International Journal of Engineering Materials and Manufacture (2025) 10(1) 1-9
https://doi.org/10.26776/ijemm.10.01.2025.01

Development of Solar-Powered Incubator for Poultry Eggs

Joseph Abutu, Mainigi Umar, James Wamayi Midala, Abdulkarim Muhammad Odeh, Garkuwa Haruna, Christian Ogwuche Ike, Sunday Albert Lawal

Received: 25 October 2024
Accepted: 11 December 2024
Published: 26 January 2025
Publisher: Deer Hill Publications

ABSTRACT

The development of solar-powered egg incubators holds promise for sustainable agriculture and poultry farming, particularly in areas with limited access to reliable electricity. Hence, in this work, locally sourced materials were used for the development of solar-powered incubator, with the aim of providing a sustainable and reliable alternative to traditional electricity-powered incubators. The design of the incubator was carried out using the different equations stipulated in literatures. Also, the performance of the incubator was investigated by determining the system temperature, relative humidity, percentage fertility and hatchability. The experimental results indicated that the total heat generated inside the incubator was 149,753.49 J, with contributions from air, eggs, water, and plywood. Also, there was consistent temperature and relative humidity readings throughout the incubation period with the temperature and relative humidity falling between 37.1-38.0°C and 50.6-56% respectively. The study also showed that the incubation process was conducted with diligence, leading to favourable outcomes (67% fertility and 75% hatchability) for embryo development and hatching success.

Keywords: Solar, Incubator, poultry eggs, temperature, relative humidity, Fertility, hatchability.

1 INTRODUCTION

The solar-powered approach provides a renewable, sustainable energy source that reduces greenhouse gas emissions, lowers energy costs, enhances energy independence, creates jobs, and promotes social equity by improving access to electricity in underserved areas. Over the years, the poultry industry has emerged as one of the most efficient sources of protein for human consumption. This sector experienced significant growth during World War II due to shortages of beef and pork, which take considerably longer to produce. In contrast, it takes only seven weeks to raise a broiler and five months to produce a laying hen [1]. The technology of incubation has provided farmers the opportunity to produce chicks from eggs without the consent of the mother hen. It is an artificial technique for the hatching of eggs and one of the fastest ways for transforming eggs to chicks. In natural incubation, the parent bird provides warmth through direct contact with the eggs rather than by surrounding them with warm air [2]. In addition, a broody hen typically hatches 10 to 12 eggs at a time over a period of 21 days. This process can reduce the hen's overall productivity, as it requires a significant amount of time to incubate and hatch the chicks. [3]. Bond et al. [4] noted that some large birds such as condors and albatross, may lay only a single egg every two year. Nevertheless, the world population is growing at alarming rate, hence, relying on the natural type of incubation is not enough. As a result, there is need for artificial incubation due to high demand of protein [5]. This way, a female bird just concentrates on laying eggs while the incubation is done for her artificially.

In addition, the development of incubator has been the focus of several studies. Using solar energy for incubators offers several advantages, including reliability, environmental friendliness, portability, and a consistent power supply, which helps prevent the loss of hatching value during power outages [6]. The solar systems typically consist of photovoltaic (PV) modules, a charge controller, deep cycle batteries, and a solar inverter [7] and the sizing of these components is determined by the specific energy consumption and heat requirements of the incubator. The work of Desalegn [8] emphasized on the protective functions of incubators, which not only safeguard preterm infants from environmental stressors but also maintain crucial conditions such as humidity and temperature. This is particularly relevant to poultry farming, where similar environmental controls are necessary for successful egg hatching. The ability of solar-powered incubators to maintain these conditions without reliance on unstable electricity sources makes them invaluable in areas like Nigeria, where power supply is often erratic. Also, Anowar [9] highlighted the necessity

[1]Joseph Abutu ✉, [1]Mainigi Umar, [1]James Wamayi Midala, [1]Abdulkarim Muhammad Odeh, [1]Garkuwa Haruna, [1]Christian Ogwuche Ike, [2]Sunday Albert Lawal
[1]Department of Mechanical Engineering, Taraba State University, Jalingo-Nigeria
[2]Department of Mechanical Engineering, Federal University of Technology, Minna-Nigeria
E-mail: abutu.joseph@tsuniversity.edu.ng

Reference: Abutu, J., Umar M., Midala, J. W., Odeh, A. M., Haruna, G., Ike, C. O. & Lawal, S. A. (2025). Development of Solar-Powered Incubator for Poultry Eggs. *International Journal of Engineering Materials and Manufacture*, 10(1), 1-9.

