



## DESIGN OF A SMART SOLAR HYBRID EGG INCUBATOR FOR SMALL SCALE POULTRY FARMERS

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### ARTICLE INFORMATION ABSTRACT

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In this study, an electro-mechanical device (incubator) was designed to provide temperature and humidity for fertilization of eggs. A 132 capacity egg crates and medium density fiber board plywood (MDF-plywood) with a 15mm thickness for the incubation chamber were used. A 200AH lithium phosphate battery, 300W capacity solar panel and inverter were used to power the 200W electric bulb and other incubator components in the time of power shortages. Incubation temperature of 37.5°C and average relative humidity of 45% were considered during the design. A 3D model of the designed incubator was produced using Solid works software package. The model provided some important information on the material properties of the proposed plywood for construction of the casing, the plastic egg crates and the egg turning tray. The required number of egg crates and egg turning trays were determined as 8 and 4 respectively with two plastic crates sitting on each tray. Heat generation and heat losses of the system were also determined as 139.482595W and 3.395925W respectively. The total power consumption of the designed incubator was 150.4159W. Design of a cost-effective solar hybrid eggs incubator (₦940, 200), with a dimension of 1100mm × 650mm × 1250mm for poultry farmers was successfully carried out with a hatching capacity of 1056eggs.

### 1.0 Introduction

An incubator is an electro-mechanical device that is used to provide temperature and humidity for fertilization of eggs (Kanu et al., 2016). Egg fertilization is an important factor in the hatching of poultry eggs. It is possible to hatch eggs without the consent of the mother hen. The fertilization of egg embryo remains a priority of any farmer since his profits depend on hatchability rate of the eggs, this embryo when mature well give birth to a chick. It is therefore necessary to manage the fertilized eggs with care which latter develop into a normal chicken. (Adegbulugbe et al., 2013) The eggs required warmness either naturally or artificially as the case may be. The natural method required the bird to provide the warmness or the required temperature by sitting on the eggs in an open space (Idoko et al., 2019). Poultry is a kind of domestic birds that can be kept at home by human so that their eggs are collected. It is second most widely eaten meat. Poultry farming include egg brooding and hatching. Incubation is a process whereby poultry undergoes to hatch their eggs. (Mohammed et al., 2015). Incubation is also being described as technology by which eggs are incubated and hatched with help of man- made technology called incubator. The incubator controls the temperature and humidity in preparation for hatching process, and also determines the fertility of egg with the moist warm air and artificial stirrer as the embryo emerges into a poultry within a period of 21 to 41 days (Kifildeen et al., 2018).

Hatching of eggs comes in two different ways; natural (where mother chicken provides the warm by direct contact with egg for the required period) and the artificial egg incubator technology which provides opportunity for farmers to produce chicks from eggs without the consent of the mother hen. Artificial incubation is one of the fastest ways of transforming eggs to chicks (Adetola et al., 2019). The most important difference between natural and artificial incubation is the fact that the natural parent provides warmth by contact rather than surrounding the egg with warm air (Salawu and Rukaiyat, 2020). Artificial incubation procedures of eggs were originated in both China and Egypt. China developed a method of burning charcoal to supply the required heat, the Egyptian incubator was developed by constructing a large brick incubator which was heated with fire right in the room where the eggs are kept for hatching (Ajani et al., 2020).

Modern poultry industry incubation requires mechanical systems to replace the mother hen for egg incubation which was commercialized into large scale only within the period of 60 -70 years (Ajani et al., 2020). The three important parameters for incubation of eggs are the relative humidity (warmed air surrounding the egg), temperature and egg turning in terms of angles of inclination of egg tray as it swing in either side of the axes within the incubator. The ambient temperature has a strong relation with the incubator as it forms the basis for calibrating the incubator chamber temperature against the ambient temperature, and this relationship can be used for predicting the incubator temperature at any given time for unknown ambient temperature (Kifildeen et al., 2018).

Solar energy has gain significant interest as means of providing the electricity to the incubator for incubation of eggs, this will have answer to the insufficient power constraints faced by poultry industries in remote areas. Continuous supply of electricity in Nigeria is a mirage due to the frequent power failure which also lead to the use of other sources like generators, kerosene and gas, therefore building and utilizing a solar powered egg incubator will improve the result of poultry chicken farming and the overall living of the farmers and communities in general (Kelebaone et al., 2019).

