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Development and Calibration of a Solar-Powered Egg Incubator

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Abstract. *This study evaluated the effects of various climatic variables on the efficiency of a solar-powered egg incubator. Results showed that generated incubation temperature (GIT) and relative humidity (GIRH) all significantly impacted the incubator's performance. Low temperatures negatively affected egg embryonic formation and hatching rates, while high humidity levels resulted in poor egg quality. Additionally, it demonstrated that the incubator could be kept at the desired temperature of 34–38 °C and relative humidity of 56–86% for high efficiency. The study also discovered that more solar radiation resulted in more reliable and effective temperature control inside the incubator. The findings of this study offer significant contributions to the enhancement of solar-powered egg incubator designs and the optimisation of their efficiency under diverse climate scenarios.*

Keywords: *Egg, Incubator, Efficiency, Temperature, Humidity, Solar-powered.*

1. Introduction

In the past twenty years, the amount of chicken meat produced worldwide has climbed by over 108%, from 54 to 112 million tonnes, meaning that its percentage of total meat production has increased by 36% [1; 2]. It is projected that the global population will continue to expand and that the average person's consumption of meat will double by 2020–2022. This trend indicates that by 2022, the world's poultry meat consumption is expected to reach 128 million tonnes [3]. Hatcheries must maximise chick output, which involves more than just incubating more fertile eggs, in order to fulfil the increasing demand for poultry meat. Increasing the hatchability of healthy chicks with high survival rates and optimising the expression of their genetic growth potential under all field conditions are two things we believe are essential to hatcheries achieving high production efficiency in a sustainable manner today.

A technique called egg incubation allows eggs to be produced from chicks without the need for the mother hen to be present during the hatching process. In the normal process of egg incubation, the hen protects the eggs by producing warmth, which promotes the growth of the embryo [5;6]. However, as technology advances, incubation eggs to produce chicks at the appropriate time requires the use of artificial methods. For millennia, this man-made procedure has been refined to achieve increased effectiveness [7]. Despite numerous initiatives, epileptic power supply remains an issue in the majority of developing nations [8]. Low productivity and industry folding result from the production of poultry. Therefore, new energy sources are necessary for the poultry business to progress. For this reason, specialists in energy prefer using renewable energy, which has low production costs and is comparatively environmentally beneficial [9]. Although electrical incubators are effective, a sizable portion of the population in poor countries does not have access to the grid [10]. Poultry farmers use bush lamps to heat their farms in rural areas where 80% of the population lives. This practice poses environmental and health risks, as evidenced by high mortality rates, low feed conversion efficiency, and high rates of parasite and disease infection [11].

Having the proper, controlled temperature and relative humidity at various stages of the egg embryo's growth is one of the most important conditions for a successful incubation process. Solar energy is an endless resource that can thus supply this need with almost no risk to the environment [11]. Numerous studies have looked into how temperature affects the ability of viable eggs to hatch, as reported by [12]. The growth of embryos, their capacity to hatch, and their performance after hatching are all significantly influenced by temperature [3]. Throughout the incubation of about 21 days of fertilised eggs in an incubator, temperature is crucial, particularly in the first week. According to numerous studies, the most crucial elements influencing the quality of chicks and their capacity to hatch are the incubation conditions, which include temperature, humidity, ventilation, and turning.

This research study focuses on developing a solar-powered egg incubator with integrated sensors to control the climate parameters inside the incubating chamber, having theoretically taken into account the significance of consistent and regulated heat during the egg incubation process.

2. Materials and methods

The solar powered incubator with capacity of hatching 90 chicken eggs were fabricated and tested for efficient performance. The incubator has dimension of 1.05 m height and 0.65 m width constructed of insulated metal sheet. One tungsten bulb of 250 Watt was incorporated to heat up the eggs, a rheostat switch was also incorporated to regulate the temperature of the incubator between 34°C to 37°C, the fan was installed to ventilate and control the air needed by the incubator. A water tray was fabricated with thin sheet and placed on the bottom of the cabinet to increase and recover humidity in the incubator during the experimental period. A solar panel of 200W, 12V battery and a DC to AC converter (inverter) is also incorporated. The 12V battery connected to the inverter to convert the DC to AC current and the inverter is connected to the bulb through the rheostat. The charged solar supplies the required energy to heat up the incubator. The materials used for the development of the solar-powered egg incubator are: solar panel, 12 V battery, charge controller, temperature sensor, humidity sensor, fan, insulator, egg tray, thermostat; cables (wires and connectors), timer; water reservoir; solar charging indicator; heating source (250w) as shown in Figure 1.