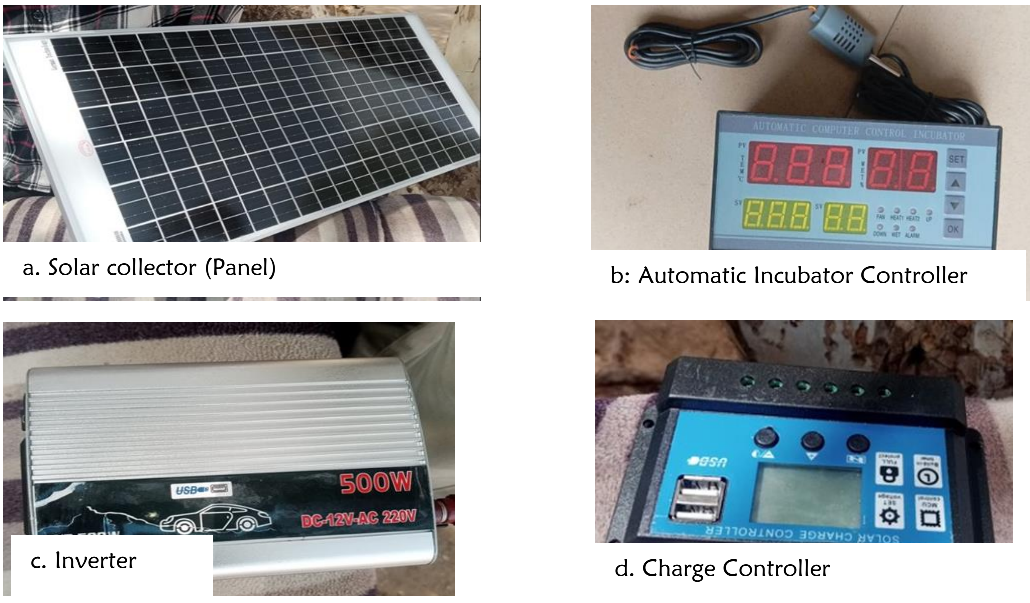
of accurate calibration and stable settings for incubators to ensure optimal growth. This requirement underscores the importance of reliable energy sources, which solar-powered incubators can provide. By addressing the challenges posed by poor power supply, solar technology enhances the effectiveness of incubation processes, thereby improving hatchability rates. In addition, the research conducted by Neves et al. [10], Alhaj-Omar et al. [11], and Peta [32] identified various energy sources for incubators, including biogas and solid fuels, each with its own advantages and drawbacks. The findings from Bykov et al. [12] further support this discussion by noting that traditional energy sources like solid fuels can produce harmful emissions that negatively impact egg hatchability. This reinforces the argument for solar energy as a cleaner alternative that minimizes environmental impact while providing reliable energy for incubation. Moreover, studies like those conducted by Metwally [13] explored the design and performance of solar-powered incubators, emphasizing their potential to operate efficiently in areas with limited electricity access. These studies highlighted that solar energy is not only feasible but also essential for modernizing poultry farming practices in developing countries.

Overall, the advancement of solar-powered egg incubators presents a promising opportunity for sustainable agriculture and poultry farming, especially in regions with limited electricity access. Additionally, maintaining proper humidity around the eggs is crucial, as excessively dry air can lead to excessive water loss from the eggs, making hatching difficult or even impossible [14]. The egg will typically become lighter as incubation continues, and the air space inside the egg will generally become larger due to evaporation from the egg. Hence, adequate humidity is needed to ensure the proper hatching of the eggs [15]. This study aims to address the challenges faced by poultry farmers due to unreliable electricity supply, which has historically hindered effective incubation practices. While there have been other solar-powered incubators developed in Nigeria, most of these incubators focused on urban or more resource-rich environments. Hence, the unique aspect of this study is its emphasis on utilizing locally sourced materials, making it both sustainable and adaptable for rural areas where access to conventional energy sources is limited. Therefore, this study focused on the development of a solar-powered poultry egg incubator tailored to accommodate up to 120 eggs which encompasses the engineering of the incubator, including the creation of a solar power system, precise temperature and humidity control mechanisms, and egg-turning functionality to ensure optimal incubation conditions. However, energy efficiency will be a key aspect, aiming to minimize power consumption and making the system suitable for solar operation. Extensive testing and optimization were conducted to enhance the incubator's performance.

