Development of a Solar Powered Poultry Egg Incubator for South West Nigeria

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Abstract*—Egg incubators with regular, effective and efficient operation have the capacities of providing enough poultry birds which can serve every household in Nigeria with sufficient amount of protein on daily basis. Although many commercial incubators in Nigeria have folded up due to epileptic and erratic electricity supply which disrupts and impairs the operation of the incubators and reduce their level of performance resulting into low production and high cost of poultry birds. In order to ensure an uninterrupted power supply and keep egg incubators in operation, a solar powered poultry egg incubator was developed. The main components of the incubator are 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. The angle of turn of the egg tray was fixed at 30o. The diameter of the crank of the turning mechanism was calculated from the maximum displacement of the egg crate support. The radius of the ventilation hole was based on the time required to empty all the air in the chamber. The total heat required in the chamber was analysed and evaluated. The size of the components of the solar powered system was based on the amount of energy needed and the duration of usage. Preliminary test was conducted on the developed solar powered poultry egg incubator. The diameter of the crank of the turning mechanism was 151 mm while the radius of the ventilation hole obtained was 13.30 mm. The heat loss through the walls by conduction, air convection and ventilation hole were 59.77 W, 10.9741 W and 0.0003222 W respectively. The total heat required was 85.44W. The energy consumption needed by all the loads in the incubator for the period of 24 hours was 10.48 MJ. The sizes of the solar panels, charge controller, batteries and inverter power designed and used were 480 W, 40 A, 400 AH and 2 kW respectively. For the duration of the days of groundwork the temperature was maintained within the recommended range of 36 to 39oC which was achieved with the aid of the temperature control system. The preliminary test on the developed solar powered system poultry egg incubator indicates that the egg incubator works effectively well within the recommended temperature required for successful hatchability.

***Keywords*— Incubator; Temperature; Relative humidity; Poultry; Solar powered system**

I. INTRODUCTION

Egg incubators with regular, effective and efficient operation have the capacities of providing enough poultry birds which can serve every household in Nigeria with sufficient amount of protein on daily basis. Incubation of egg is a process of transforming embryo in an egg into chick under favorable environmental condition with or without the consent of mother birds. There are two ways hatching of eggs can take place; one is by natural incubation which involves the broody bird sitting on a clutch of eggs while the other way is by artificial incubation which involves the use of incubator. The most important difference between natural and artificial incubation is that the parent provides warmth and stirring of the eggs by contact rather than surrounding the egg with warm air and provision of artificial stirrer.

A broody hen can just hatch about 10-12 eggs at once in 21 days, which reduces its productivity as it takes time to incubate and hatch the chicks [1]. Benjamin and Oye [2] noted that some large birds such as condors and albatross, may lay only a single egg every two years. For the world growing population at alarming rate, relying on the natural type of incubation is not enough, hence there is need for artificial incubation due to high demand of protein [3]. This way, a female bird just concentrates on laying eggs while the incubation is done for her artificially.

Incubator for egg hatching has made a great impact in the agriculture world. It stimulates economic growth and enhances foreign exchange earnings for the country as a result of its ability to largely increase the production of chicken, ostrich, duck, guinea fowl, turkey and their meats and eggs to the food industry when fully utilized. Venturing into artificial incubation would enhance national food security and provide a source of livelihood to the rural community.

The most vital factor of incubation is the constant temperature required for the embryo development over a specific period. The humidity is also critical; when the air surrounding the egg in incubation is too dry the egg will lose too much water to the atmosphere, which can make hatching difficult or impossible. Oluyemi and Roberts [4] recommended that the minimum and maximum temperature for the first 18 days should be 37.7oC and 39.3oC respectively. After 18 days of incubation, the temperature should be reduced from 37.8oC to 36.0oC until the chicks were hatched. Hence for the whole period of incubation, the temperature should be maintained within the range of 36oC and 39oC which is in accordance to the report by other researchers [4,5,6,7,8,9,10,11,12,13,14]

The ambient temperature has strong linear relationship with the incubator temperature [7]. The relationship between the incubator temperature and ambient temperature formed the basis for calibrating the incubator chamber temperature against the ambient temperature to produce a chart for temperature regulation [12] and this relationship can be used to predict the incubator temperature at any given time for a known value of the ambient temperature.

