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Development and Evaluation of a Locally Designed Solar Integrated Egg Incubator

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Abstract: There is need for subsistence poultry farmers to maximize chick production to supply the increasing demand for poultry meat. This research developed and evaluated an egg incubator powered by a renewable energy source generated from solar modules. The incubator was incorporated with temperature and humidity sensors which measured and regulated the conditions suitable for the egg incubation. The direct current (DC) heater, sensor, microcontroller and DC fan provided suitable temperature and humidity for the eggs. The developed incubator was evaluated by monitoring the temperature and Relative Humidity (RH) readings over a range of time and the hatchability rate was also evaluated. The temperature within the incubator chamber ranged 37-38°C with an error margin of $\pm$0.1°C while the RH ranged between of 30-35% with an error margin of $\pm$5%. An average hatchability rate of 92% was obtained from the evaluation of the incubator. The evaluation gave a standardized temperature and relative humidity range of values necessary for incubation of eggs. The study has shown that solar energy could be used to successfully power incubator systems with good hatchability for the whole incubation period.

Keywords: Chick, fertilized eggs, candling, hatching; Incubation, Poultry, Solar, Machine Construction

I. Introduction

The incessant rise in the population of the entire globe necessitated the amplified demand of high-quality, protein -rich food products [1, 2]. The predicted 9.7 billion global population by 2050 [3] will entail an upsurge in the production of good quality food by 25%–70% [4, 5].

The rate of meat production across the entire world has almost increased by four times over the last two decades from 78 million tons in 1963 to 308 million tons in 2015 [6], the production of poultry meat has also encountered about 108% rise from 54 to 112 million tons), corresponding to about 36% increase of its portion in over-all production of meat [7]. The production of meat was projected to double by 2020-2022 due to the increase in the world population and consumption of meat per capita [8]. There is therefore the need for poultry farmers to maximize production of chicks so as to meet the increasing demand for poultry meat to achieve high production efficiency in a sustainable and affordable manner.

The poultry industry is currently plagued with varying challenges like unsuitable egg storage; extreme hotness especially in the last 3 days of incubation' inappropriate temperature regulation during incubation, and heredity

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issues. Other problems encountered by the poultry industries during egg hatching include improper handling, sanitation, and inappropriate record keeping [9]. Eggs must be stored and incubated carefully for a successful hatch.

The natural chick incubation process requires 20-21 days, which can increase up to 30 days for other birds which might not be suitable for hatching large number of eggs at a time [6]. Moreover, the natural incubation also comes with unpredictable number of eggs and risk of predators / parasites, low hatchability rate, exposure of eggs to harsh weather conditions and high possibility of abandonment of eggs [10]. There is need for maintainable supply of energy for adequate profitability, optimum operation and performance in poultry egg incubation. [11] developed and evaluated a kerosine heated chicken egg incubator which also comes with some cost of energy usage while literature is scanty on use of solar energy for incubators.

Solar energy is thus considered a good energy substitute, free of cost, non – polluting, clean and readily available. However, the quantity and intensity of the solar energy is dependent on position of the sun and weather conditions. The operational utilization of the radiation from the sun using appropriate technologies has the tendency to improve the energy availability for socio-economic practices and enhance the living standard of poultry farmers.

Most of the rural farmers in the developing countries do not have access to modern incubators because they are expensive. Also, non –availability of regular power supply and high cost of diesel necessitate the need to develop an affordable, available and readily accessible incubator which utilizes renewable source of energy most especially for poultry farms located in rural areas. The incessant problems associated with natural incubation and hatching process necessitated the need for the development of modern incubator in this study.