2 MATERIALS AND METHODS

2.1 Materials

The materials used for this project were locally sourced. These materials include; mild steel (angle iron and square pipe 1 inch), wood (MBF board), watts filament bulb (Power: 100W, Voltage: 220-240V), 12V Battery (Korea Technology; Voltage DC 12V 75AH – Dry Cell), humidifying fan (120mm), Solar panel (Dimension: 680*350, Max. system voltage: DC 1500V, Short-circuit current: 167A) – Figure 1a, Automatic incubator controller (Intelligent instruments and Meters; Working Voltage: 160V-204V,50Hz)- Figure 1b, inverter (UP-500W; UNI-PEC; China), plastic water reservoir, plastic egg trays (Figure 1c) and Charge controller (Model: LCD2410; 12V/24V, 10A, China)-Figure 1d.



a. Solar collector (Panel)

b: Automatic Incubator Controller

c. Inverter

d. Charge Controller

Figure 1: Materials for construction of incubator

2.2 Methods

This research was carried out in four stages; the first stage involved the design of the solar powered incubator. The second stage involved constructing of the box. This was followed by the installation of the solar system, and finally, performance evaluation of the developed incubator

2.2.1 Design of the Incubator

a. Determination of Absolute Humidity

The absolute humidity necessary for incubating poultry eggs was determined as the mass of water vapor per unit volume of air (refer to Equations 1 and 2 in the Appendix). This measurement is crucial to prevent excessive moisture loss from the eggs during the incubation process. However, absolute humidity is influenced by factors such as the mass flow of air, temperature, and fan speed.

b. Determination of Heat Generation

The heat generated inside the incubator, which is necessary to raise the temperature of the air, eggs, egg tray, water, and wooden walls, was calculated using the heat generation equations presented by Peprah et al. [16] (see Equations 3 and 4 in the Appendix). According to Pérez-Reyes et al. [17], the mass of air (MA) is 28.97, while the specific heat capacity of air (CA) is 1000 J/kg·K. Additionally, Ivan et al. [21] reported that the specific heat capacity of an egg (Ce) is also 1000 J/kg·K. In this study, the total mass of the eggs used was calculated as follows: mass of one egg (Me) = 160.1711 g × 6 eggs = 961.0266 g, which is equivalent to 0.961 kg.

In addition, according to Zhou et al. [18], specific heat capacity of water (Cw) = 4182 J/kgK while the mass of water (Mw) used in this study was 18.01528g. The mass of plywood (Mw) used in this study was 312 g. Etuk et al. [19] revealed that the specific heat capacity (Cp) of plywood is 1210J/kgK. Therefore, the total heat required to raise the temperature inside the incubators is the summation of all the heat that was required inside incubator. Hence, the total heat required (QI) was calculated (refer to Equation 5 in the Appendix).

c. Selection of DC Electric Motor

The DC electric motor to be used in turning the incubator tray was obtained using the torque of electric motor (refer to Equation 6 in the Appendix).

d. Design Drawing

The design drawings were obtained using AutoCAD 2018 and are presented in Figure 2. The assembly view in Figure 2a provides a comprehensive look at how different parts fit together, which is crucial for understanding the overall structure and functionality of the incubator. The closed view presented in Figure 2b shows perspective of the incubator when it is fully assembled, highlighting its external features and dimensions. Meanwhile, the sectional view shown in Figure 2c reveals internal components and their arrangement, which is essential for assessing airflow, heat distribution, and other critical factors that affect incubation performance.

