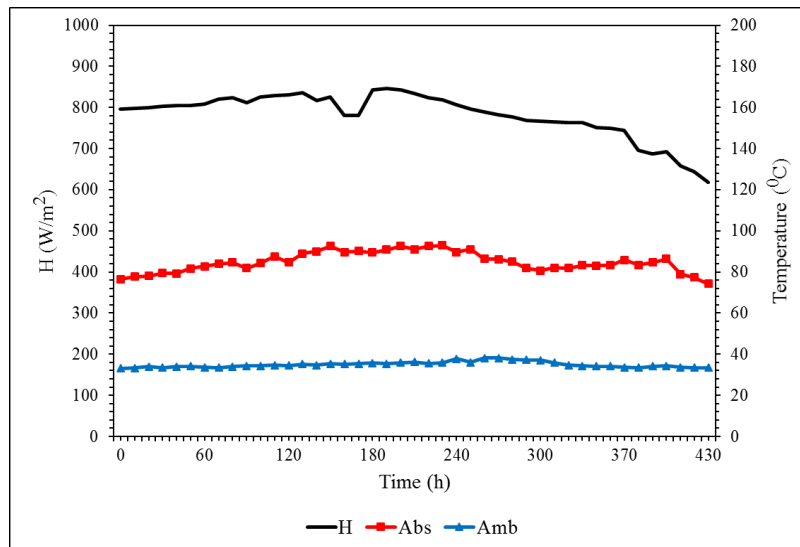


Figure 3. Average stagnation test results

3.2.2 Performance Load Test Results

Each test began at 9:00 AM and concluded at 5:00 PM, capturing key parameters such as solar intensity, water temperature, inlet and outlet fluid temperatures, absorber temperature, wind speed, and ambient temperature (see Figure 4). On 03-June-2024, the maximum and average water temperatures reached were 59.5°C and 52.5°C, respectively, with an average solar intensity of 777.8 W/m². The absorber temperature averaged 80.6°C, while thermal efficiency was calculated at 16%. The load test on 04-June-2024 revealed a slight decline in performance, with maximum and average water temperatures recorded at 56.3°C and 47.3°C, respectively. Despite an average solar intensity of 719.7 W/m², the thermal efficiency dropped to 13%, likely due to lower absorber temperatures (80.1°C) and a slight decrease in solar radiation intensity. A more significant reduction in performance was observed on 05-June-2024, where the maximum and average water temperatures were 49.6°C and 43.2°C, respectively. The solar intensity for the day averaged 651.3 W/m², and thermal efficiency declined further to 12%. The relatively low absorber temperature of 74.3°C highlights the impact of reduced solar radiation on the cooker's efficiency. Conversely, on 06-June-2024, the cooker achieved its highest performance, with maximum and average water temperatures of 66.9°C and 56.0°C, respectively. The high solar intensity of 851.8 W/m² and the absorber temperature of 107.4°C contributed to a thermal efficiency of 15%. These results highlight the cooker's peak efficiency under optimal solar conditions. On 13-June-2024, the maximum and average water temperatures were recorded at 55.6°C and 46.6°C, with an average solar intensity of 715.1 W/m². Thermal efficiency was 13%, consistent with previous days of similar solar conditions. The absorber temperature averaged 72.2°C, slightly limiting the cooker's output. Performance on 24-June-2024 was comparable to that of 03-June-2024, with a maximum water temperature of 59.4°C and an average of 52.0°C. The solar intensity averaged 775.1 W/m², and thermal efficiency reached 16%, reaffirming the cooker's reliability under consistent solar radiation. Finally, on 25-June-2024, the cooker achieved a maximum water temperature of 65.6°C and an average of 54.0°C, supported by an average solar intensity of 781.8 W/m². The absorber temperature of 85.2°C ensured a thermal efficiency of 16%, demonstrating consistent performance during high solar intensity periods.

