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Fabrication and Performance Evaluation of a Solar Powered Chicken Egg Incubator

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Abstract **– In this study, *a* solar photovoltaic powered chicken egg incubator was designed, fabricated and tested to evaluate its performance. The major components of this design are the incubating unit, automatic temperature device and solar PV system. The incubating chamber was generally maintained throughout the incubating period at a temperature range of 36.8°C to 37.9°C and an average relative humidity of 67.3%. The results showed that the percentage fertility and hatchability of eggs were 43.3% and 23.1%, respectively. This low hatchability rate could have resulted from many factors including an overcast weather experienced on day three of the incubating period, poor storage of the eggs prior to loading in the incubator, time and energy wasted in the turning of the eggs, or maybe most of the eggs were faulty from the on-set. Engineering equations involving heat and mass balances were used to estimate the components elements of the incubator.**

Keywords **- egg, fertility, hatchability, incubator, solar energy**

I. INTRODUCTION

The use of artificial egg hatcheries is a key solution to traditional backyard poultry farming. Not only can it improve poultry production considerably, but also allow regularity in income generation, enabling subsistence farmers to transition into viable rural entrepreneurs [1]. Several sources of energy such as kerosene based systems, generators or the combination are used by poultry farmers to power incubators in rural Sierra Leone. The use of kerosene systems can lead to fire outbreak and are known to produce toxic gases which are harmful to eggs, poultry and poultry farmers [2]. Diesel-based generators pose technical and operational challenges that rural areas cannot currently cope with. The cost of diesel fuel reaching scattered rural communities is very high due to poor transport facilities, so that electricity generation becomes very costly. The use of diesel fuel is also polluting the environment and contributing to the country's emissions of greenhouse gases.

Poultry egg incubation is an activity that requires sustainable energy supply for efficient performance, operation and profitability.

With the Sierra Leone Government's inability to supply adequate and reliable energy to ensure energy security in the urban areas, it then becomes extremely unlikely that the rural areas will be considered in the short term especially considering their low load factor and the economy of grid connection. Rural areas that are not economically viable for grid extension will therefore have to be served by an alternative source of energy such as solar energy that is abundant, non-polluting and inexhaustible. A special feature of solar powered incubator is that it could harness solar energy by using available materials and is adaptable to both rural and urban poultry production.

The overall objective of this work is to design, fabricate and test the performance of a solar photovoltaic (PV) powered chicken egg incubator for the purpose of meeting the protein needs of the Sierra Leone rural populace using locally available materials. This incubator is expected to revive Sierra Leone's rural economy and empower smallholder farmers to create jobs and increase their income.

II. MATERIALS AND METHODS

A. Description of the Solar PV Powered Chicken Egg Incubator

A sketch of the constructed incubator chamber and pictorial view of the solar PV egg incubator setup are shown in Figures 1 and 2. The major components of this design are the incubating unit, automatic temperature device and solar PV system. The incubating unit was made up of inner and outer boxes constructed from plywood. The external length, width and height of the incubator are 75.8 cm, 53.6 cm and 67.4 cm, respectively. The space between the inner and outer boxes was filled with polystyrene material of about 1.5 cm thick and thermal conductivity of 0.03 W/m K to reduce heat losses. The inside of the cabinet was lined with aluminum foil to minimize heat losses through absorption and transmission through the walls to the atmosphere. The egg incubation chamber consisted of an egg tray with dimensions 69 cm x 47 cm x 3.9 cm and an evaporative moisture pan to control humidity.

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This pan was made up of a 1.3 mm thick aluminium sheet with a dimension of 59.2 cm x 44.1 cm x 7 cm and can take up to 10 liters of water. A digital thermocouple was positioned in a tight-fitted 6 cm diameter hole and at a height of about 20 cm from the bottom of the incubator. A mercury thermometer wrapped in wet sponge was positioned at the same height with the thermocouple through the right hand slot at about 15 cm away from it. Two air vents were positioned on either side of the incubator at a height of 14.2 cm from the bottom of the incubator and the two transparent windows fitted on either side of the box at a height of 22.1 cm from the bottom of the incubator helped to monitor and inspect the incubator chamber from outside without opening the incubator door.