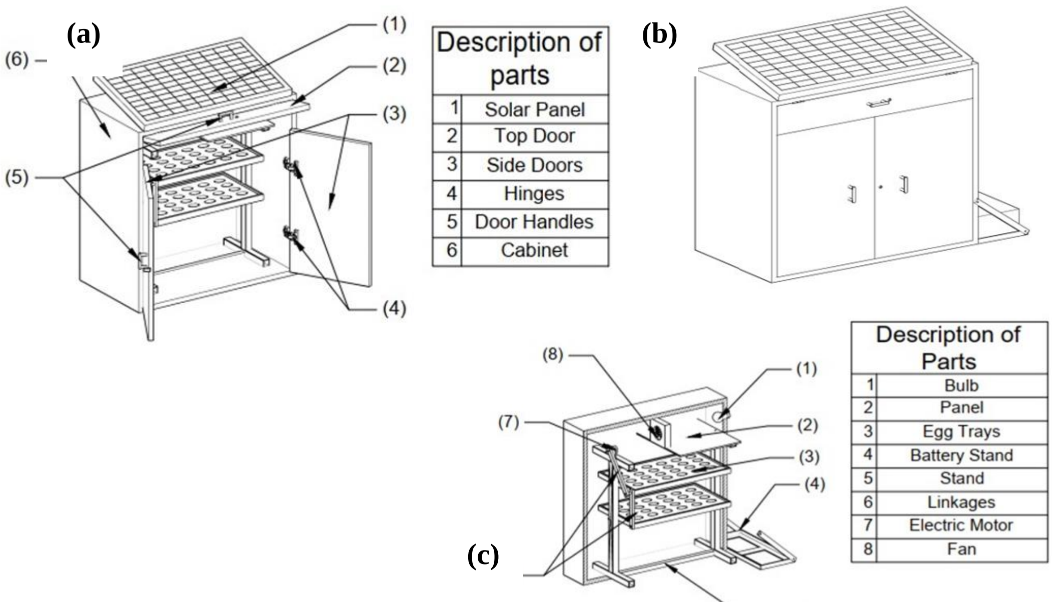


Figure 2: Design drawing of the solar incubator (a) assembly (b) closed view (c) sectional view

2.2.2 Construction Procedure

The solar incubator was constructed using locally available materials. Simple machining processes such as drilling, cutting, grinding and joining were employed in the construction process. In addition, two trays containing 60 eggs each was installed alongside a heat source a lamp of 100 Watts filament bulb. Thereafter, water reservoir was placed at the bottom cabinet floor to increase and recover humidity in the cabinets. Also, automatic computer control incubator was installed to control and measure the temperature and humidity in incubator cabinets, while a fan was also mounted to ventilate air inside cabinet. Additionally, an electric motor was fixed inside the cabinet to automatically turned eggs trays. This procedure was followed by the installation of the solar system as energy source of the incubator by determining the power needs of the incubator (the wattage and voltage requirements), selecting the appropriate solar panels based on the power requirements of the incubator and taking into consideration, the available space for installation as well as the amount of sunlight the panels receives. The skeletal views of the constructed incubator are shown in Figure 3.

In addition, the installation of solar charge controller and battery involved connecting the charge controller to the solar panels to regulate the voltage and current entering the battery and installing a deep cycle battery to store the solar energy for use during low light conditions. This was followed by the connection of the inverter, the solar panels, charge controller, battery, and inverter in accordance with the manufacturer's specification. The outer and inner views of the developed solar powered incubator are presented in Figure 4. The outer view presented in Figure 4a provides a comprehensive perspective on the incubator's overall structure, highlighting its portability and aesthetic features while the inner view in Figure 4b reveals the internal components and layout of the incubator, which are crucial for understanding how it operates.

Figure 3: Skeletal view of the incubator (a) Metallic frame (b) cabinet frame

Figure 4: The developed solar powered incubator (a) outer and (b) inner view

3 RESULTS AND DISCUSSION

a. Temperature and Humidity

The performance of the developed solar-powered incubator was evaluated using six poultry eggs, maintaining a maximum temperature of 38°C. The response parameters for testing the incubator included temperature and relative humidity. These parameters were measured and monitored at two-hour intervals using the automatic incubator controller installed in the system, ensuring that the overshoot temperature did not exceed 2°C above the set point and that the temperature remained stable for at least one hour. Humidity levels were monitored to prevent excessive moisture loss from the eggs and to ensure that temperature and relative humidity readings did not exceed 38°C and 50-55%, respectively. Data for temperature and humidity were recorded every two hours from 9am to 3 pm daily over a period of nineteen days until all the chicks hatched. Fig. 5 illustrates the experimental setup of the developed incubator.

Figure 5: Experimental settings of the developed incubator

b. Fertility and Hatchability

The percentage of fertility and hatchability for the six eggs placed inside the incubator were calculated using Equations 7 and 8, respectively, as outlined in the Appendix.

3. RESULTS AND DISCUSSIONS

3.1. Design Calculations

The results obtained from design calculation are presented in Table 1. The results revealed that the total heat generated inside the incubator was 149,753.49 J. This includes contributions from different materials and contents, Air: 8,995.19 J. Eggs: 165.14 J, Water: 23,373.20 J and Plywood: 117,219.96J. Li et al. [20] have revealed that incubator's design must ensure that the total heat generated (149,753.49 J) is sufficient to meet this requirement, factoring in heat losses that may occur through conduction and other means. In addition, the humidity level is crucial for successful incubation [23]. The absolute humidity of 0.02304 kg/m³ suggests a moderate level of moisture in the air. This level is suitable for various applications, including maintaining optimal conditions for incubation, where humidity levels typically need to be managed carefully to ensure successful hatching. Also, the torque generated by the electric motor is 6,820.04 Nm, which is significant for driving mechanisms such as egg turners and the cross-sectional area of 0.62 m² could relate to the size of the incubator or the area through which heat is exchanged.