II. Materials and Methods

A. System Design Consideration and Specification

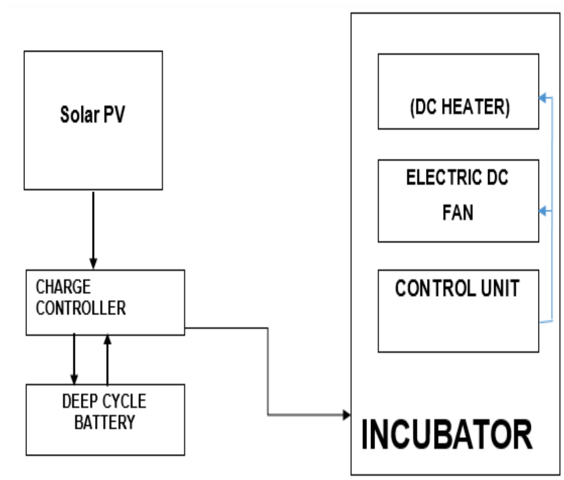
The major factors considered in the design and construction of the incubator include simplicity, economic, material availability, aesthetics and ergonomics. The study also considered the fact that modern egg incubators should be able to incubate and hatch various egg sizes [1]. The parameters of importance include humidity, temperature, and uninterruptible supply of power through the incorporation of a solar powered system.

i. System Description

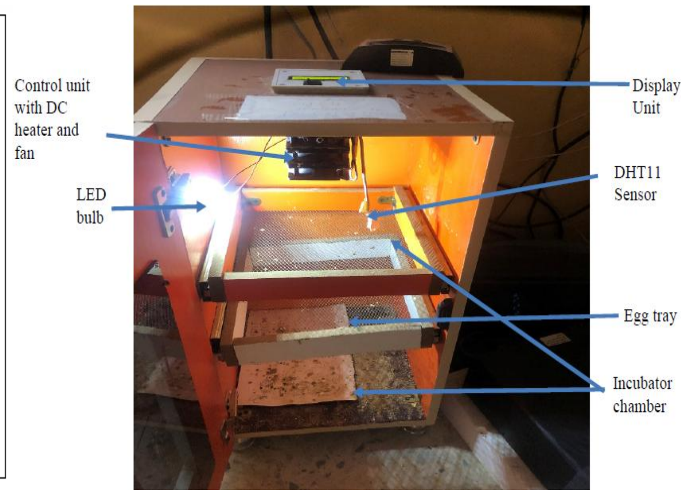
The developed incubator comprises a heating chamber made of a DC heater which generates and heat and a forced-convective DC fan aids the even distribution of the heat generated to the inner parts of the incubator. The Relative Humidity (RH) and uniform temperature conditions are monitored within the incubation chamber with the aid of sensors and microcontroller. The solar modules, charge controller and battery forms the power generating and supply section. Energy generated from solar panel are stored in the battery through the charge controller. The developed incubator has a LCD screen which displays the status and operating conditions of the incubator. Figure 1a shows the block diagram of incubator design system while Figure 1b shows the component parts of the incubator. The major components of the incubator are:

Incubator chamber: *Mansoniaaltissima*wood was used for constructing this chamber due to its strength and durability [12, 13]. The inner part of the incubator was lagged using fiber glass to prevent heat loss. The incubator chamber measures 38 x 35 x 67 cm (lwh) and can accommodate about 30 eggs.

i. **DC heater:** A 25 W heater was placed around the base of the fan inside the incubator chamber to ensure uniform heat distribution.



(a)



(b)

Figure 1: (a) - Incubator design system, (b) – Component Parts of the Constructed Incubator

DC fan: this component has 15 Watts rating and aids uniform circulation and distribution oftheheat supplied through the DC heater and also controls the RH and temperature in the incubator chamber.

Sensors: The sensor unit consists of the DHT11 which is was used for measuring the temperature and humidity..

Display unit: The display unit consist of an LCD and LED backlights. This section supports an interface between the incubation system and operator during initial setting of the machine. It displays the RH and temperature in the incubator.

Incubator Control System: The incubator control system (as shown in Figure 2) consists of microcontroller, transistor, sensor and LCD display unit. The microcontroller receives information from DHT11 through programme regulates the temperature automatically to be between the required 37 - 38°C.

System Power Supply: The incubator system is powered by a solar photovoltaic (PV) system, which is a renewable energy system that uses PV modules to change sunlight into electricity.