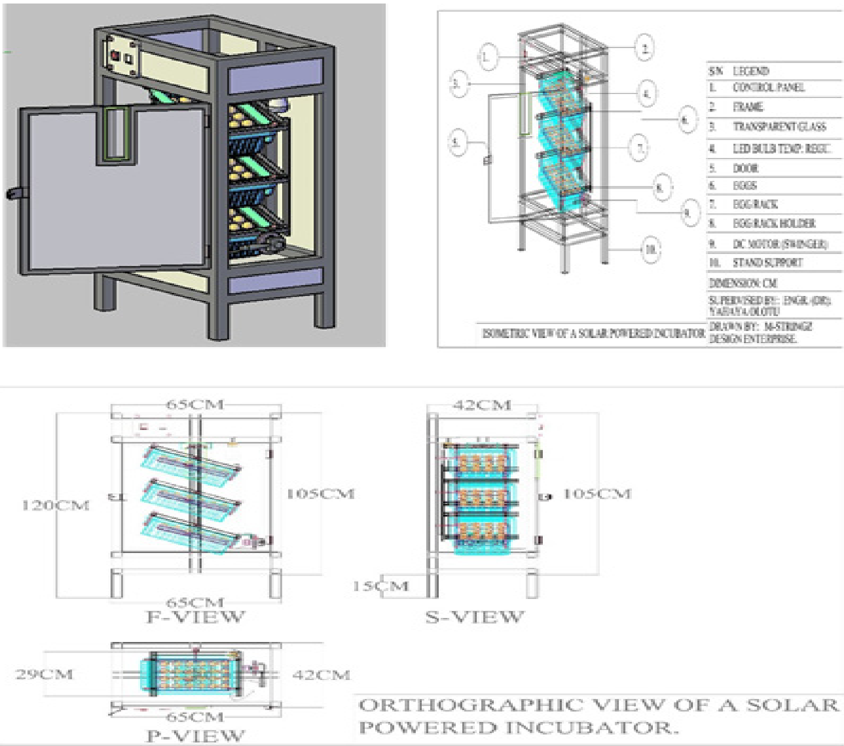

Figure 1. Sectional drawing of solar-powered egg incubator

2.2. Design consideration for solar-powered egg incubator

Incubator capacity

The capacity of the solar-powered egg incubator was designed using the expression as follows:

$$A = B \times C \times D \tag{1}$$

where:

A = Capacity of the solar-powered egg incubator
B = Height of the incubator

C = Width of the incubator
D = Breadth of the incubator

Design egg tray

A 90-egg capacity tray was designed using the equation 2:

$$P = Q \times R \tag{2}$$

where:
P = Cross sectional area of the egg tray
Q = Length of the egg tray
R = Width of the egg tray

2.3. Development relative humidity for solar-powered egg incubator

The relative humidity required for the incubation of eggs was calculated as the mass of water vapour (MVP) per unit volume over unit volume of air as shown in equation 3:

$$H = \frac{m_v}{V} \tag{3}$$

where:
H = relative humidity inside the incubating chamber,
mv = Molar mass of water,
V = speed of fan [13].

2.4. Design for heat generation

Heat generated from the incubator was determined as MCΔT, which implies that the heat required to raise the temperature of the incubator. as shown in equation 4:

$$Q_I = M_I C_I \Delta T \tag{4}$$

where:
Q = heat quantity,
C = specific heat capacity,
ΔT = change in temperature,
M_1= molar mass.