Table 1: Results of design calculation

S/N	Design parameter	Value
1	Absolute Humidity (kg/m³)	0.02304
2	Heat Generation (for air)	8995.19J
3	Heat Generation (for egg)	165.14J
4	Heat Generation (for water)	23373.20J
5	Heat Generation (for plywood)	117219.96J
6	Heat Generated Inside Incubator	149753.49J.
12	Heat required for the system	14951.33J
13	Cross-sectional area (m²)	0.62
14	Torque generated by electric motor	6820.04Nm

3.2 Temperature and Relative Humidity

The results presented in Table 2 shows the values of temperature (T) and relative humidity (RH) readings taken at three different time intervals (2 hours, 4 hours, and 6 hours) over a 19-day period. This data which are represented in Figure 6 and 7 was critical for monitoring the conditions in the incubator during the egg's incubation process. It was observed that the temperatures generally remain within a narrow range, fluctuating between 37.1°C and 38.0°C. The average temperature across all days and time intervals appears to hover around 37.5°C, which is within the recommended range for egg incubation [24]. In addition, the relative humidity (RH) values vary from 50.6% to 56%, with most readings falling between 51% and 55%. However, the average relative humidity is consistent with the recommended range for the first 18 days of incubation (45-55%), with some days showing slightly higher values, particularly during the later days. Generally, Initial days (Days 1-5) showed stable temperatures around 37.4°C to 37.9°C with relative humidity mostly in the low 50s while at Days 6-10, a slight increase in temperature and humidity was noted, especially on Day 10, where humidity reaches 54%. The humidity peaks at 56% on Day 13, indicating a potential adjustment to maintain moisture levels as the eggs develop. Finally, within the 16-19th days, the temperatures remain stable, with humidity fluctuating but staying within the acceptable ranges. Based on this data, it can be concluded that there was a well-maintained incubator environment conducive to successful egg incubation since the temperature and relative humidity readings are consistent with best practices, indicating that the conditions are being effectively managed throughout the incubation period. Hence, the need for continuous monitoring and adjustments for maximizing hatch rates and ensuring the health of the chicks.

Table 2: Results of relative humidity and temperature

Time interval (hr)	2		4		6	
Day	T (ºC)	RH (%)	T (ºC)	RH (%)	T (ºC)	RH (%)
1	37.4	51	37	50.6	37.5	52.7
2	37.5	52.7	37.1	51	37.4	52.5
3	37.1	53	37.2	50.8	37.6	53
4	37.5	52.5	37.3	51.5	37.5	52.8
5	37.9	53	37.5	52	37.7	53.2
6	37.8	52	37.4	51.2	37.8	54
7	37.6	51	37.6	52.3	37.6	53.5
8	37.7	50	37.5	53	37.5	52.9
9	37.5	53	37.7	52.5	37.4	51.5
10	37.4	52	37.8	54	37.3	52
11	37.6	54	37.5	53.5	37.5	53.1
12	37.5	55	37.4	52.8	37.6	54.3
13	37.8	56	37.6	53.2	37.8	55
14	37.7	54	37.8	54.5	37.9	56
15	37.5	52	37.9	55	37.7	54.5
16	37.6	53	37.7	54.2	37.5	53
17	37.9	55	37.5	53	37.4	52.8
18	38	51	37	50.6	37.6	53.2
19	37.5	52.7	37.4	52	37.5	54

