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Performance Evaluation of a Solar Powered Poultry Egg Incubator

Kifilideen L. Osanyinpeju[1*], Adewole A. Aderinlewo[1], Olayide R. Adetunji[2], Emmanuel S. A. Ajisegiri[1]
[1]Agricultural and Bio-Resources Engineering Department, College of Engineering, Federal University of Agriculture Abeokuta
[2]Mechanical Engineering Department, College of Engineering, Federal University of Agriculture Abeokuta
Email address: amkifilideenosanyinpeju@gmail.com, prof_4us@yahoo.com

Abstract— *The utilization of solar incubator would proffers solution to a major constraint of power inadequacy for commercial poultry egg incubation in Nigeria. A solar powered poultry egg incubator was developed and the main components included incubating chamber, control system and solar powered system. The developed solar incubator was 610 mm × 607 mm × 1649 mm in size with a capacity for 150 eggs. This study conducted performance evaluation on the solar powered poultry egg incubator developed. The performance parameters include, hatchability, the percentage of chicks with unabsorbed yolk, fully developed chicks but not hatched and banger (exploded eggs) which were evaluated by loading total of 147 eggs for 21 days. Throughout the period of incubation the temperature was maintained within the recommended range of 36 to 39 ^{o}C which was achieved with the aid of the temperature control system. The fertility of the eggs loaded was 64 % while the hatchability of the fertile eggs obtained was 44 %. The percentage of chicks that hatched, fully developed chicks but not hatched, chicks with unabsorbed yolk and banger (exploded eggs) were 44 %, 13 %, 40 % and 3 % respectively. The solar powered system proved to be a good source of power which could provide continuous supply throughout the period of the incubation without failing.*

Keywords— *Egg incubator, Solar powered system, Poultry, Hatchability, Fertility, Performance evaluation.*

I. Introduction

An incubator is a machine which provides fertilized eggs with moist warm air and artificial stirrer, as the embryo emerges into a chick in the short period of 21 days. Adeosun [1] describes incubator as box-like structure with controls for regulation of air, moisture and heat. The art of incubator by artificial means has been known for several thousand of years which is an ancient practice but it has been employed on a commercial scale only within the last 60-70 years [4]. The Chinese developed the first incubator at least as early as 246 B.C. [5] by using a mud barrel, heated with charcoals which bring about embryonic development; the eggs were turned by hand. These early incubation methods were often practiced on a large scale, a single location perhaps having capacity of 36, 000 eggs [13]. The Egyptian was first artisans to construct large incubators which was made from brick and heated by fires built in the same rooms where the eggs were incubated. According to Parkhurst and Mountney [26], the first large incubators in the United States were built in 1895 by Charles A. Cyphers. It was a 20, 000 eggs capacity room type incubator for duck eggs. NIIR Board of Consultants and Engineers [22] said that modern day hatcheries are impressive by using banks of incubators as many as one millions chicks in a week can be hatched.

One of the greatest miracles of nature is the transformation of the egg into the chick. When the egg is laid and its temperature drops below about 27^{o}C, cell development ceases [28] until proper cell environmental conditions are established for incubation process to resume. To better carry out an investigation on hatchability it is necessary to have knowledge of the way the embryo develops from day to day. This allows the hatchery manager to determine at what age/stage embryos may have died. This is important information when attempting to identify the cause of any poor results.

As reported by various researchers incubation conditions such as temperature, humidity, ventilation and turning are the most important factors significantly affecting the hatchability of poultry eggs and chick quality [9, 10, 12, 14, 33, 20, 21, 29, 32]. Meir and Ar [18] identified that the effect of temperature on the hatchability of fertile eggs had been examined by many researches. Wilson [31] reported that the increase in temperature during incubation was very critical for chick embryos. Moreover, it was revealed that growth was retarded or ceased and the incidence of poor second quality chicks increased as the temperature was raised. Temperature is a very important factor affecting embryo development hatchability [8, 31], and post hatch performance [31]. Temperature is extremely important during incubation (especially during the first week). Tazawa et al. [30] stated that chicken embryos are poikilothermic, relying on an external source (hen or incubator) to provide heat to develop and maintain normal metabolic functions.