Nevertheless, Lourens et al. [15] ; King'ori [16]; Geneve [17] identified that overheating of the egg is much more critical than under-heating, it will speed up the rate of development causing abnormal embryos development in the early stages, and lower the percentage of hatchability. Running the incubator at 41oC for 15 minutes will seriously affect the embryos [18], while running it at 35oC for 3 to 4 hours will only slow the chick's metabolic rate [17,19]. Any rise in temperature above 40.5 °C is fatal [20]. Temperature drops will delay hatching but are less harmful than increases in temperature [20,21]. The production of chicks from a developing embryo is a very sensitive task which requires proper monitoring.

Komolafe et al. [22]; Oluyemi and Roberts [4] recommended that the minimum and maximum humidity values within 18 days should be 52% and 62% respectively. After the 18th days, the relative humidity should be increased from 55% to 71% until the end of the period of incubation which is in line with related research works. Hence for the whole period of incubation, the relative humidity should be varied between 52% and 71%.

Wilson [23] stated that it is best to turn the eggs more than three times a day for manual turning, they should be turned at an odd number of times so that the egg will not be in the same position every night because that is the longest stretch of time between turns.

More so, candling is very helpful during incubation, as it helps to determine whether the embryo is developing. The usual times for testing are 7th and 14th days of incubation, sometimes testing is done only once on the 10th day. The eggs must not be candled after the 18th day to avoid disturbing the unhatched chicks because they need to rest and should not be handled during the last few days [24].

In poultry egg incubation, sustainable power supply is necessary for all incubators for efficient performance and operation. If there is any breakdown in the power supply then the eggs lose their hatching value. The solar incubator does not face this problem. The solar incubators also have the advantage of been reliable, provide clean or friendly environment, light in weight and handy for carrying. Silent and power saving incubator is an innovative machine for rural poultry farming. Moreover, solar incubator creates employment opportunity for rural women and also improves their lifestyle with free green energy.

However, energy conservation has always been an important issue among the scientists and policy makers. Seeking a viable alternative energy source has always been the centre of attention particularly in the agricultural sector [25]. It was found out that solar energy application was the most attractive option for a sustainable energy supply in poultry production [26].

The use of solar energy has been gaining significance as a continuous supply of alternative power source, which seems to have an answer to frequent power constraints faced by farmers. Osanyinpeju [27] clearly expressed that putting more focus on solar energy optimum harvesting and utilization can eventually solve the problem of energy shortage by balancing up the energy demand of the nation. Kuye et al. [25] specified that continuous supply of conventional energy in Nigeria is a mirage, due to frequent power outage. This research work developed a solar powered poultry egg incubator for South West, Nigeria.

II. Statement of Problem

Many commercial incubators in Nigeria have folded up due to epileptic and erratic electricity supply which disrupts and impairs the operation of the incubators and reduce their level of performance resulting into low production and high cost of poultry birds. The use of generators greatly increase the running cost of commercial incubators thereby making day old chicks to become very expensive.

Electricity supply does not get to some rural areas but they have large areas of land where artificial incubator can be installed and operated and birds could be raised for boosting of the production of protein in the country.

The existing poultry egg incubator faces issue of loss of heat due to poor method of turning of the eggs and poor thermal insulation of the chamber which leads to temperature fluctuation and reduces the workability and hatchability of the system. They also encountered non- uniformity in the temperature in the chamber due to improper distribution of heat and uncontrollable temperature in the chamber due to improper temperature regulator.

III. Gather Pertinent Information/Do Background Research

Pertinent information on the design of the egg incubator must be gather to be able to address the issues facing the existing poultry egg incubator in order to proffers solution and differentiate itself from previous design.

Little or no accessibility to electricity supply control grid by customer utilizing the conventional egg incubator in the rural or remote area is one of the problems facing the people using conventional egg incubator which can be addressed by using the advantage of abundant availability of solar energy almost all year round. To harvest the solar energy, the most common way is to use solar panel in which the electric current generated by the solar panel can be stored by a battery and the battery discharges the current when the sun as set making the energy generated to be available if even when there is no sun shine.