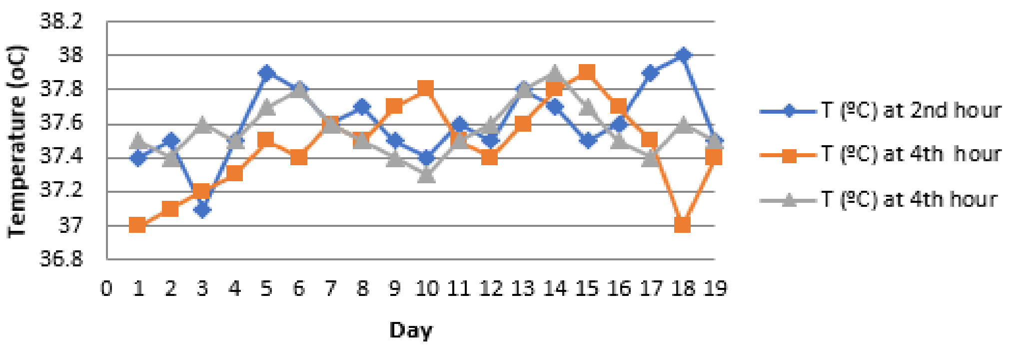


Figure 6: Temperature variation at different hours and days

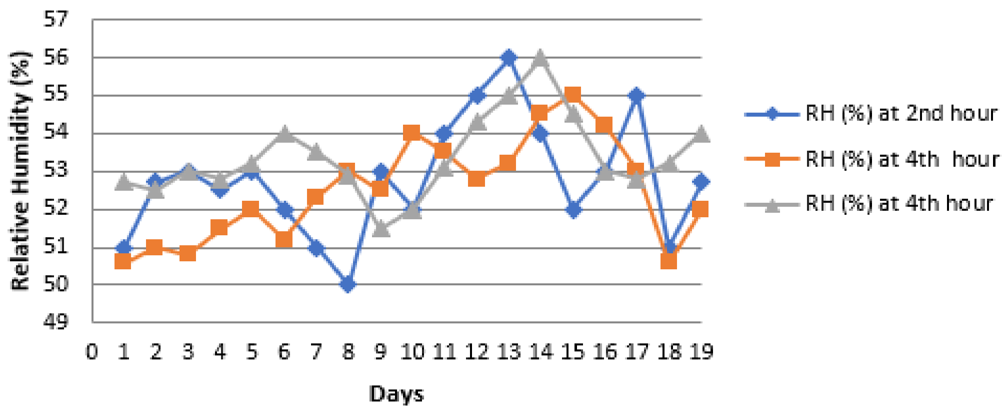


Figure 7: Relative Humidity variation at different hours and days

3.3 Percentage Fertility and Hatchability

a. Percentage Fertility

The 67% fertility rate obtained in this study indicates that the developed incubator has created optimal conditions for egg development, likely due to effective management of the incubation environment [25]. When compared to other solar-powered incubators and alternative designs, this fertility rate shows varied performance across different systems. For instance, a solar thermal incubator studied by Bi et al. [26] yielded a remarkable fertility rate of 93% when 30 eggs were tested, indicating high efficiency in maintaining ideal incubation conditions through effective temperature and humidity control. In contrast, a solar-powered incubator with integrated thermal energy storage developed by Olotu et al. [27] achieved a fertility rate of 61.11% and a hatchability of 27.27%, suggesting that while it maintained adequate environmental conditions, it fell short in overall performance compared to the incubator developed in this study

Numbers of Egg in the incubator = 6
Number of fertile eggs = 4
Percentage Fertility= 4/6 x 100 = 400/6 = 67%

b. Percentage Hatchability

The percentage hatchability achieved in this study indicates that 75% of the eggs placed in the incubator successfully hatched into chicks. This result reflects a successful incubation process, suggesting that the conditions were likely favourable for embryo development [28]. In comparison, Muleta [29] evaluated a solar incubator with integrated thermal energy storage and found a hatchability rate of 61.11%, which is lower than the current study's results. Similarly, a solar incubator designed by Dalangin and Ancheta [30] achieved a hatchability rate of 73%, while Uzodinma et al. [31] reported an average hatchability percentage of 62.3%. These variations in hatchability rates highlight the significant impact that design and environmental management have on incubation success. Overall, the findings from this study demonstrate that effective environmental control can lead to improved hatchability outcomes, positioning it favourably against other solar-powered incubators and emphasizing the importance of optimizing incubation conditions for successful poultry production.

Numbers of Egg hatched out = 3
Number of fertile eggs = 4
Percentage hatchability= 3/4 x 100 = 300/4 = 75%

4. CONCLUSIONS

In this study, locally sourced materials were utilized to develop a solar-powered incubator, aiming to provide a sustainable and reliable alternative to traditional electricity-powered incubators. Based on the results obtained, the following conclusions can be drawn:

i. The total heat generated inside the incubator was 149,753.49 J, contributed by air (8,995.19 J), eggs (165.14 J), water (23,373.20 J), and plywood (117,219.96 J). This underscores the importance of efficient heat generation, humidity control, and appropriate motor selection in achieving successful egg incubation.
ii. Throughout the incubation period, temperature and relative humidity readings remained consistent, with temperatures ranging from 37.1 to 38.0°C and relative humidity levels between 50.6% and 56%. This consistency demonstrates that the incubator environment was well-maintained, adhering to best practices for effective egg incubation.
iii. Effective management of incubation conditions is vital for maximizing hatch rates and ensuring the health of the chicks. The findings indicate that the incubation process was conducted with care, resulting in favourable outcomes of 67% fertility and 75% hatchability for embryo development and hatching success.
iv. However, further improvements could be made to enhance scalability and cost-effectiveness. Conducting a comprehensive cost analysis would help identify potential savings and funding opportunities for wider adoption of this technology.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ACKNOWLEDGEMENT

The authors are grateful to Tertiary Education Trust Fund (TETFund) for the grant (TETFUND/TSU/2024/IBR) allocated to this research.