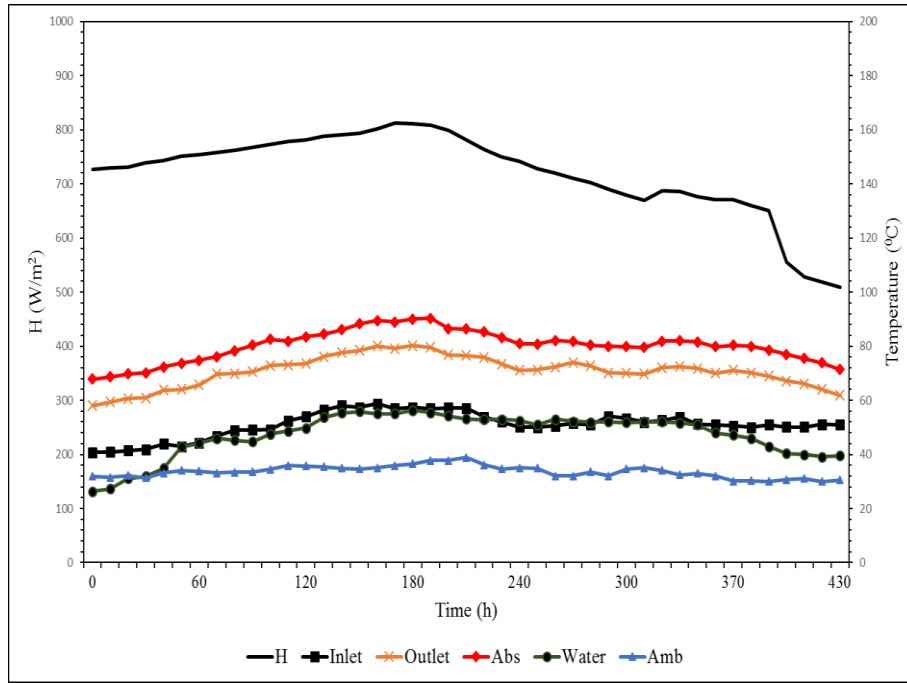


Figure 4. Average load test results

The data obtained from the calculated parameter in Equations (11) and (12) was used to develop a model equation. The model developed used a linear regression analysis. The equation was developed by plotting the graph of standardized cooking power, (P_s) (W), against the temperature difference, (T_d) ($^{\circ}\text{C}$), for each time interval and presented in Figure 5. Additionally, a linear regression of the plotted points is used to find the relationship between cooking power and temperature difference in terms of intercept, a (W), and slope, b ($\text{W}/^{\circ}\text{C}$). From the plotted graph in Figure 5, it is found that the coefficient of determination of variation (R^2) was obtained to be 0.8177 which is higher than 0.75 and within the approved range specified by ASAE test protocol [17]. Also, a linear equation was developed from the graph and found to be $P_s(\text{W}) = 3.0936T_d(^{\circ}\text{C}) + 111.58$.

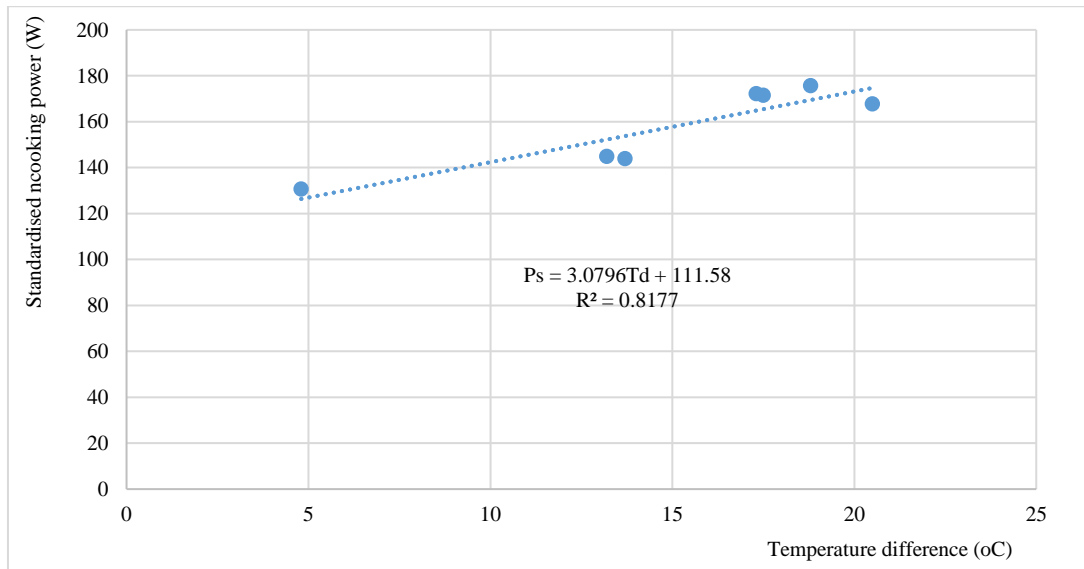


Figure 5. The graph of standardized cooking power P_s (W), against temperature difference

Results of the present work such as date of experiment, efficiency, cooking power, receiver insulation, collector cover, tracking mode, thermal fluid type, receiver material, and heat transfer fluid (HTF) were analysed and compared with some similar existing literature in Table 2.

Table 2. Results comparison with available literature

Study Area	Ethiopia [14]	Egypt [12]	Ethiopia [10]	India [18]	Present work
Experiment date	19-April-2011	August-2023	September-2010	December-2020	May-June 2024
Efficiency (%)	6.00	12.80	2.80	5.00	15.00
Cooking power (W)	288.5	167.2	181	41.4	158.3
Receiver cover	Corrugate aluminium sheet	Not covered	Corrugate aluminium	Aluminium sheet	Transparent glass
Collector cover	Not covered	Not covered	Not covered	Not covered	Transparent glass
Tracking	Manual tracking	Manual tracking	Manual tracking	Manual tracking	Manual tracking
Thermal fluid	Soya bean oil	Graphene oxide nanofluid	Soya bean oil	Not mentioned	Used engine oil
Receiver type	Galvanised steel	Copper pipe	Copper pipe	Copper pipe	Copper pipe
HTF circulation mode	Thermosyphon	Electric pump	Thermosyphon	Hydraulic pump	Thermosyphon