High demand in day old poultry chick by commercial poultry farmers has always been on the increase, since the process of natural incubation alone cannot sustain the poultry demand considering the fact that eggs are being exposed to diseases and predators due to lack of care by the mother hen, there ever increase in poultry meat all over our immediate environment in response to public concern over dietary fat (Kifildeen et al., 2018). Some incubators cannot be used commercially due to minimum numbers of eggs they can accommodate, their mode of operation and maintenance of power failure is also a hindrance to the development of the poultry industry which result to difficulties in the smooth running of the incubator for hatching large number of eggs, difficulties in sourcing of electricity from stand -by generator in order to compliment the shortage of power for the incubator (Kifildeen et al., 2018).

The significance of this research work is to improve the production rate and capacity of a day-old poultry chick for sustainable economic development. This design was carried out by considering locally source available materials to promote easy construction of the incubator. This work is based on the design of a smart solar hybrid eggs incubator with 1056 hatching capacity egg incubator for the hatching of chicken, duck, guinea fowl, and pigeon and turkey eggs.

## 2. Materials and Methods

### 2.1 Material Selection and Design Analysis

The research design is divided into two section, mechanical systems design, and electrical system design these two combines to give the hybrid egg incubator for hatching varieties of eggs. The mechanical section of the incubator consists of the incubator chamber, egg turning tray, rotation mechanism while the electrical sections includes the dc fan for humidification, and ventilation, intelligent hatch controller. The incubator design will be in such that the solar power will complement the shortage of electricity at the period of power failure.

In order to design the incubator system, the following consideration were made.

- i. Plastic crate with capacity of 132 eggs
- ii. Medium density fiber –board plywood (MDF plywood) of 15mm thickness.
- iii. Optimum incubation temperature 37.5 °C
- iv. Humidity within the incubator of average of 45%
- v. Capacity of the incubator 1056 eggs
- vi. Angle iron 3mm thickness.
- vii. Maximum distance between egg trays 150mm.

### 2.2 Design Consideration

Detail design analysis of incubator sections such as egg tray, incubator casing or chamber, strength of the wood is provided below

#### 2.2.1 Design of egg tray and incubator chamber

The egg turning tray was designed from an angle iron and plastic crates. Each of the tray contained 264 eggs and four trays. Since the incubator was designed to hatch all types of domestic eggs. Egg with the maximum mass was considered in the design of the egg turning tray. Area of the egg turning tray for 1056 eggs was obtained from equation 1.

$$Area = length \times breadth \quad (1)$$

Let “n” be the Number of eggs to be hatched in this case is 1056 eggs

$$C = \text{Number of crates required in the incubator} = \frac{n}{132} \quad (2)$$

$$\text{The number of egg tray} = \frac{\text{number of crates}}{\text{number of crates on each tray}}$$

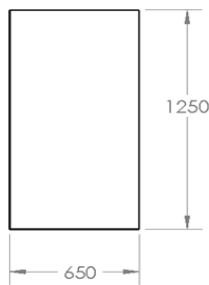
$M_e$  = the average mass of egg is 0.068kg

Where g is the acceleration due to gravity is 9.81m/s<sup>2</sup>

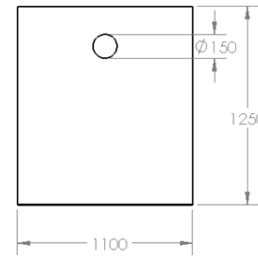
$$W_{\text{total}} = \text{total weight} = M_{\text{total}} \times g \quad (3)$$

$$\text{Weight of egg tray } W_{\text{tr}} = \frac{W_{\text{total}}}{8} \quad (4)$$

The incubator chamber was rectangular box like structure, which was designed to contain the egg trays and its turning mechanism, hatching tray, electrical components and circuit. The volume of the incubator was obtained from Figure 1a and 1b using equation 5.