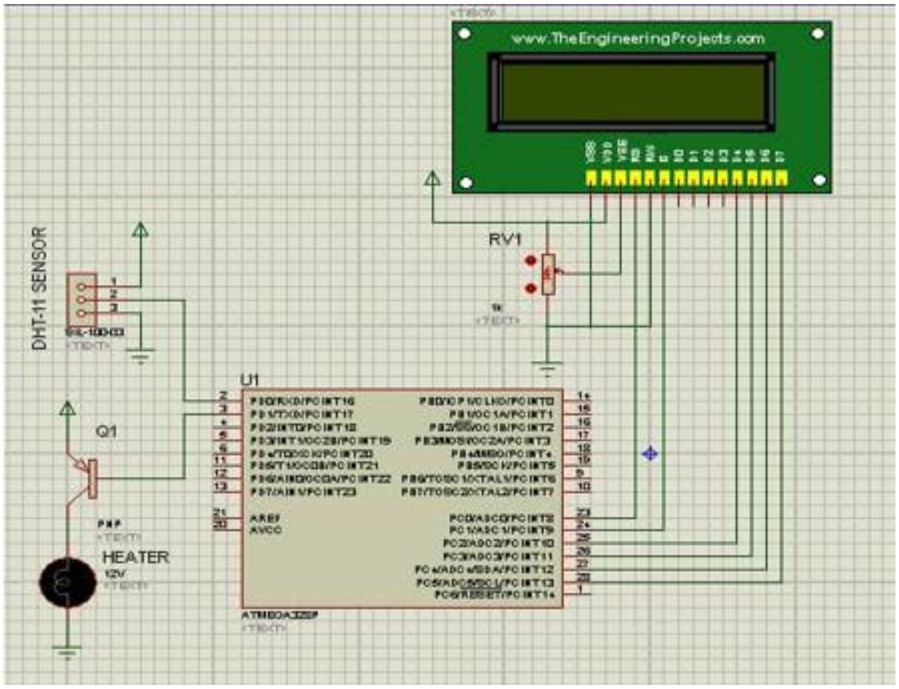


Figure 2: Incubator control system circuit diagram

B. Major Parts of the PV-based Solar System Components

The solar PV unit is made up of different mechanisms which depend on the location of site, application and system type. The connection of the solar powered system followed the order presented in Figure 3. The major mechanisms of this unit include:

PV module: this converts sunlight into DC electricity.

Solar charge controller: this controls the current and voltage coming from the PV to battery and stops overcharging of battery thus prolonging the entire life of the battery. It also provides the terminal to connect the incubator.

Battery: this stores energy for future use.

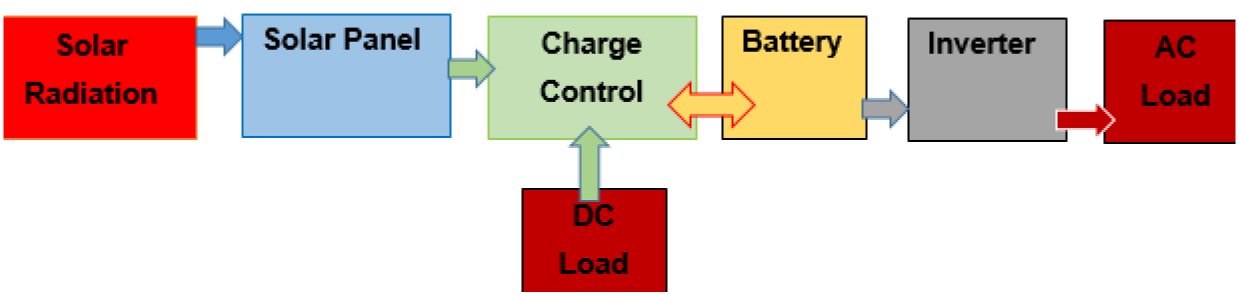


Figure 3: Solar Powered System Connection

C. System Power Requirement

The electric fan, control system and electric (DC) are the electric loads in the incubator powered by the solar system. These loads amount to 30Watts. It should be noted that the LED bulb is only needed whenever the operator wants illumination in the incubation chamber. The duration the bulb is needed is very small, hence, its power wasn't considered during sizing of parts [14]. However, forward approximation for the size of part caters for the LED bulbs. To power the incubator using solar energy, there is need to size the solar panel, charge controller and battery.

D. Sizing of the PV panel

Since the incubator is to be powered for 24 hours and the power requirement has been known to be 30 W, the total daily energy requirement is;

$30 \times 24 = 720 \text{ Wh}$

The size of solar module that can provide 720 WH is given below as [20];

$$SSM = \frac{TD_E}{ASH \times \eta_{SP}} \qquad [1]$$

Where: SSM is the size of solar modules in watt, TD_E is the total daily energy required, ASH is the daily average sun hour and η_{SP} is the solar panel efficiency.