The windows are of equal dimensions of 29.2 cm x 24.4 cm.

An automatic temperature device, designed and fabricated for this study, regulated and controlled the temperature of the incubation chamber so as to maintain its recommended set-point temperature. Heat supply in the incubation chamber was by a 100 watts automobile bulb (H3-JC-12V100W with luminous flux of 2000 Lm) powered by a solar PV system. The solar PV system consisted of four arrayed PV modules of 75 Watts and 12 Volts per module, two lead-acid batteries of 200 Amp-hours each and a 10 Amps charge controller.

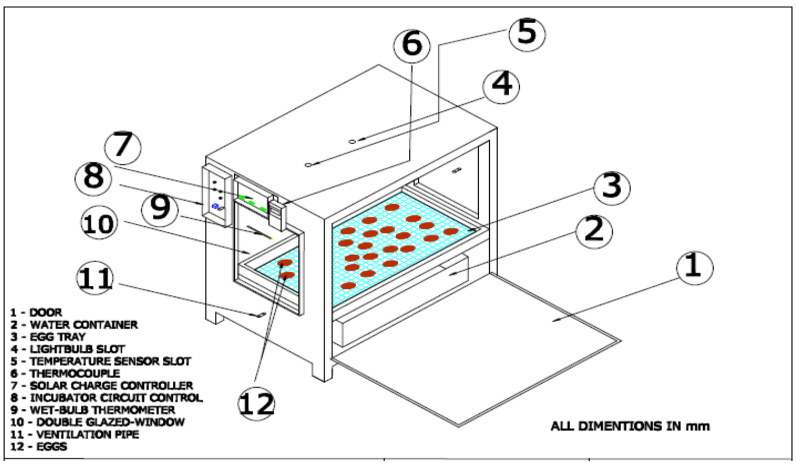

Figure 1. Diagram of the constructed incubator box.

Figure 2. Pictorial view of the incubator setup.

B. Methodology

The first operational task was to clean the incubator and then suffumigate it with potassium permanganate and formalin. The incubator was initially run empty for 48 hours without eggs to ensure that the levels of the operating conditions (temperature, relative humidity and ventilation) of the incubation chamber were right. The incubator was then loaded with thirty fertilized chicken eggs. The eggs were set with each marked 'x' with a non-alcoholic marker so as to make their turning easier. The eggs were turned manually about 45^o four times each day starting from the 2nd day through to the 18th day of incubation. This was done to avoid sticking of the egg yolks on the shell. The physical measurements involved the use of thermocouple type K to measure the ambient and incubator temperatures while a mercury thermometer wrapped in wet sponge was used to measure the wet bulb temperature, a value subsequently used to determine the incubator humidity. Engineering equations involving heat and mass balances were used to estimate the components elements of the incubator.

Eight days into the incubation period, the eggs were candled to determine their percent fertility and hatchability. Candling is the process in which eggs are held individually against light, with a view of detecting those eggs with dark spots or cracked shells or any other undesirable characteristic. It is an easy process that gives you assurance that your eggs are fertile and developing properly. The candling was done by holding the candler to the side of each egg around its blunt end and rotating the egg slowly so as to get the best view since the embryo often sits on one side of the egg. This test was done in the dark. Upon performing this test, infertile eggs and even bad eggs were identified and hence separated from the fertile eggs.