Different incubator manufacturers have different means of circulating air: paddles, blades, and fans. In most cases, it is the pattern of airflow that is most important. In a poorly maintained machine insufficient air is circulated through the mass of eggs resulting in hot and cold spots, which in turn creates slow hatches, reduced hatchability, and lower chick quality [17]. Bell and Weaver [6] pointed out that incubator maintenance is critical to achieve optimum air flow**.**

Since the 1930s and 1940s, the poultry industry has become one of the most efficient producers of protein for human consumption [7, 25]. It expanded rapidly during World War II because of the shortage of beef, which require a much longer time to develop; only seven weeks are required to produce a broiler and five months to produce a laying hen. More recently, in response to public concern over dietary fat, poultry has again become a popular substitute for beef. The high demand for chicken, fowl and turkey in market, hotels, guesthouses and hospital has make chick production from developing embryo to become commercialized.

Adewunmi [2] carried out preliminary studies on A.C/D.C heat source cum kerosene lantern for egg incubator using maximum of 28 eggs for the performance evaluation. The maximum record of percentage hatchability in the incubator for the studies was 18.75% and the low in value was linked to inadequate air supply in the incubator.

Gbabo et al. [11] designed, constructed and evaluated the performance of an electric powered egg incubator. In their assessment of its performance, the developed incubator gave 33% hatchability out of the 25 eggs loaded. It was recommended that there is need for a constant supply to enable unobstructed operation of the incubator. Meanwhile, a microcontroller based egg incubator for small scale poultry production was designed and developed by Rogelio and Vinyl [27]. The egg incubator was powered by electricity supply and tested by loading 20 chicken eggs. The percentage egg fertility and hatchability were found to be 55% and 27%, respectively. The low hatchability of the fertile eggs was attributed to frequent power outage of 2 to 6 hours a day during the entire incubation period.

Mansaray and Yansaneh [16] designed, fabricated and tested a solar powered chicken egg incubator where 30 chicken eggs were loaded for evaluation. The results obtained indicate the fertility and hatchability of the eggs as 43.3% and 23.1%, respectively. It was stated that the low hatchability rate could be as a result of time and energy wasted in turning the eggs manually. This study carried out performance evaluation of a developed solar powered (photovoltaic power source) poultry egg incubator of capacity 150 eggs using an automatic control temperature and turning system.

II. Material and Methods

Materials

The materials used for the performance evaluation for the solar powered poultry egg incubator were eggs, obtained from a reliable source, the developed solar powered poultry egg incubator, the heating container for the heating section and measuring devices. The eggs incubated were from marshal boiler breed.

Methods

Timing of the Electric Motor

The turning of the eggs was automated using crank and connecting bar mechanism and powered by an electric motor. The electric motor serves as the mechanical power source or energy converter. The switching on and off of the electric motor were accomplished using on and off relay timer with contactor. However, for automated system it is recommended that the turner should be set to operate few seconds after every one hour. The electric motor with a speed reducer was used for the turning. The power of the electric motor was 1hp. A low speed electric motor is required to prevent cracking of the eggs due to vibration, collision and continuous agitation of the egg with the component of the incubator such as egg crate support, connectors (bolts), linkages, etc. More so, the angular velocity of the electric motor was determined by counting the number of oscillations the crank made in one minute. The counted value of the number of revolutions per minute (angular velocity) of the electric motor obtained was 16revs/min.

Never the less, the on relay timer was timed in such a way that few seconds of operation the egg crate change position from its neutral equilibrium to crest, next time of operation the position change from crest to neutral equilibrium, next neutral equilibrium to trough position, next trough to equilibrium position in that sequence. To achieve the above sequence of positions, the number of oscillations of reciprocation of the egg tray should be $\frac{3}{4}$ rev or $\frac{5}{4}$ rev. The turning mechanism was designed in such a way that when the crank of the electric motor make one complete rotation, the egg tray would also have made one complete reciprocation. Furthermore, the more the number of revolutions of the egg tray for the few seconds of operation of the electric motor the more the energy consumption for turning. For maximum optimization of energy to be used for turning $\frac{3}{4}$ rev was adopted and recommended. To determine the time of turn after every one hour for the above sequence of positions of egg tray, the formula below was used:

Time of turn after every one hour =

$$\frac{\textit{number of oscillations},\ \textit{rev}}{\textit{Angular velocity of electric motor},\ \textit{revs / second}} \tag{1}$$

The recommended number of oscillation = $\frac{3}{4}$ rev

Angular velocity of the electric motor = 16revs/min = $\frac{16}{60}$ revs/second

Time of turn after every one hour = $\dfrac{\frac{3}{4}\,\text{rev}}{\frac{16}{60}\,\text{revs/second}}$

Time of turn after every one hour = 2.8 seconds

Time of turn after every one hour = 3 seconds

The on and off relay timers were set to 3 seconds and 1 hour respectively throughout the incubation period. During the operation mode of the electric motor the egg crate moved through position $1 \rightarrow 2 \rightarrow 1 \rightarrow 3$ and stop after 3 seconds.