With the knowledge of principle of energy transformation an electric heater (electric bulb) serving as energy converter can be connected to the solar system to generate the heat needed by the incubator to incubate the egg to produce the baby bird.

Another way to harvest the solar energy is to use solar collector which involve the passage of water or air through the solar collector. As the collector accumulates heat due to incident ray from the sun the water or air gets heated up. The heat accumulated by the water or air can be used to elevate the temperatue of the incubator by passing the heated water or air through heat exchanger in the incubator. Problem with this system is how to maintain and preserve the temperature of the water or air when the sun as set. In conclusion to the above problem the solar panel will provide the best solution to the irregularity of the electric power supply.

Another critical problem facing the conventional egg incubator is loss of heat through the wall of the chamber due to poor thermal insulation of the chamber which leads to temperature fluctuation and reduce the workability and hatchability of the system. This problem encountered by customer utilizing the conventional egg incubator was dealt with by utilizing the knowledge that temperature fluctuation can be resulted when there is migration of heat in an enclosure. To solve this problem a well-insulated material of low thermal conductivity which will have low ability to allow heat to pass through it should be incorporated in the wall of the incubator. This can also help in minimizing heat loss. Fiber glass has proven its ability to make enclosure of a system more energy efficient, reduce utility costs and retaining the desired temperature of the enclosed spaces. It was incorporated in the design of the solar incubator to help in minimizing heat loss taking advantage of it low thermal conductivity of 0.04W/mK-1and high R-value of R-25.

Furthermore, loss of heat and temperature fluctuation due to poor method of turning of the eggs in the chamber is another critical issue confronted by customer utilizing the conventional incubator which must be dealt with in order to reduce the amount of heat required for incubation so that the efficiency of the incubation process can be increased. Proper insulation of heating equipment is important for efficient utilization of heat energy. The turning of egg in existing egg incubator is done manually which lead to great amount of heat loss which can affect the hatchability value of the egg. Looking at the amount of heat that would be loss to turn 150 eggs where by the incubator system is opened in the process there is need for automated turning system which must be reliable and cost effective.

However, there are different turning mechanisms that can be employed in turning the egg which are the use of lever mechanism, crank and connecting rod mechanism, cam and follower mechanism, rack and pinion mechanism and so on. The crank and connecting rod mechanism is employed in the design of the solar incubator because it more convenient. The crank is mounted on the shaft of the electric motor and the connecting rods link the crank to the egg trays. As the electric motor is on “ON” mode the turning system is set into operation. The trays are hinged to the side walls of the incubator to facilitate smooth turning of the incubator. The crank undergoes rotary (rotational) motion and the connecting rods help in transmitting the motion to the trays making each tray to oscillate.

Never the less, the customer using the conventional egg incubator experienced problem of non-uniformity in the temperature in the incubator chamber i.e. improper distribution of heat in the chamber. This non- uniformity lead to non-uniform in the growth of the embryo of the eggs. This problem can be addressed by the introduction of fan in the system. Electric fan help in circulation of air and heat in the incubator chamber and allow uniform distribution of heat.

The last problem faced by the customer utilizing the conventional incubator is uncontrollable temperature in the chamber which leads to failure in hatchability. To address this problem a control was introduced in the system to control the temperature. In the design a thermostat was used to regulate and control the temperature in the incubating unit.

When the temperature in the incubating chamber increases to about 38.5oC, the thermostat is to switch off and shut the electric current flowing from the inverter to the electric bulb making the bulb to go off so that the temperature does not go beyond 38.5oC to avoid cooking of the eggs. Similarly when the temperature falls below 35oC, the thermostat is to switch on and start allowing electric current to flow through the electric bulb in the incubating chamber since a lower temperature than this will slow the chick’s metabolic rate. The temperature of the incubator is maintained between 36-38 degrees Celsius by thermostat controlled heater.