**Figure 1a:** Side view of the incubator chamber



**Figure 1b:** back view of the incubator chamber

$$volume = length \times breadth \times height \tag{5}$$

### 2.2.2 Determination of Heat Requirement of the Incubator

The amount of heat generated in the incubator chamber is determined from the expression  $MC\Delta T$  (Ajani et al., 2020). The amount of heat required to raise the temperature of the incubator will be heat required to raise the temperature of air, eggs, egg turning tray, water, and the

$$Q_i = M_i C_i \Delta T_i$$

Therefore, the heat required to raise the temperature of air, eggs, wooden egg turning tray can be determine as follow.

Considering the heat generated in the incubator as  $Q_i$ ;

$$Q_i = M_i C_i \Delta T \tag{6}$$

To determine the heat required in the incubator, the volume of the incubator chamber is first determined as suggested by (Bharosh et al., 2021)

$$M_{air} = \rho_{air} \times V_{air} \tag{7}$$

Total heat required in the incubator chamber

$$Q_{inc} = M_{air} C_{air} \Delta T_{air} + M_s C_s \Delta T_s \tag{8}$$

Where:

(Ajani et al., 2020).

### 2.2.3 Heat Loss by the Incubator

There is heat loss through the wooden wall, 100% work is not guaranteed, there would be heat loss due to conduction. Considering the plane layer of the thickness  $dx$  with one face maintained at temperature  $T$  and other end as  $(T+dt)$ . The heat loss due to conduction can be estimated from the following equation. (Ajani et al., 2020).

$$Q = -KA \left( \frac{dT}{dx} \right) \tag{9}$$

The flow of air is a steady inside the incubator therefore it does not vary with time

Therefore

$$Qd_x = -kAdT \tag{10}$$

$$Q = -KA\left(\frac{T_{inc} - T_s}{X}\right) \quad (11)$$

Where Q is the heat

K is the thermal conductivity coefficient of the plywood (0.65) in this design

X is the thickness of the plywood 15mm.

Heat loss during the incubation is given as

Top and bottom of the plywood

$$Q_{pt,pbt,ps,pf,pb} = -KA\left(\frac{T_{inc} - T_s}{X}\right) \times 2 \quad (12)$$

Where Q = is the heat (Bala et al., 2020)

P<sub>f</sub> = plywood front, P<sub>s</sub> plywood side P<sub>b</sub> plywood back side and P<sub>t</sub> = is the plywood top P<sub>bt</sub> and bottom.

A is the area of the incubator's chamber, K is thermal conductivity coefficient (0.65 for MDF plywood (Ajani et al., 2020)

The quantity of heat is loss is calculated using the following expression

$$Q_L = Q_{PTB} + Q_{PSS} + Q_{PFB} \quad (13)$$

The actual heat required for the incubation is

$$Q = Q_L + Q_i \quad (14)$$

#### 2.2.4 Design of Ventilation

Ventilation is provided on the incubator in order to allow of air in and out of the incubator. It is the volume of mass flow in and out of the incubator.

Volume of flow rate = cross-sectional area  $\times$  velocity (Ajani et al., 2020).

$$\text{Where the volume} = \frac{pd^3}{4} \quad (15)$$

DC electric motor will be based on the torque generated by electric motor

$$T_m = \frac{\text{power}}{\text{angular velocity}} = \frac{60 \times \text{power}}{2\pi N} \text{ where } N \text{ is the speed of the fan.}$$

#### 2.2.5 Determination of Humidity

Humidity is moisture in circulation within the incubator, in order to estimate the humidity requirement of the incubator. It is calculated as mass of water vapor per unit volume over a unit volume of air. The humidity keeps the eggs from losing too much moisture in the process of incubation (Ajani et al., 2020).

Mathematically is calculated from the following relation

$$H = \frac{m_v}{v} \quad (16)$$

$$\rho = m_v R_v T \quad (17)$$

$$H = \frac{v}{R_v T} \quad (18)$$

Where

H = humidity,

$\rho$  = energy density or heat density of water,

T = temperature

M<sub>v</sub> = molar mass of water ,

R<sub>v</sub> = gas constant

V = volume of the incubator's chamber

### 2.2.6 Determination of Bending Moment and Shear Forces

The uniformly distributed load UDL will be the weight of the egg divided by the total span of the wood which is 1.1m in this design.

$$UDL = \frac{w_e}{L} \quad (19)$$

Shear force at point A and B will be calculated from the relation.