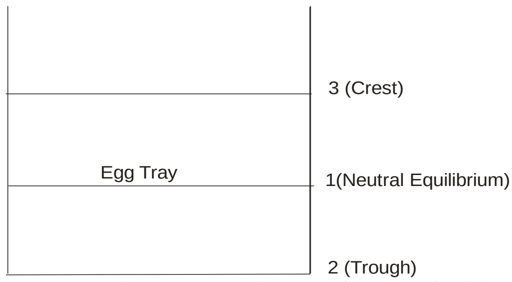

Fig. 1. The positions of the egg crate after every few seconds of the ‘on’ mode of the turning mechanism.

Afterward, for one hour the electric motor was at rest mode then it picked up after the one hour has lapsed. Simultaneous the egg tray then changed position from $3 \rightarrow 1 \rightarrow 2 \rightarrow 1$ stop, then after another one hour the egg crate changed position

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from 1 $\rightarrow 3 \rightarrow 1 \rightarrow 2$, after another one hour the egg crate changed position from 2 $\rightarrow 1 \rightarrow 3 \rightarrow 1$ and continue in that sequence.

Performance Evaluation on the Solar Powered Poultry Egg Incubator

To have successful hatchability of the fertile eggs performance test and evaluation were carried out on the egg incubator and the solar powered system and modification were made. This is to ascertain the workability of the developed solar powered poultry egg incubator for hatching of eggs. The egg incubator and the solar powered system were installed in Agricultural and Bio-Resources Engineering processing laboratory of Agricultural Engineering department at Federal University of Agriculture, Abeokuta.

Test Before Loading

Several preliminary tests and modification were done on the egg incubator and the solar powered system before loading the eggs to avoid or safeguared any intermediate failure during the incubation period.

Test After Loading

A total of 150 eggs were purchased while 147 eggs were successfully loaded for the performance evaluation of the egg incubator. The eggs were loaded on Tuesday, 23/12/2015. 1 egg out of the 147 eggs loaded was broken due to vibration during the incubation period and 3 eggs were broken during transportation of the eggs to the laboratory. Proper monitoring was done on the solar powered system and the egg incubator due to the sensitivity in the process of hatching of egg. More so, the inner temperature of the incubator was monitored using a thermostat and thermometer while the ambient temperature and relative humidity were monitored using the hygro-thermometer clock. For the turning of the egg trays, the on and off relay timers of the electric motor were under monitoring for any incidence of failure throughout the period of incubation. The turning mechanism worked effectively on the area of timing and there was no record of failure throughout the incubation period.

The tests carried out after the loading of the eggs which covered the whole period of incubation were; the effect of instantaneous ambient temperature on the instantaneous interior temperature of the incubator chamber, investigation on the daily average ambient and interior temperature of the incubator throughout the incubation period and performance test on the egg incubator.

The effect of ambient temperature on the interior temperature of the incubator during incubation period

The effect of instantaneous ambient temperature on the interior instantaneous temperature of the incubator chamber was monitored and readings were taken and recorded throughout the period of the incubation from 7: 00 to 18: 30. The reading obtained and recorded on 31/12/2015 was used for analysis.

Investigation on the daily average ambient and interior temperature of the incubator during incubation period

The daily ambient and interior temperature of the egg incubator and its average for the whole incubation period were taken and recorded.

Performance test on the egg incubator

Total of 147 eggs were loaded for 21 days (from 23/12/2015 to 13/1/2016) after series of tests on the solar powered system, egg incubator mechanism and the control system and there were assurance from the results obtained that the components would work continuously without breaking down for a second.