Fertility and hatchability are two major parameters that highly influence the supply of day-old chicks. Fertility refers to the percentage of incubated eggs that are fertile while hatchability is the percentage of fertile eggs that hatch. The fertility and hatchability percentages were determined using equations 1 and 2 [3].

$$Fertility\ Rate = \frac{Number\ of\ fertile\ eggs}{Number\ of\ eggs\ loaded} \times 100\% \quad (1)$$

$$Hatchability\ Rate = \frac{Number\ of\ eggs\ hatched}{Number\ of\ fertile\ eggs} \times 100\% \quad (2)$$

The shell temperatures of the eggs were also measured on the eighth day using a thermos scan. Checking for the shell temperatures of the eggs is equally important as that of candling.

In egg shell temperature analyses, the objective is to know if the temperature of the housing is favourable for the loaded eggs, a major factor contributing to the fertility and hatchability rates. The test was done in a clear room by placing the lens of the thermo scan about the same point on the egg shell as in the candling test. The temperatures were read from its screen.

III. DESIGN CALCULATIONS

A. Heat Load of the Poultry Egg Incubator

The heat balance equation of the incubator chamber was estimated by the following equation [2]:

$$Q_{load} = Q_{pv} + Q_{egg} + Q_{cond} + Q_{conv} \quad (3)$$

Q_{load} = heat load of the incubator, W
Q_{pv} = heat supply by PV panels, W
Q_{egg} = heat supply due to metabolic activities of eggs, W
Q_{cond} = heat loss by conduction through the incubator walls to the ambient, W
Q_{conv} = heat loss through air convention, W

Conduction heat loss was expressed using Fourier heat conduction equation as [4]

$$Q_{cond} = -\frac{kA\Delta T}{\Delta x} \quad (4)$$

ΔT = change in temperature, ^oC
A = total area of incubation walls, W/m^2
k = thermal conductivity of incubator wall, W/m^2 ^oC
Δx = thickness of incubator wall, m

Heat loss by air convention through the incubator air vents was expressed using equation 5 [4]

$$Q_{conv} = v\rho C\Delta T \quad (5)$$

v = rate of ventilation, m^3 /sec
ρ = density of outlet air, kg/ m^3
C = specific heat capacity of air, kJ/kg K

A heat production rate of 155 mW due to the metabolic activities of big eggs [7] was used for the design.

B. Solar Photovoltaic System

The following solar PV system design steps were considered in this study [5, 6]:

1. System Amperage

To determine the amperage of this 12 voltages system, the total power consumption needed by the incubator bulb system was divided by 12. Hence, this 100 watts incubator needed 100/12 ≈ 8.3 amps to function.

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2. Battery Capacity

A battery capacity that can power the system for 24 hours minimum is required. Since the solar PV is a 12 volt system, a 12 volt battery with an amp rating of 200 amps was chosen in this work. In order to calculate how much time the battery can last, the amp rating of the battery was divided by the amp consumption of the system. That is, 200 amps/8.3 amps will provide 24 hours of power to the 8.3 amps system.

3. Solar Panel

A solar panel powerful enough to charge the battery was selected. The solar panel's power output needs to be at least three times as high as the energy consumption of the system. Therefore, for this system using 100 watts, four 75 watts panels (totaling 300 watts) were used.

4. Charge Controller

A 10 Amp charge controller was used in this study.

IV. RESULTS AND DISCUSSION

The results showed that the incubator chamber operated at an average relative humidity of 67.3% and was mostly maintained within the incubation temperature range of 36.8°C to 37.9°C throughout the incubation period except on the 3rd day of incubation when incubator temperature dropped to 27.9°C as indicated in Figure 3. This drop in temperature could have resulted from the poor performance of the solar PV system due 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.

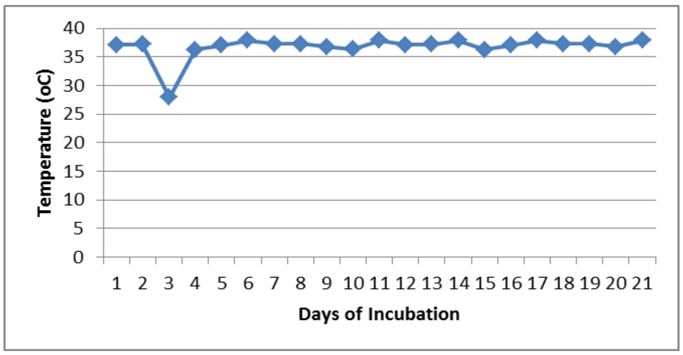

Figure 3. Average temperatures during the incubation period.