REFERENCE

[1] Longo, J. (2024). Socio-economic Determinants of Choice between Layers and Broilers Farming among Smallholder Chicken Farmers in Tanzania. Tanzania Journal of Agricultural Sciences, 23(1), 223-233.
[2] Ritchison, G. (2023). Avian Reproduction: Clutch Sizes, Incubation, and Hatching. In In a Class of Their Own: A Detailed Examination of Avian Forms and Functions (2285-2382). Cham: Springer International Publishing.
[3] Sarkar, P. K. (2022). Broodiness and broody hen management during egg incubation. Reviews in Agricultural Science, 10, 337-343.

[4] Bond, A. L., McClelland, G. T., Cuthbert, R. J., Glass, T., Repetto, J., & Ryan, P. G. (2020). No change in Atlantic Yellow-nosed Albatross (Thalassarche chlororhynchos) egg size over 160 years. Emu-Austral Ornithology, 120(2), 142-149.

[5] Sunday, A. A., Ogunbode, O. A., Babatunde, E. G., & Olalekan, A. M. (2020). Design and construction of automated eggs incubator for small scale poultry farmers. International Journal of Technical Research & Science, 5(8), 1-9.

[6] Sreekumar, G., Chekkichalil, V., Oshmitha, A., & Nair, A. S. (2021). Smart Solar Portable Power Supply System for Emergency Medical Equipments. 5th international conference on trends in electronics and informatics. 261-266. IEEE.

[7] Rathore, N., Panwar, N. L., Yettou, F., & Gama, A. (2021). A comprehensive review of different types of solar photovoltaic cells and their applications. International Journal of Ambient Energy, 42(10), 1200-1217.

[8] Desalegn, W. T. (2021). Developing Knowledge-Based System for Diagnosis and Treatment Recommendation of Neonatal Diseases: The Case of Gandhi Memorial Hospital (Doctoral dissertation).

[9] Anowar, M. (2023). Design and Implementation of a Microcontroller Based Forced Air Egg Incubator (Doctoral dissertation, Duet).

[10] Neves, D., Baptista, P., & Pires, J. M. (2021). Sustainable and inclusive energy solutions in refugee camps: Developing a modelling approach for energy demand and alternative renewable power supply. Journal of Cleaner Production, 298, 126745.

[11] Alhaj-Omar, F., Mahmoud, I., & Cedano-Villavicencio, K. G. (2022). Prospects of PV energy systems in addressing energy poverty in Syria. Ibrahim and Cedano-Villavicencio, KG, Prospects of Pv Energy Systems in Addressing Energy Poverty in Syria.

[12] Bykov, E., Paulauskas, R., Striūgas, N., & Buidovas, P. (2023). Influence of the plasma assistance on chemiluminescence from flames of artificial biogas mixture. In CYSENI 2023: 19th international conference of young scientists on energy and natural sciences issues, 23-26 May, 2023, Kaunas, Lithuania:[proceedings].. Lietuvos energetikos institutas.

[13] Metwally, A. (2020). Improving Performance of the Poultry Eggs Incubator using the Pulse Repetition Frequency. Journal of Soil Sciences and Agricultural Engineering, 11(5), 151-156.

[14] Veldsman, L. M., Kylin, H., Bronkhorst, P., Engelbrecht, I., & Bouwman, H. (2020). A method to determine the combined effects of climate change (temperature and humidity) and eggshell thickness on water loss from bird eggs. Environmental geochemistry and health, 42, 781-793.

[15] Hossain, E., Zeyad, M., Ahmed, S. M., & Anubhove, M. S. T. (2021, September). Duck Eggs Hatching Procedure with A Low Cost User Convenient Integrated Device for Developing Countries. In 2021 IEEE 9th Region 10 Humanitarian Technology Conference. 1-6), IEEE.

[16] Peprah, F., Gyamfi, S., Amo-Boateng, M., Buadi, E., & Obeng, M. (2022). Design and construction of smart solar powered egg incubator based on GSM/IoT. Scientific African, 17, e01326.

[17] Pérez-Reyes, M. E., Tang, J., Barbosa-Cánovas, G. V., & Zhu, M. J. (2021). Influence of water activity and dry-heating time on egg white powders quality. LWT, 140, 110717.

[18] Zhou, R., Ma, X., Li, H., Sun, C., & Bai, B. (2021). Specific heat capacity of confined water in extremely narrow graphene nanochannels. Frontiers in Energy Research, 9, 736713.