The probe (sensor) of the thermostat was placed in between tray AM 3 and AM 4 while the fan and the electric bulbs (heater) were positioned above tray AM 1. The fan blew the heat generated by the electric bulb through tray AM 1 down to tray AM 5. The trays have perforated holes and there were clearance between the egg crate support and the side wall of the chamber. This allow for easy transmission and distribution of heat in the chamber. The On and Off delay timers for the electric motor were set to 3 seconds and 1 hour respectively for the first 18 days and the turning system was switched off for the remaining period of the incubation. Meanwhile, the turning of the egg tray for automatic turning system was done at a low speed to prevent cracking or breaking of the egg causable by vibration, collision and continuous agitation of the egg with components of the incubator such as linkages, connectors, bolts, and crate supports.

The control systems for the automation were test run and all wires were tightly connected to afford partial contact. The control system was taken so much important because any failure of this section of the incubator could lead to complete breakdown of the incubation process for some hours before rectification could be made. These would automatically lead to reduction in hatchability.

For the first 14 days of incubation turning was done 3 seconds after every one hour for each day. This was done by setting the on and off delay timers of the electric motor 3 seconds and one hour, respectively. From 15th day to 18th day turning was done 3 seconds after every one hour for 12 hours during the day. After the 18th day of incubation, the egg crate supports were made horizontal and turning was stop. The crates of the eggs were changed after the 18th day of incubation to flat plate to allow for convenient hatching of the chick and prevent felling of the hatched chick since the crate levelled up with the edge of the crate support.

According to Ogunwande *et al.* [23] and Gbabo *et al.* [11] the biological performance parameters were determined using the following formulas:

$$\%\ \text{Fertility of eggs} = \frac{\text{number of fertile eggs}}{\text{total number of eggs}} \times 100\% \quad (2)$$

% Hatchability of the fertile egg in the chamber

$$= \frac{\text{number of hatched eggs}}{\text{total number of fertile eggs}} \times 100\% \quad (3)$$

The other biological performance parameters also evaluated were determined using the formulas as follows:

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% of Normality of hatched chicks

$$= \frac{\text{number of normal chicks hatched}}{\text{total number of hatchd chicks}} \times 100\% \quad (4)$$

% of chicks that were fully developed but not hatched =

$$\frac{\text{number of chicks that were fully develop but not hatched}}{\text{total number of fertile eggs}} \times 100\% \quad (5)$$

% of chicks with unabsorbed yolk =

$$\frac{\text{number of chicks with unabsorbed yolk}}{\text{total number of fertile eggs}} \times 100\% \quad (6)$$

% of fractured chick (broken leg or abnormality) =

$$\frac{\text{number of chicks with broken leg}}{\text{total number of chick that hatched}} \times 100\% \quad (7)$$

% of hatchery waste (chick that did not hatch) =

$$\frac{\text{waste of chicks that did not hatch}}{\text{total number of fertile eggs}} \times 100\% \quad (8)$$

III. RESULTS AND DISCUSSIONS

Table 1 shows the effect of ambient temperature on the interior temperature of the solar powered poultry egg incubator during incubation period. The result indicates that the ambient temperature had a great influence on the interior temperature of the incubator which made the interior of the incubator not having a constant temperature throughout the period of incubation. Figure 2 presents the regression line and correlation (linear relationship) between the interior and ambient temperature of the egg incubator using excel software application. Also, a first order model was obtained from the Figure 3 to predict the incubator temperature as a function of the ambient temperature.

TABLE 1. The effect of ambient temperature on the interior temperature of the egg incubator.

Time	Temperature, °C (Incubator)	Temperature, °C (Ambient)	Electric Bulb (time on), seconds	Electric Bulb (time off), seconds
7:00	36	24.7	20	5
7:30	36	24.6	20	5
8:00	36	24.5	17	5
8:30	36	24.6	16	6
9:00	36	24.4	14	7
9:30	36	24.9	14	7
10:00	36	25.2	12	8
10:30	36	25.8	12	8
11:00	36	26.8	11	9
11:30	37	27.1	10	10
12:00noon	37	27.3	10	10
12:30	37	27.6	9	12
13:00	37	28.3	9	13
13:30	38	29.0	8	14
14:00	38	29.9	8	15
14:30	38	30.3	8	15
15:00	38	30.1	8	16
15:30	38	30.2	8	17
16:00	38	33.2	7	20
16:30	39	33.7	7	24
17:00	39	32.2	7	28
17:30	39	32.7	7	26
18:00	38	31.6	7	20
18:30	38	30.1	8	12

(Day of record: Thursday, 31/12/2015)

The model obtained predicted the observed data well with a coefficient of determination (R square-value) of 0.9080 as shown in the same Figure 2. The R-value of the linear relationship between the ambient and interior temperature of the egg incubator determined was 0.9532.