2.5. Design of ventilation hole

Incubation ventilation was designed as the product of the volume of mass flow in and out and cross sectional area of the incubator as follows:

$$V = (\prod d2/4)V \tag{5}$$

where:

V = Volume flow rate
A = Cross sectional area
V = Velocity

2.6. Working principle of the incubator

The temperature of incubator was maintained between 34-37°C using a set of pre-set temperature sensors which regulate and control the temperature and the relative humidity. Adequate control of the heat was maintained to avoid overheating and under heating which can affect the hatchability of the embryo. The moisture level was also maintained around using the creation of water vapour within the incubating chamber at 52-56% and later increased to around 87% in the last three (3) days at the hatcher tray. Water surface was maintained as large as the wideness of the egg tray and positioned inside a pan under the egg tray, this helps to humidify the system. This air regulation is necessary during embryo development for efficient output. This was achieved by using the fan to effectively circulate the air. The eggs were placed inside the trays and automatically turned at an interval three (3) minutes so that all sides get exposed to heat. This process continues and temperature regulated until the eggs are hatched. Plate 1 a-d show the assemblage of the solar powered incubator. The adopted circuit diagram for heating system for a solar-powered egg incubator is depicted in Figure 2.

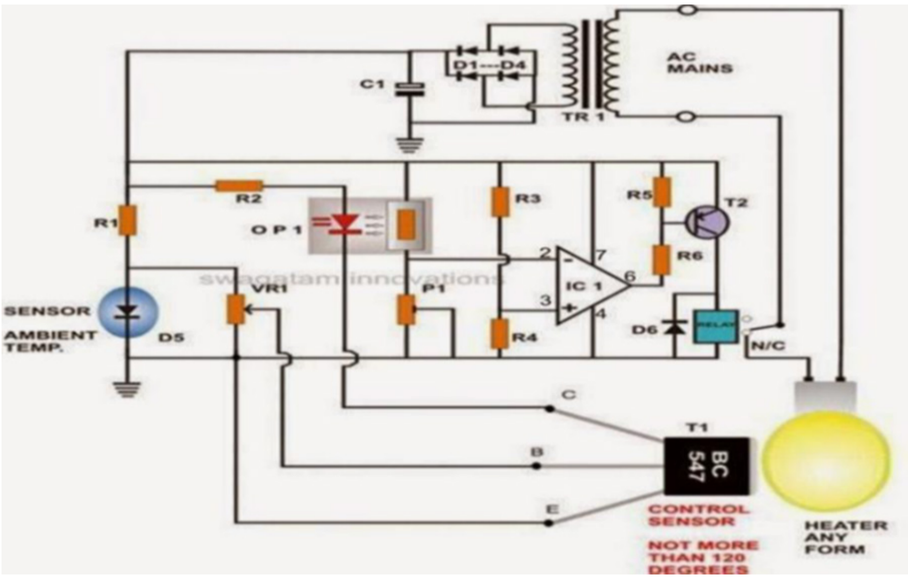

Figure 2. Circuit diagram for heating incubator
Source: [14]

Plate 1. Arrangement of incubator skeleton (a), assemble of incubator members (b), rotating egg tray inside incubating chamber (c), and completed solar-powered incubator connected to the solar power

3. Results and discussion

3.1. Calibration of solar-powered incubator

An evaluation of the system's performance was conducted by testing the egg incubator. 2024 July was the test month. Egg incubator was used for the preliminary test, which was carried out to determine the system's effectiveness. Temperature adjustments were made to the incubator using a thermostat. To prevent harming the eggs, the thermostat is designed to turn off and close the air duct when the incubating chamber reaches approximately 37 ^{o}C, as depicted in plate 2 a-b. This stops hot air from the thermal storage unit from entering the chamber. Likewise, if the temperature drops below 34 ^{o}C, the thermostat is supposed to activate and begin supplying hot air to the incubating chamber because a temperature lower than that will cause the chick's metabolism to slow down. The incubating unit's evaporative moisture pan is utilised to supply the necessary humidity. The incubating unit's evaporative moisture pan is taken out when the hygrometer reading reaches 65% or higher. Likewise, the evaporative moisture pan is returned if the hygrometer reading falls below 60%. At a predetermined 3-minute interval, the eggs in the incubating chamber are automatically turned.