4 CONCLUSIONS

The development and testing of the enhanced parabolic trough solar cooker equipped with a heat storage and thermosyphon system demonstrated its potential as a sustainable cooking technology suitable for regions like Maiduguri with abundant solar radiation. Performance evaluation through stagnation and load tests validated the effectiveness of the solar cooker in achieving and maintaining high temperatures suitable for diverse cooking applications. The system's thermal efficiency and standardized cooking power met internationally recognized benchmarks, confirming its practical applicability and reliability under real-world conditions. This study highlights the viability of leveraging renewable energy technologies to mitigate energy access challenges, reduce dependence on fossil fuels, and promote environmental sustainability in developing regions. Future work could focus on further optimizing the design for higher thermal efficiency and exploring cost-effective materials to enhance affordability and scalability for widespread adoption.

REFERENCES

1. Giwa, A., Alabi, A., Yusuf, A. and Olukah, T. (2017). A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. *Renewable and Sustainable Energy Reviews*, vol. 69, pp. 620-641.
2. Oyedepo, S.O. (2014). Towards achieving energy for sustainable development in Nigeria. *Renewable and Sustainable Energy Reviews*, vol. 34, pp. 255-272.
3. Herez, A., Ramadan, M. and Mahmoud, K. (2018). Review on Solar Cooker Systems: Economic and Environmental Study for Different Lebanese Scenarios. *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 421-432.
4. Abdulrahim, A.T. (2014). Solar Concentrators Developments in Nigeria: Prospect and Challenges. *Journal of Emerging Trends in Engineering and Applied Science*, vol. 5, no. 7, pp. 73-77.
5. Kabir, E., Kumar, P., Kumar, S., Adelodun, A.A. and Kim, K.H. (2018). Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 894-900.

6. Ngala, G.M., Maina, M. and Babagana, M.T. (2015). Design and Construction of High Concentration Solar Cooker. *International Journal of Research in Mechanical Engineering*, vol. 3, pp. 1-7.
7. Musa, B.U., Zangina, U. and Aminu, M. (2012). Estimation of global solar radiation in Maiduguri, Nigeria using angstrom model. *Journal of Engineering and Applied Sciences*, vol. 7, pp. 1623-1627.
8. Shuara, J. and Olaolu, O.E. (2022). Implications of the 2022 Q2 Consumer Price Index (CPI) on Nigerian Consumers - Way Out. *American Journal of Multidisciplinary Research in Africa*, vol. 3, pp. 1-8.
9. Kimambo, C. (2007). Development and Performance Testing of Solar Cookers. *Journal of Energy in Southern Africa*, vol. 18, no. 3, pp. 41-50.
10. Gebray, P., Mulu, B. and Adam, M.S. (2011). Design of Solar Cooker Based on Concentrating Collectors Using Heat Transfer Fluid. *30th ISES Biennial Solar World Congress 2011*, vol. 6, pp. 4944-4955.
11. Arun, K. and Shukla, S.K. (2016). Mathematical Modeling and Optimization of a Parabolic Trough Concentrator for the Improvement of Collection Efficiency. *International Journal of Innovative Research in Engineering & Management (IJIREM)*, vol. 3, no. 5, pp. 375-380.
12. Shaaban, F.M., Abdel-Salam, M.F., Farroh, K.Y., Wang, H. and Atia, M.F. (2024). Thermal Performance Analysis of an Indirect Solar Cooker Using a Graphene Oxide Nanofluid. *Sustainability*, vol. 16, pp. 2539-2557.
13. Yahuza, I., Rufai, Y. and Tanimu, L. (2016). Design, Construction and Testing of Parabolic Solar Oven. *Journal of Applied Mechanical Engineering*, vol. 5, no. 4, pp. 212-217.
14. Haftom, A., Mulu, B., Kimambo, C.Z., Petros, G. and Adam, M.S. (2014). Performance Test of Parabolic Trough Solar Cooker for Indoor Cooking. *Momona Ethiopian Journal of Science*, vol. 6, no. 2, pp. 39-54.
15. El Moussaoui, N., Rhiat, M., Lamkaddem, A., Malek, R., Kassmi, K., Schwarzer, K., Bachiri, N. (2022). Innovative Solar Pressure Cooker with Parabolic Trough Concentrator Using Water Vapour. *International Journal of Renewable Energy Research*, vol. 12, no. 3, pp. 1216-1224.
16. Ibitoye, F. (2013). The millennium development goals and household energy requirements in Nigeria. *SpringerPlus*, vol. 2, Article no. 259.
17. Funk, P. (2000). Evaluating the International Standard Procedure for Testing Solar Cookers and Reporting Performance. *Solar Energy*, vol. 68, no. 1, pp. 1-7.
18. Piyushkumar, M.M., Kedar, P., Raj, K.S. and Jigar, C.G. (2023). Experimental Analysis of Solar Parabolic Trough Collector for Novel Solar Cooking System in Gujarat, India. *IOP Conference Series: Earth and Environmental Science*, vol. 1279, pp. 12002-12012.