The obtained R-value reveals that there was a strong positive linear relationship between the ambient and interior temperature of the egg incubator. This also implies that the ambient temperature of the egg incubator has great effect on the interior temperature making the interior temperature to be varied. But with the aid of effective temperature control system the interior temperature of the incubator was still kept within the recommended range of 36°C to 39°C by setting the thermostat to 39°C. This same observation was reported by Adewumi [6]. The thermostat acted as breaks and makes device to control the operation of the electric bulb. To maintain temperature in the incubator the electric bulb needed to be switched off and on while the length in which its operation varies with time. More so, it was observed from table 1 that as the ambient and interior temperatures were increasing the time the electric bulb was in operation was decreasing as time proceeded. This revealed that the heat required to maintain the interior temperature within the range of the recommended value reduced as the ambient temperature increase while its increased as the ambient temperature decreases. To enhance the hatchability of the fertile eggs the temperature of the incubator was maintain at a precise range value and temperature fluctuation was avoided.

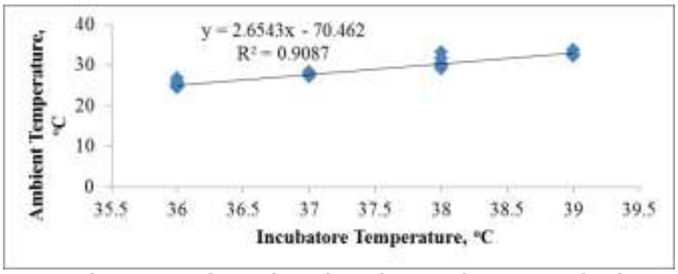

Fig. 2. The regression line and correlation between the interior and ambient temperature of the egg incubator.

Table 2 shows the average daily temperature of the incubator with day of incubation. Throughout the period of incubation the temperature was maintained within the recommended range of 36 to 39°C with average daily temperature ranging from 37.1 to 38.0 °C which was achieved with the aid of the temperature control system by setting the thermostat to temperature of 39°C for the first 18th day of incubation and 38°C for the last three days of incubation. Figure 3 indicates the average daily interior temperature of the incubator with days of incubation.

Table 3 shows the status of egg loaded in each crate after 21 days of incubation and table 5 shows the biological performance of the loaded eggs. The number of eggs that hatched in trays 1 to 5 were 06, 14, 7, 10 and 04 representing 14.63%, 34.15%, 17.07%, 24.39% and 9.76%, respectively of the total number of eggs that hatched (41) in the chamber . The hatchability of the fertile eggs in each tray 1 to 5 were 46.2%, 60.9%, 31.8%, 55.6% and 23.5%, respectively. The

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number of eggs that were fertile in trays 1 to 5 were 17, 07, 08, 10 and 11 representing 32.08%, 13.21%, 18.87% and 20.75%, respectively of the total number of eggs that were fertile (53) in the chamber. The fertilities of the eggs in each tray 1 to 5 were 43.3% 73.3% 73.3% 62.1% and 62.0%, respectively.

TABLE 2. The average daily interior temperature of the incubator with days of incubation.

Days of Incubation	Average daily temperature of the Incubator, ºC
1	37.6
2	37.6
3	37.5
4	36.9
5	37.8
6	37.8
7	37.1
8	37.2
9	37.5
10	37.4
11	37.9
12	37.7
13	37.3
14	37.8
15	37.2
16	37.8
17	38.0
18	37.8
19	37.0
20	37.2
21	37.0

(Day of record: 24/12/2015 to 13/1/2016).

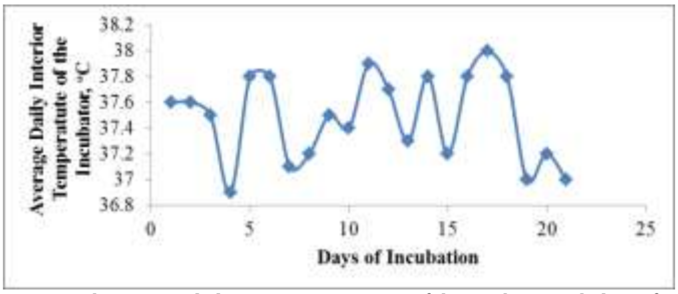

Fig. 3. The average daily interior temperature of the incubator with days of incubation.