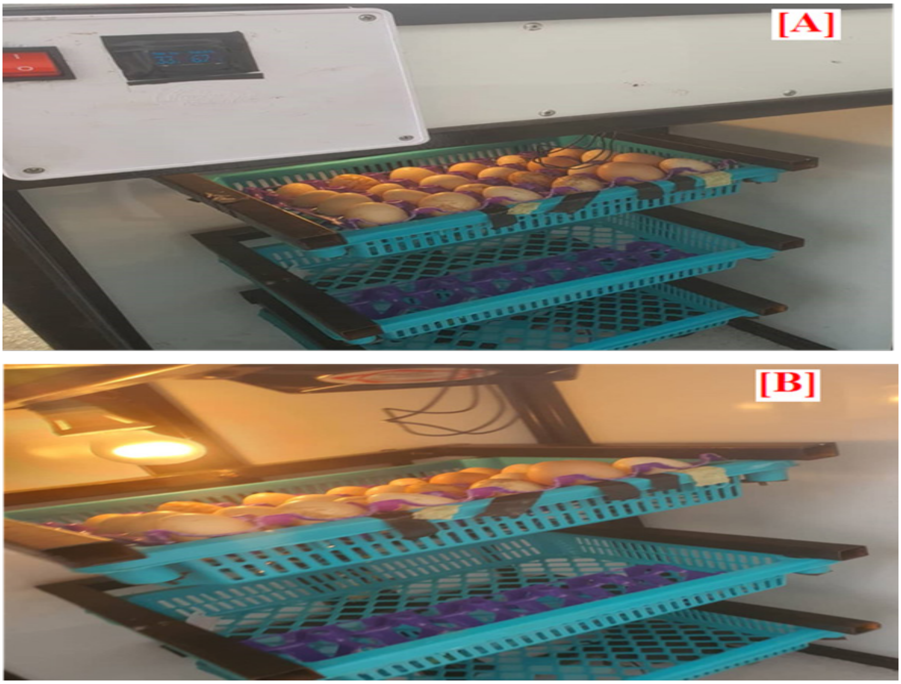

Plate 2. Incubating eggs with temperature and relative humidity datalogger

3.2. Generated climatic variables in incubation chamber

A 10-day average of relative humidity and temperature inside the incubating chamber was collected within 15- minutes through the built-in data logger. The result presented in Figure 3a showed that the generated incubation temperature (GTI) of 29.0 ^{o}C was recorded at 07:50 am, and the GTI increased steadily to 38 ^{o}C at 10:25 am, dropped to 34 ^{o}C at 11:35 am through 11:50 am, and rose to 36 ^{o}C at 12:20 pm through 12:35 pm, while at 01:05 pm the GTI declined to 35 ^{o}C. The regression line for the generated incubation and time showed that there was no relationship between GIT and the time of incubation with r and r^2 of 0.37 and 0.14, respectively. The fluctuations in the temperature of the incubating chamber could be attributed to possible heat loss or transfer to the surrounding incubator wall and the environment. Also, the possibility of energy drops and low solar radiation due to continuous rainfall could cause the heating element or bulb not to work perfectly. However, the fluctuation in the generated temperature does not have a significant effect on the performance of the solar-powered egg incubator. The finding is consistent with the study of [16], which revealed that a drop in temperature could have resulted from the poor performance of the solar PV system due to heavy overcast weather on that day. Despite this trend, the results generally showed that steady incubation operating conditions could be achieved and maintained using solar energy for sustained egg incubation. The embryonic formation of the eggs inside the incubator was measured starting on day 5 of the incubation process. The result showed that 85% of the eggs showed about 30% embryonic formation. Several studies have supported that 30% of egg embryonic formation at the initial 5-day incubation period is a good development for a higher hatchery rate. Figure 3b shows the effect of an average relative humidity on the incubation chamber for the ten (10) days of the experiment. It was observed that the average relative humidity of the incubation chamber ranged from 55–86%.