IV. Justification

Majority of the hatcheries have little or no access to the national grid system but operate at about 60 per cent below the installation capacity [12]. They have access if located in urban areas but even when there is access, there is still the problem of irregularities in the power supply. Generally, environmental pollution generated as a result of the use of fossil fuel as source of heat, unreliability and lack of access to grid power supply, high cost of running of generator and low performance of these sources (electricity, generator and fossil fuels) characterize the condition which hamper and adversely affect the establishment of medium to large scale poultry production outfits in the rural areas of the country [12].

Based on this set back, there is need to carry out further studies on other sources of energy to generate the power required by the incubator such as use of renewable energy source. Solar energy has advantage over most other sources of energy and it is abundantly available everywhere and almost all the year round. Osanyinpeju et al. [7] identified that the utilization of solar incubator would proffers solution to a major constraint of power inadequacy for commercial poultry egg incubation in Nigeria.

V. Literature Review

Many researchers had worked on development of egg incubator where various sources of energy were used to power the egg incubator.

Okeoma [29]; French [30]; Akuru et al. [31]; Anthony [32] stated that incubator could be electrical, biogas, solid fuel (charcoal), fossil oil (kerosene or gas, diesel – based generator) or solar types based on the source of energy. The various types of incubators have their merits and limitations [33,34]. Adewunmi and Falayi [35] observed that incubator having solid fuel, fossil, oil or biogas as their source of heat generate soots and other combustion products which could lower the percentage of hatchability of eggs.

Agboola et al. [36] performed work on increasing livestock production in Nigeria: development of cost-effective models for bird-egg incubator. In their model involving the use of still air and oil lamp as a source of heat for the egg incubator they indicated that still-air incubator is the most tedious process and in the model they obtained 33 % of success rate of hatchability.

Mansaray and Yansaneh [37] carried out work on fabrication and performance evaluation of a solar powered chicken egg incubator. They identified that diesel – based generator pose techanical and operational challenges that rural area cannot currently cope with.

Ahiaba [38] accomplished work on development and evaluation of a passive solar powered system for poultry egg Incubation. According to Ahiaba et al. [38] electricity supply in developing country such as Nigeria has remained inadequate and unreliable alternative methods of meeting the energy needs in agriculture and in the poultry industry specifically.

Graham et al. [39] Performed work on a thermal storage solution. They harvested solar energy using solar collector to power incubator. Meanwhile, Graham et al. [14] pointed out that there is drawback using solar thermal collectors, they heat water, air, oil or other flowing materials, and that heated material cannot simply be put into a battery unlike the electricity generated by a solar panel can do. The problem with his system is how the thermal storage unit would be able to store and release the heat when the sun as set and especially on days when the sun is hidden behind clouds.

Osanyinepeju et al. [40] fulfilled study on performance evaluation of mono-crystalline photovoltaic panels in FUNAAB, Alabata, and Ogun State, Nigeria weather condition. Osanyinepeju et al. [40] recommended that performance test must be carried out on the solar panels whenever it’s to be to use to power any load (egg incubator) to ensure that the provide solar PV solar panel would be able to produce the power required to power the load (egg incubator) without failing.

Rogelio and Vinyl [41] succeeded in designing and developing a microcontroller based egg incubator for small scale poultry production. In their work they put forward that a stable power supply is needed for optimal hatching performance of the incubator. In order to ensure an uninterrupted power supply and keep egg incubators in operation, a solar powered poultry egg incubator had been developed.

VI. Materials And Methods

A. *Materials - Construction Materials And Tools*

The construction of the egg incubator was carried out at the central workshop of the College of Engineering of Federal University of Agriculture, Abeokuta located at the back of the College of Engineering building. All the materials used for the construction were locally sourced. The main components of the incubator were; incubating chamber, control system and solar powered system. To establish the construction of the egg incubator, the machines and tools used were; hacksaw, bench vice, drilling machine, welding machine, riveting pin and riveting gun, bench grinder, hand grinder, bending machine, lathe machine, drill bit, scriber, drilling machine, measuring tape, punch, chisel, spanner, screw driver and plier.