The ASH and η_{SP} have been taken to be 4.38 hours and 89.35%, respectively, for this work as established by [14]. So, from equation (1),

$$SSM = \frac{720 \text{ Wh}}{4.38 \text{ h} \times 0.8935} = 183.98 \text{ W}$$

The closest available solar module to 183.98 W is 200 W. So, two pieces of 100 W mono panels were selected for this work.

E. Battery sizing

Equation 2 was adopted to obtain the battery size [20]:

$$SOB = \frac{TE_{WNS}}{V_{bat} \times DOD} \qquad [2]$$

Where: SOB is the size of battery, TE_{WNS} is the total energy required without sunlight, V_{bat} is the rated battery voltage and DOD is the battery depth of discharge. 70% was assumed for DOD. As stated earlier, the average sun hour considered is **4.38** hours. So, the average period without sun is 24 – 4.38 = 19.68 hours.

With

$TE_{WNS} = 30 \times 19.68 = 588.6 \text{ Wh}, V_{bat} = 12 \text{ V and } DOD = 70\%$

$$SOB = \frac{588.6}{12 \times 0.7} = 70.07 \text{ Ah}$$

As at the time of carrying out this study, the closest available battery to 70.07 Ah in market is 100 Ah.

F. Solar Charge Controller

This is a regulator which regulates the quantity of current going to and from the battery pack. They help to avoid overcharging and complete battery drain. These controllers vary based on the mode of voltage regulation, sizes, and features of display. In selecting an appropriate controller, the short circuit current of the solar panel is required with the maximum current demand from load. Therefore, the rating of controller should be higher than short circuit current of the solar panel and load current demanded. Since the load power has been known to be 30W (which is the summation of the loads obtained from electric fan, control system and electric DC), the current demand for the load is;

$$I = \frac{30\,W}{12\,V} = 2.5 \text{ A}$$

The short circuit current of each 100 W panel is 6.75 A, so, both panels have a total short circuit current of 13.5 A. With a load current of 2.5 A and panels' short circuit current of 13.5 A, the closest available charge controller of 20 A was selected.

G. Evaluation of the Solar Powered Incubator

No load test: The incubator was evaluated for a complete day while there eggs have not been loaded to regulate the in-built atmosphere and obtain essential RH and temperature values within chamber. The ambient humidity and temperature and those measured within the incubator were recorded.

Hatchability Rate: Hatchability is the ratio of hatched fertile eggs in every incubation period. Eggs obtained from local fowl were placed in the incubator to fill up the entire capacity. The eggs were turned at a period of 6 hours from the second day of evaluation to eighteenth day. A powerful professional LED light egg candler made with stainless steel tester was used to determine the percentage fertility and hatchability of the eggs on the eight and eighteenth day respectively. Equations 3 and 4 were used to obtain ratio of fertility and hatchability [15]:

$$\%\ fertility = \frac{\text{Number of fertile eggs}}{\text{number of eggs loaded}} \times 100$$

$$\%\ Hatchability = \frac{\text{Number of hatched eggs}}{\text{number of fertile eggs}} \times 100$$

H. Data Analysis

Duncan's Multiple Range Test (DMRT) was used for multiple comparison procedures to compare the means at 95% level of confidence also, coefficient of variation (CV%) was used to analyse the range of the mean deviations and Least Significance Difference (LSD) was used for the mean values that too close.

III. RESULTS AND DISCUSSION

The constructed incubator was analysed to determine the temperature fluctuation under no load test, hatchability rate and thermal efficiency. Results obtained are presented in subsequent sib-sections:

A. No Load test

Table 1 shows the ambient relative humidity and temperature and the respective incubation readings over a 24 day period. The incubator has been conditioned to sustain the environmental temperature within the chamber in the range of 37-38°C with an error margin of $\pm$0.1°C and the humidity in the range of 30%-35% with an error margin of $\pm$5%.The temperature readings falls within acceptable ratings for incubation of eggs. This was obtained using on-off Bang-bang control type used in controlling the RH and temperature in an incubator which gave a temperature fluctuation between 37-38°C. The width of the dead band (the interval around the starting point) is 1°C.