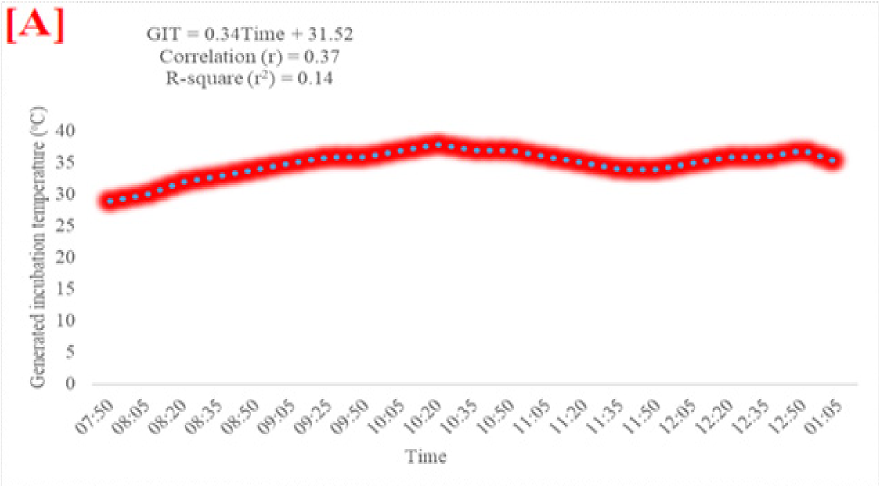

Figure 3.a. Generated incubation temperature

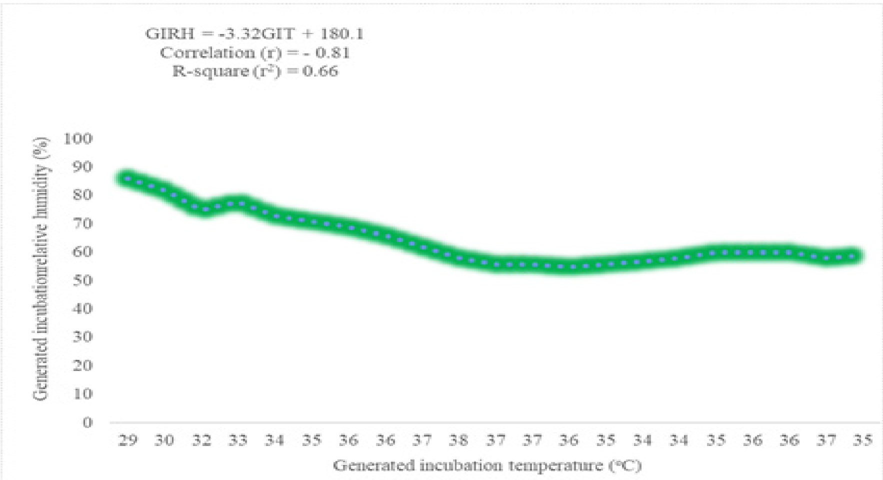

Figure 3.b. Effect of an average relative humidity on the incubation

The regression line between the generated relative humidity and the incubating time shows a correlation (r) and coefficient of determination (r^2) of -0.42 and 0.17, respectively. Low humidity will cause the eggs to lose too much weight, which means the air space will be larger than what is ideal. A large air space also means the chick will be smaller than normal. Small chicks are weak chicks, and weak chicks cannot always hatch on their own, and they may die just before or just after hatching. High relative humidity (RH) appears to have a detrimental effect on embryonic development, as evidenced by several studies.

Humidity and temperature have an inversely proportional relationship. Relative humidity will decrease with rising temperatures, making the air drier. Relative humidity rises as a result of the air becoming wetter as the temperature drops. 50% humidity at 21.1 °C and 50% humidity at 32 °C are not the same. Elevating the temperature in an incubator without adding water will result in a decrease in the relative humidity (RH%) because the maximum possible water vapour capacity increases with temperature. Both models experienced condensation on the cold portions of the canopy when the incubator's humidity level was high, but the sealed cavity wall's increased insulation lessened the likelihood of this issue.

4. Conclusions

The egg incubation system powered by solar photovoltaics designed and developed was evaluated with fertile eggs to ascertain its ability to incubate and hatch fertile eggs. The system was developed using locally sourced materials. During the first five days of incubation, 30.3% of the eggs showed signs of embryonic formation, according to tests conducted on the solar-powered incubator. Furthermore, it is anticipated that by the end of the sixteen (16) day incubation period, over 95% of embryos will have developed. Additionally, it demonstrated that the incubator could be kept at the desired temperature of 34–38 °C and relative humidity of 56–86%. The egg incubator was equipped with an automatic turning system, and it has been determined that this method of rotating the eggs throughout incubation is efficient. It was discovered that the incubator system is capable of successfully hatching chicken eggs. The use of solar incubators would provide an answer to a significant problem of power shortages for commercial chicken egg incubation in Nigeria.

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Conflicts of Interest: The authors declare no conflict of interest.

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