The results in Table 3 also present that the number of eggs that have embryos with unabsorbed yolk in each tray 1 to 5 were 2, 7, 13, 7 and 8 representing 5.41%, 18.92%, 35.14%, 18.92% and 21.62%, respectively of the total number of eggs that have embryos with unabsorbed yolk (37) in the incubator. The percentages of eggs that have embryos with unabsorbed yolk in each tray 1 to 5 were 6.67%, 23.33%, 43.33%, 24.14% and 29.63% respectively. The number of eggs that have fully developed chicks but not hatched in each tray 1 to 5 were 4, 1, 2, 1 and 4 representing 33.33%, 8.33%, 16.67%, 8.33% and 33.33%, respectively of the total number of eggs that have fully developed chicks (12) in the chamber. The percentage of eggs that have embryos fully developed chicks but not hatched in each tray 1 to 5 were 13.33%, 3.33% 6.67%, 3.33% and 14.81% respectively.

Nevertheless, hatching stated on 21^{st} day of incubation and 17 chicks hatched that day. The total number of chicks that hatched on the 22^{nd} day of incubation were 14. Most of the chicks that hatched on the 23^{rd} day of the incubation died. The total number of chicks that hatched on the 23^{rd} day of incubation were 10. However, the chicks that hatched after 21^{st} day of incubation were so weak compared to the ones that hatched on the 21^{st} day of incubation. It was observed that the more the days away from the 21 days of incubation the more weaker the chicks hatched.

For that reason incubation was stop after the 23^{rd} day and diagnoses were done on the remaining eggs that did not hatch by breaking the eggs one after the other to find the cause of failure and record were collated for analysis so as to recommend corrective measures for further research. The late hatching was due to the continuous opening of the chamber at the last stage of the incubation which eventually retarded the development of the embryo. Although the temperature was maintained within the recommended range with the aid of the temperature control system but there was significant quantity of heat loss during the process which led to temperature fluctuation. The opening of the chamber could have been completely eliminated if the incubator was completely automated for relative humidity which could have enhanced the hatchability.

It was observed that relative humidity is another most critical factor of incubation during the point of hatching. More so, it was discovered during the course of the performance evaluation on the incubator that correct relative humidity was needed for successful emergence of the chick from the shell. Moreover, if the humidity is high the chick may feel uncomfortable and may eventually get drunk and die. Even if the embryo was able to develop to the last stage of incubation period due the correct temperature set, it would be difficult for the chick to hatch when the relative humidity is too low. If the relative humidity is low the shell would be so hard for the chick to pipe and to break through the shell would also be difficult. The study revealed that temperature was the determinant for embryonic development; it is the factor that simulates growth of the embryo. It was observed that the hatched chicks did not feed for few hours after hatch despite the availability of feeds. This may be due to the yolk absorbed by the chicks at last stage of development which could sustain them for three days without dying.

The candling of the eggs should have been done on the 7^{th} and 14^{th} day of incubation to discard the infertile eggs from the incubator system but the goal of the project was to afford opening of the incubator to the barest minimum and to see the effect of minimum opening of the chamber on the hatchability of the eggs. More so, considering the number of eggs to be candled, the amount of heat that would have been lost during the candling process and the possibility of temperature drop below recommended value for long minutes of candling, hence, candling was not carried out. The fertility of the eggs were known on the 24^{th} day of incubation during the diagnosing of the causes for failure of the eggs that did not hatch so as to recommend corrective measures on further research. However, the diagnoses were done on each egg that did not hatch in each tray by breaking the eggs one after the order and record were collated for analysis.

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On day 10 of the incubation it was observed that the speed of the tray had increased which was noticed during the refilling of the humidifiers in the incubator which lead to the jacking of the fourth tray back and front. This eventually caused one of the eggs in tray AM 4 to break. The broken egg was taken out and broken further. It was observed there was live embryo in it which eventually died some few seconds later. The picture of the developing embryo from the broken egg at the 10^{th} day of the incubation was shown in Plate 4. The observed change in speed was traced to the change in position of the control of the speed reducer of the electric motor from the set position. The control was set back to the pre-set position to ensure 16 revs/min for the crank so as the 3 seconds set for the on relay timer delay would make the egg tray to stop at crest, trough and neutral equilibrium. After the rectification there was no issue recorded for change in position of the control for the remaining period of the incubation.