$$S_A = \frac{wl}{2} \quad (20)$$

And

$$S_B = \frac{wl}{2} \quad (21)$$

Then bending moment is the product of the force and the perpendicular distance from the supports. The distance is taken as 1/2 of the total length of the incubator chamber, in this case 0.55m.s

$$\text{Bending moment about the center } C \quad M_c = S_A \times dc \quad (22)$$

### 2.2.7 Total Power Consumption

The total power consumption of the entire incubator system can be calculated from the following relation.

$$\text{Total power consumption } PT = Ph + Pfs + Pfb + Pc \quad (23)$$

Where;

$P_i$  = Power of the incubator chamber

$P_{fv}$  = Power of ventilation fan

$P_{fh}$  = Power of humidity fan

$P_c$  = Power of control board

Hence total power consumption. (Bala, et al., 2020)

### 2.2.8 Power Requirements and Selection of Battery Solar Panel and inverter.

Total power consumption is added up to 150.4159W. Base on the total power requirement of the incubator, a 200AH lithium phosphate acid battery 12V, a 1KVA inverter and a 300W solar panel will be used to power the entire incubator. The maximum total power requirement of the incubator is 200W; therefore, a 200A/H battery will serve.

Since power is given by:

$P = IV$ , a fully charged 200A/H battery rate at 12V with a load of 200W will be discharged in 12 hours.

Where:  $P = 200W$ ,  $V = 12V$

$$I = \frac{P}{V} = \frac{200}{12} = 16.667A.$$

200A/H battery will be discharged in  $\frac{200}{16.667} = 12\text{hours}$

In order to sustained the insufficient electricity a solar panel of 300W capacity can be used to properly charge the battery and used.

## 2.3 Bills of Engineering Measurements and Evaluation

The production cost is evaluated based on market prices of materials, the overhead and labour cost which is presented under section 2.3.1.

### 2.3.1 Analysis of Bill of Engineering Measurements

The material cost depends on the market prices, given in Table I, as MC = ₦ 626,800

**Table I:** Price of Materials

S/No.	Description	Rate (₦)	Quantity	Amount (₦)
1	MDF Plywood 15cm	30,000	4	120,000
2	Plastic egg crates	600	8	4,800
3	Angle iron 3mm thickness	10,000	2 length	20,000
4	Aluminum sheet	4,000	½ sheets	2000
5	4.8W Direct current (DC) fan	4,500	1	4,500
6	i. Humidity and temperature sensor. ii. Intelligent hatch controller	95,000	1	95,000
7	4.8W Ventilation fan (DC fan)	4,500	1	4,500
8	Photovoltaic solar panels 300W	95,000	1	95,000
9	Inverter	70,000	1	70,000
10	Chain and sprocket	1000	1	1000
11	Electric motor (savor motor)	35,000	1	35,000
12	Battery 240V	175,000	1	175,000
<b>Total</b>				<b>626,800</b>

Direct labour cost was assumed to be 40% of the material cost from table I, that is,

$$DLC = \frac{40}{100} \times 626,800 = ₦ 250,720.00$$

Overhead cost was assumed to be 10% of the material cost;

$$OHC = \frac{10}{100} \times 626,800 = ₦ 62,680.00$$

$$Production\ Cost\ CP = 626,800 + 62,680 + 250,720 = ₦ 940,200.00$$

From the market survey conducted so far, the price of similar device ranges from ₦1,200,000 to ₦1,300,000. This indicates the cost effectiveness of the present device.

## 3. Results and Discussion

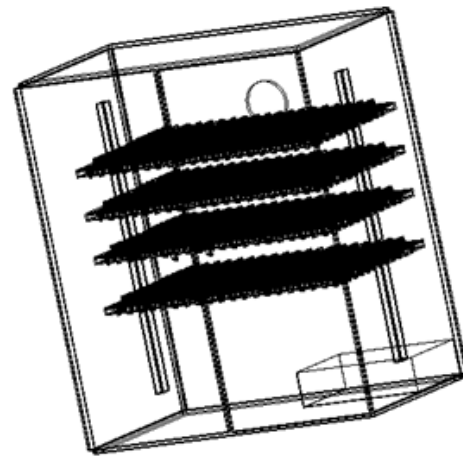
The design of the solar hybrid eggs incubator with a capacity of 1056eggs was carried out, the number of eggs trays and the crates, the heat requirement, heat losses and the strength of the plywood, power consumption were determined

### 3.1 Results

The modelling of the incubator is shown in Figure 2. The solid works software was used to draw the incubator chamber, egg crate and the egg turning trays. Each of the material properties was estimated from the solid works design software.