The candling test results showed that out of the 30 chicken eggs loaded, 17 were infertile and 13 were fertile as indicated in Table 1. Fertile eggs were identified upon seeing ring lines running across and/or red-like dark patches [9].

The egg shell temperature tests revealed that the temperature of 13 eggs were in the range of 37.8 and 37.9°C. Since this range falls within the acceptable incubation temperature range of 36.0°C to 38.9°C [7], it implies that these eggs were fertile. Out of the 13 fertile eggs, 3 were hatched at the end of the incubation period.

TABLE 1
CANDLING TEST RESULTS

Group	Number of Eggs	Development	Observation	Remark
1	10	Not visible	Clear	Infertile
2	7	Not visible	Large air space (bad eggs)	Infertile
3	4	Visible at the center	Visible patches of red strains	Fertile
4	9	Visible at one end	Lines running across (rings)	Fertile

Using equations 1 and 2, the fertility and hatchability rates were estimated as follows:

$$Fertility\ Rate = \frac{13}{30} \times 100\% = 43.3\%$$

$$Hatchability\ Rate = \frac{3}{13} \times 100\% = 23.1\%$$

The percent fertility and percent hatchability of the eggs estimated were 43.3% and 23.1%, respectively. Photograph of the day old hatched chicks is shown in Figure 4.

Figure 4. Photograph of day old hatched chicks.

The average percent hatchability reported in the literature ranges between 27% and 75% [2], [3], [7], [8], [9] and [14]. However, from the experiment performed, such results were not obtained. This study yielded 23.1% hatchability. This poor hatchability could have resulted from the overcast weather experienced on day three of the incubating period which resulted in a drop in temperature to 27.9^{o}C. Other factors that could have contributed to this performance include poor storage of the eggs prior to loading in the incubator, time and energy wasted in the turning of the eggs, or maybe most of the eggs were faulty from the on-set. It has been reported that temperature is the most critical factor for incubation as it affects both quantity and quality of hatching [8], [10], [11], [12] and [13]. A constant incubation temperature of 37.8^{o}C is the thermal homeostasis in the chick embryo and gives the best embryo development and hatchability [7] and [16]. These researchers recommended that incubator temperature should be maintained between 37.2^{o}C and 37.7^{o}C but suggested that a range of 36 - 38.9^{o}C is acceptable. Mortality is seen if the temperature drops below 35.6^{o}C or rises above 39.4^{o}C for a number of hours. If the temperature stays at either extreme for several days, the eggs may not hatch. [15] and [16]. Significant embryo mortality and lower hatchability in chicken eggs when they were subjected to an incubation temperature less than 35.6^{o}C has been reported [16].

V. CONCLUSION

A Solar photovoltaic powered chicken egg incubator was designed and fabricated using locally sourced materials so as to make it relatively affordable to the average poor farmer dwelling in the rural areas of Sierra Leone. The major components of this design are the incubating unit, automatic temperature device and solar photovoltaic system.

The incubating unit was tested at the Department of Mechanical and Maintenance Engineering, Fourah Bay College, University of Sierra Leone. The results yielded 23.1% hatchability and 43.3% fertility, but this can be improved if the constrains incurred during the tests such as fluctuating temperatures due to cloudy weather are overcome. The incubating chamber was mostly maintained within a temperature range of 36.8^{o}C to 37.9^{o}C and an average relative humidity of 67.3%. A follow-up study is underway to incorporate an automatic egg tuning system in the design with the view to saving the lost heat experienced in the manual turning.

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