Table 1: Ambient and Incubator Relative humidity and Temperature

	Relative Humidity (%)		Temperature (^oC)	
Days	**Ambient**	**Incubator**	**Ambient**	**Incubator**
1	91.2	57.2	27.1	35.7
2	90.8	61.4	26.5	36.3
3	92.5	60.3	25.8	34.9
4	80.7	58.2	28.1	38.3
5	82	59.7	29.4	37.4
6	86.1	57.8	28.5	36.2
7	78.4	57.1	30.1	40.4
8	77.9	58.2	29.9	37.6
9	73.2	59	28.4	38.2
10	81	60.1	26.8	40.1
11	79.2	58.9	29.4	38.4
12	69.3	57.3	30	40.5
13	68.2	59	32.5	40.1
14	71.4	60.2	29.1	37.8
15	84.6	57.8	28.4	35.7
16	89.2	60	24.9	36.4
17	78.4	59.3	28.9	35.2
18	68.3	57.4	32.8	35.9
19	91.3	58.7	23.3	38.3
20	93.6	57.9	22.7	36.4
21	89.5	60.1	26.5	36.2
22	77.4	58.3	28.5	38.2
23	78.1	59	30.3	39.1
24	68.2	56.9	33.2	37.1
Mean	***80.85417***	***58.74167***	***28.37917***	***37.51667***
SD	***8.172157***	***1.189509***	***2.600798***	***1.647641***
CV (%)	***10.10728***	***2.024983***	***9.164462***	***4.391759***

Table 2: Hatchability Rate

Trial	**No of eggs in incubator**	**No of eggs hatched**	**Hatchability rate (%)**
1	5	5	100
2	5	4	80
3	5	5	100
4	5	4	80
5	5	5	100
Mean	20	4.6	92
SD	0	0.489898	9.797959
CV (%)	0	10.64996	10.64996

CV – Coefficient of variation, SD – Standard Deviation

B. Hatchability Rate

The rate of hatchability of the incubator after five different trials is presented in Table 2. An average hatchability rate of 92% was obtained from the evaluation of the incubator which is higher than 80% reported by [16] for natural incubation and [11] in the evaluation of a kerosene heated chicken egg incubator. The values are also higher than the 77% reported by [17] in the evaluation of mini incubator hatched indigenous chicken in rural areas of Bangladesh. Each trial took about 21 days on average to hatch the eggs once incubation begins. The heat source was put on and the temperature with relative humidity value was carefully taken before placing the eggs in the incubator. The hatching period of 21 days falls within the reported number of days for both the natural and artificial incubation process [17, 18, 19]. The hourly data obtained from the hatchability test showed that there were slight variations between the temperature readings and RH values from one hour to another, the values obtained falls within required conditions for egg incubation.

C. Bill of Engineering Measurement and Evaluation (BEME)

The material used in construction of solar powered incubator and coast associated are outlined in Table 3. Most of the materials were sourced locally and total cost of ₦112, 210 was expended which is affordable and falls within reasonable limit for processing machines [20].

Table 3: Bill of Engineering Measurement and Evaluation

S/N	MATERIALS	QUANTITY	RATE	₦
1.	Solar Panel 100 Watt	2	20,000	40,000
2.	Charge Controller 10A	1	5,000	5,000
3.	Battery 100AH	1	55,000	55,000
4.	LED	1	500	500
5.	Modern Furniture Board	1	8,000	8,000
6.	Italian hidges	2	400	800
7.	1¼ screw	5 dozen	42	210
8.	¼ screw	5 dozen	30	150
9.	1 screw	5 dozen	30	150
10.	Top bond	1	300	300
11.	Cutting	1	1000	1,000
12.	Small nail	1kg	100	100
13.	Net	2	500	1,000
			Total (₦)	**112,210**

IV. Conclusion

The incessant problems associated with natural incubation and hatching process has led to development of incubators which are mostly expensive to procure and hence grossly inadequate in developing countries as many rural farmers and small scale poultry farmers do not access to functional incubators. A solar powered incubator system was constructed and evaluated. The incubator has a hatchability rate of 93%. The developed incubator has a capacity of 30 eggs per turn. The study has also proven that solar energy could be used to successfully power incubator systems without the addition of an inverter. However, there may be need to explore other renewable sources of energy.

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