[19] Etuk, S. E., Robert, U. W., & Agbasi, O. E. (2020). Design and performance evaluation of a device for determination of specific heat capacity of thermal insulators. Beni-Suef University Journal of Basic and Applied Sciences, 9, 1-7.

[21] Ivan, M. N. A. S., Saleque, A. M., Ahmed, S., Cheng, P. K., Qiao, J., Alam, T. I., & Tsang, Y. H. (2022). Waste egg tray and toner-derived highly efficient 3D solar evaporator for freshwater generation. ACS Applied Materials & Interfaces, 14(6), 7936-7948.

[20] Li, S., Qu, Z., & Song, Z. (2020). A Multifunctional Combination Incubator. Energies, 13(24), 6622.

[22] Lide, D. R. (Ed.). (2004). CRC handbook of chemistry and physics (Vol. 85). CRC Press. pp. 6–8. ISBN 978-0-8493-0485-9.

[23] Izadeen, G. Y., & Kocher, I. S. H. (2022). Smart Egg Incubator Based on Microcontroller: a Review. Academic Journal of Nawroz University, 11(4), 139-146.

[24] Wijnen, H. J., Molenaar, R., van Roovert-Reijrink, I. A. M., Van der Pol, C. W., Kemp, B., & Van den Brand, H. (2020). Effects of incubation temperature pattern on broiler performance. Poultry Science, 99(8), 3897-3907.

[25] Oliveira, G. D. S., Dos Santos, V. M., Rodrigues, J. C., & Nascimento, S. T. (2020). Effects of different egg turning frequencies on incubation efficiency parameters. Poultry science, 99(9), 4417-4420.

[26] Bi, B. E. B., Koffi, E. P. M., & Gbaha, P. (2024). Experimental Study of a Solar Thermal Incubator Using a Phase-Change Material for Off-Grid Use. Open Journal of Applied Sciences, 14(9), 2471-2481.

[29] Muleta, D. T. (2023). Experimental Evaluation of Solar Powered Egg Incubator with Integrated Thermal Energy Storage:(Case Study: West Showa Zone Bako District, Ethiopia)., International Journal of Sustainable and Green Energy, 12(3), 2023, 35-45.

[28] Pokhrel, N., Sela-Donenfeld, D., & Cinnamon, Y. (2021). The chick blastoderm during diapause, a landmark for optimization of preincubation storage conditions. Poultry Science, 100(8), 101227.

[32] Peta, M. M. (2021). Exploring the efficacy of solar photovoltaic application as an alternative energy source for rural households in Atok, Limpopo. University of Johannesburg (South Africa).
[31] Uzodinma E.O., Ojike O., Etoamaihe U.J., Okonkwo W.I. (2020), Performance study of a solar poultry egg incubator with phase change heat storage subsystem; Case Studies in Thermal Engineering 18(2020)100593;
[30] Dalangin, F. A. T. and Ancheta, A. C. (2018). Performance Evaluation of the Developed Solar Powered Poultry Egg Incubator for Chicken. Journal of Science, Engineering and Technology (JSET), 6, 67-81.

APPENDIX

$$Absolute\ Humidity\ \ (AH) = \frac{P_a}{R_v T} \quad (1)$$

Where; R_v = specific gas constant for water vapour (461.5 J/kg·K), T = room temperature in kelvin (25ºC+273 = 298K), P_a = Actual vapour pressure of water vapour. According to Lide et al. [22], P_a at room temperature= 3.1690kPa)

Temperature in Kelvin = Temperature in ºC + 273 (2)

Quantity of Heat Generated $Q_i = M_i \ x\ C_i\ x \Delta T$ (3)

Change in Temperature (ΔT) = $T_2 - T_1$ (4)

Where, M = mass of the object, C = specific heat capacity and ΔT = change in temperature, T_2 = final temperature and T_1 = initial temperature.

The total heat required (Q_I) = $Q_A + Q_e + Q_w + Q_P$ (5)

Where; Q_A, Q_e, Q_w and Q_P is the quantity of heat generated by air, eggs, water and plywood.

Torque of Electric motor (T_m) = $\frac{60 \text{ x Power}}{2\pi N}$ (6)
Where N = speed in $\frac{1}{240}$ rpm which is one cycle after every four hours = 0.0042rpm, power, P = 3W

$$\%\ Percentage\ fertility = \frac{Number\ of\ \ fertile\ eggs}{Number\ of\ Eggs\ in\ the\ incubator}\ x100 \quad (7)$$

$$Percentage\ hatchability = \frac{Number\ of\ \ eggs\ hatched\ out}{Number\ of\ Fertile\ \ Eggs}\ x100 \quad (8)$$