**Figure 2a:** Egg tray support incubator and egg trays



**Figure 2b:** Frame view of egg incubator and egg trays

Table 2 shows the number egg trays, number of crate per tray and number egg on each tray.

**Table 2:** Incubator specifications in terms of capacity number of crates and trays

Number of crates per tray.	2
Number of eggs per tray is	264
Total number of crate	8
Number of egg trays	4

The shear force and bending moment of the incubator were also determined and for both side and is presented in table 3

**Table 3:** Uniformly distributed load UDL shear force and bending moment

Uniformly distributed load	$38.2746KN/m$
Shear forces and point A	$S_A = -21.05103KN/m.$
Shear stresses force at point B	$S_B = 21.05103KN/m.$
Bending moment bending moment about the center	$11.5780665NM.$

Table 4 shows the heat generation heat loss of the entire incubator, 200Watt of heat is derived from electric bulb which is the main source of heat in the system

**Table 4:** The vale heat generation, heat loss

Heat generation and heat losses in the incubator	Heat generation is 200W. Heat required in the incubator = $139.482595J/s = 139.482595W.$ Total heat losses = $-3.395925W.$
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### 3.2 Discussion

The solid work software was used to design the incubator chamber, egg crates and egg turning tray, it provides vital information concerning materials and components, medium density fiber board plywood is suitable which earlier suggested by (Bala et al.,2020). The egg crate and egg



turning tray also is crucial in the designing of the incubator a plastics crate material was selected in the solid work software because of its light weight, availability and does not also conduct too much heat the weight and strength were determined from solid work drawings based on the dimensions of the crate, and egg turning tray, 4 egg trays are the required in order to accommodate 1056 eggs each tray containing 264 eggs.

In order to avoid failure on materials for construction the shear stress and bending moments were also calculated as shown table 2 above the shear stresses of the egg trays that carries a total of 1056 egg for both side are  $S_A = -21.05103KN/m$ ,  $S_B = 21.05103KN/m$ . Uniformly distributed load UDL was also determined as  $38.2746KN/m$ . The Bending moment bending moment about the center.  $11.5780665NM$ .

Table 3 showing the heat generation and losses as Heat generation is 200W. This value was estimated as the heat of the bulb which is the main source of heat within the incubator's chamber the heat required in the incubator is  $139.482595J/s = 139.482595W$ . Total heat losses =  $3.395925W$ . According to Ajani, et al., (2020) and Bala, et al., (2020) and others, the heat generated is sufficient to provide the required temperature of  $37.5^{\circ}C$  and average humidity of 45%. Other components such as the intelligent hatch controller, thermostat, and electric savor motor humidity fan and ventilation fan does not consumed much power.

The total power consumption of the incubator is  $150.4159W$ . Lithium phosphate battery 200AH 12volt capacity with 300W solar panel can provide the power to the incubator system, this battery will be discharge in a period of 12hours.

#### 4. Conclusion

The design of solar hybrid egg incubator for poultry farmers to contain 1056 involved, designing the incubator's chamber, egg crate and egg trays the simulation was done using solid works software in order to determine the properties of the materials for predicting some parameters, the strength of the materials such as Medium density fiber board plywood, angle iron steel, and plastic egg crate were determined and recorded, the bending moment and shear forces were calculated as  $11.5780665NM$ ,  $-21.05103KN/m$ , and  $21.05103KN/m$  respectively. Heat transfer principles were considered in determining the heat requirement of the incubator was also calculated as  $139.482595W$ . A 200AH lithium phosphate acid battery 12V and 300W solar panel were used to power the entire incubator, ventilation fan, electric motor, humidity fan. The temperature of  $37.5^{\circ}C$  and average humidity of 45% were achieved.

The following recommendations were drawn after successfully designing the incubator

1. Information obtained from this design should be made available to relevant agencies for direct uses.
2. There is need to construct and test the incubator of this capacity.

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