Banger of eggs (exploded eggs) was observed doing the diagnosis of the eggs that did not hatch. The banger (explosion) of eggs may be as a result of infection of the eggs with fungi when they were laid. The numbers of bangers of eggs observed were 3. During hatching a heating section was installed for the hatched chicks because they required heat for their survival immediately after hatching. Also to dry up the chicks that were wet during hatching. Temperature stimulates growth of poultry birds.

Any little failure in the control system can affect the hatchability of the eggs since time to be spent in bringing back the control system to life would result to loss of life of the developing embryos. The automation should be well connected and all wires should be tightly fixed so as to avoid partial contacts. Partial contact can lead to failure and/or burning of components. Also, system failure may result into manual method for turning of eggs which has proven to be tedious for large scale production.

The study shows that the solar powered system proves to serve as a reliable source for the incubator which provided continuous power supply throughout the period of the incubation without failing in accordance to Okonkwo and Chukwuezie [24] report. The research on the incubator reveals that production of chicks from a developing embryo is a very sensitive task which requires proper monitoring.

Any little failure in any of the parameters of production during the period of incubation would lower the hatchability of the fertile eggs with temperature being the most critical parameter. It has been found that temperature is the simulative and most *critical* factor that brings about the complete successful development of the embryo that hatch into chick.

According to the laws of conservation of matter and energy which state that matter or energy can neither be created non destroyed but can be transformed from one form to another; the heat supplied by the electric bulb has only been transformed in the developing the eye, bone and flesh of the developing embryo (chemical energy). Also, Albert Einstein in his special theory of relativity indicated that mass (matter) and energy are interchangeable [15, 19]. The increase in size of the developing embryo during the period of incubation may be due to the conversion of the heat energy from the electric bulb into matter which leads to the development, division and multiplication of the cells and development of the various parts of the embryo.

If by measurement, the mass of the embryo increase as the incubation process proceed in the present of the heat supply while other factor remain constant, this increment may be as a result of the conversion of the energy from the heat to mass while the cells of the embryo serve as energy (heat) converter or processor leading to matter formation.

The study has shown based on observation that at the last stage of incubation humidity is another most critical factor that must be considered for successful hatching of the eggs that were able to develop till the last stage of incubation. Frequent opening of the chamber during turning and adding of water to the humidifier automatically affect the growing embryo and may lead to dead in germ or dead in shell of the embryo.

More so, it has been observed that the best result of hatchability of the fertile eggs in the incubator system can be achieved by design of the chamber such that there is minimal opening of the incubation system. Furthermore, relative humidity has proven to be another critical factor when the temperature is set accurately till the last stage of hatching but fully developed embryo finds it difficult to hatch when the relative humidity is not within the recommended value of 70% thus reducing hatchability.

However, automation of temperature regulation helps in conservation and optimization of energy usage in the incubator system. This increases the hatchability of fertile eggs due to minimal opening of the incubator chamber. It also reduces stress when it comes to large production of chicks as temperature control and turning was with little or no human intervention. Opening of the chambers was strictly for purpose of humidity control.

Furthermore, large scale production of chicks where number of loaded eggs is more than 100 require automated turning as manual turning eventually drops the temperature below recommended value. The incubator system was automated for turning to avoid large loss or reduction in the hatchability of the fertile eggs as drop in temperature below recommended value at the early stage of incubator affects hatchability significantly.

TABLE 3. The status of the egg loaded in each tray after 21 days of incubation.

S/N	Status	Tray 1	Tray 2	Tray 3	Tray 4	Tray 5	Total
1	H	06	14	07	10	04	41
2	I	17	07	08	10	11	53
3	U	02	07	13	07	08	37
4	F	04	01	02	01	04	12
5	B	01	01	-	-	01	3
6	G	-	-	-	-	-	-
7	BRV	-	-	-	01	-	01
Total		030	030	030	029	028	147

KEY

- ✓ H - Hatched
- ✓ I - Infertile
- ✓ F- Fully Developed Chick but Not Hatched
- ✓ U - embryo with unabsorbed yolk
- ✓ G - Dead in germ
- ✓ B - Banger (Exploded eggs)
- ✓ BRV – Broken egg due to vibration

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Meanwhile, the egg crate was turned at a low speed and once in every hour to prevent cracking or breaking of the egg causable by vibration or collision of the egg with the component of the incubator such as crate support, bolt, connectors, linkages, etc. Never the less, the automatic egg incubator model has proven far better in terms of efficiency in hatchability rate with less human monitoring, and hassle-free as observable in manual way of egg turning in the manually operated models.

Table 4 shows the performance evaluation of loaded eggs on each tray. From table 4, tray AM 2 had the highest hatchability (60.9 %) follow by tray AM 4 (55.6 %). The first tray would have had the highest hatchability since it was closed to heat source but due to the large number of infertile eggs it contained few eggs were able to emerge as chicks. It was also observed that the ambient temperature may have also contributed to the low hatchability in tray one compare to tray two. In the evening (between 16:30 and 19:30), incubation temperature reading taken was mostly 39^{o}C which was the reading between tray 3 and tray 4 since the sensor of the thermostat was installed there. With this the temperature on tray 1 could be higher than that value which was out of range of the recommended temperature for successful hatching of eggs. More so, the last tray had the lowest hatchability due its farrest away from the heat source. It was also observed that the ambient temperature may have also contributed to the low hatchability in tray 5. In the morning (between 6:30 and 10:00), incubation temperature reading taken was mostly 36^{o}C which was the reading between tray 3 and tray 4 since the sensor of the thermostat was installed there. With this, the temperature on tray 5 may have been lower than that value which was out of range of the recommended temperature for successful hatching of eggs

TABLE 4. The performance evaluation of the loaded eggs on each tray.

TRAY	**Number of hatched**	**Number of fertile eggs**	**Total number of eggs**	**Fertility of the eggs (%)**	**Hatchability of the fertile eggs (%)**
AM1	06	13	30	43.3	46.2
AM2	14	23	30	73.3	60.9
AM3	07	22	30	73.3	31.8
AM4	10	18	29	62.1	55.6
AM5	04	17	27	62.0	23.5
Total	41	93	146		

TABLE 5. The biological performance of the loaded eggs.

Biological Performance Parameter	**Evaluation**	**Percentage (%)**
Fertile eggs (Fertility)	93	64
Hatched eggs (Hatchability)	41	44
Normal chicks hatched (Normality)	21	51
Chicks with broken leg (Abnormality)	20	49
Chicks that hatched late	24	59
Chicks that were fully develop but not hatched	12	13
Chicks with unabsorbed yolk	37	40
Dead in germ	0	0
Banger of eggs (Exploded eggs)	3	3
Hatchery waste (chick that did not hatch)	49	53
Total number of eggs loaded	146	100

Plate 1. The solar egg incubator during construction and after 18th day of the Incubation period respectively.

Plate 2. View of the hatched normal chicks that are healthy and the hatched chicks with broken leg respectively.

Plate 3. View of the chick with unabsorbed yolk and chick that were fully developed but not hatched respectively.

Plate 4. Pictures of the developing embryo from the broken egg on the 10th day of the incubation period and view of the two of the hatched chicks in the chamber respectively.

Plate 5. The picture showing the heating section and the chicks after 3 weeks of incubation period respectively.

Plate 6. Picture of some of the chicks After One Month and picture showing one of the chick at Four Months, respectively

Plate 7. Picture of the Hatched Chicks after five months and picture of some of the hatched chicks after five and half months, respectively.

Plate 8. Picture of the One of hatched chicks with well grown straight Comb and picture of one of the hatched chick with well grown curved comb.

IV. CONCLUSION

Performance evaluation was conducted on the developed solar powered poultry egg incubator with a capacity of 150 eggs. The solar powered system provided uninterrupted power supply to the incubator throughout the period of incubation and the hatchability and fertility of the system were 44 % and 64 %, respectively. An automatic turning system was introduced in the egg incubator and the effectiveness of the mechanism of the turning of the eggs during incubation has been examined and found effective. The system was able to maintain the interior temperature of the incubator between 36 and 39 ^oC throughout the incubation period with the aid of the temperature control system and the energy source employed. It was found that the incubator system is capable to incubate and hatch poultry eggs effectively. The utilization of the solar incubator would proffers solution to a major constraint of power inadequacy for commercial poultry egg incubation in Nigeria.

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