The materials used for the construction of the incubating chamber were; 1 inch by 1 inch Angle iron for tray support, 1 inch square pipe for frame of the incubator, guage 16 Mirror Stainless steel, guage 16 Galvanized Steel, Ball and roller bearing, Bolt (long length) and Nut, Stainless Steel electrode, Mild steel electrode, Riveting pin, Fibre glass, Crank (cut plate), Linkages (long bar), Rubber for the front edge of the incubator and edge of the door, Egg crate, Bar for the crank, Screw and small bolt.

Automation was introduced to reduce the need for human involvement in the production of chicks using control system and information technologies. Moreover, it was used in the egg incubator to save labor, energy, improve quality, accuracy and precision of the incubator system with minimal or reduced human intervention. The parameters of the incubation process that required automation are humidity, temperature, turning and ventilation. Automatic control units were provided for temperature and turning to minimize human intervention in area of turning and provide accuracy and correct precision in area of temperature control.

For automatic control of the turning system the devices used were; on delay timer (controller), 2.5 mm cable wires, 2.5 mm cable wires, off delay timer (controller), contactor (electric control switch or electromechanical device) for the electric motor, 1 hp electric motor (actuator) with gear reducer, switch and capacitor. For automatic temperature control the devices used were; thermostat (controller), contactor (electric control switch or electromechanical device) for the thermostat, sensor (probe), heater (100 W electric bulb which serves as energy converter), dimmer (variable resistor) for heater, fan (for uniform distribution of heat) and dimmer (rheostat) for fan. While, for measure of the humidity the devices used were hygro-thermometer clock and sensor (probe).

Meanwhile, the material used for the installation of the solar powered system were; six 80 W Solar Panel (480 W), 200 AH Solar Batteries (400 AH), 40 A Solar Charge Controller, 2000 W Solar Inverter, 4 mm Core Wire (red and blue) and 16 mm Core Wire (red and blue).

B. *Methods*

The construction of the solar powered poultry egg incubator was executed at Federal University of Agriculture, Abeokuta (FUNAAB), Alabata a location at the outskirt of Abeokuta, Ogun State, in South West, Nigeria.

1) *Design methodology:* Design analysis and construction.

The incubator design calculations were based on the conditions required for the machine to work effectively. Some of the conditions were the temperature of the incubator which was to be maintained, relative humidity and the turning mechanism which turns few seconds after every one hour.

Heat required to raise the temperature of egg from 25oC to 38oC

$$Q_{egg} = m_{egg}\, c_{egg}\, \Delta T \quad (1)$$

Where,

Q_{egg} = quantity of heat required to raise the temperature of egg from 25ºC to 38ºC

m_{egg} = mass of eggs (Kg)

c_{egg} = specific heat capacity of egg ($KJ/Kg\,K^{-1}$)

ΔT = temperature difference (K)

The heat energy required for 200 eggs Q_{egg} was calculated as 471.276 kJ

This is the total heat required to raise the temperature of the 200 eggs from 25°C to 38°C. But this heat was provided gradually to avoid cooking of the eggs. The quantity of heat required to raise temperature of the 200 eggs from 25°C to 38°C in Watts is calculated as follow:

According to Bell and Weaver [42] the air in the incubator needs to be changed about eight times a day or once every 3 hours for adequate ventilation. This same quantity of air within every 3 hours contains the heat energy required to raise the temperature of egg from 25°C to 38°C.

T_{safe} = Safe time require to empty all the air in the chamber in seconds = $3 \times 60 \times 60 = 10800$ seconds

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$$\dot{Q}_{egg} = \frac{\text{the total heat required to raise the temperature of the eggs from 25 to 38°C}}{\text{Safe time require to empty all the air in the chamber in seconds}} \quad (2)$$

$$\dot{Q}_{egg} = \frac{471276}{10800} = 43.64\ W$$

Heat required to raise the temperature of air from 25°C to 38°C

Heat required to raise the temperature of air from 25°C to 38°C

$$Q_{air} = m_{air}\, c_{air}\, \Delta T \quad (3)$$

Where,

Q_{air} = quantity of heat required to raise the temperature of air from 25°C to 38°C

m_{air} = mass of air (Kg)

c_{air} = specific heat capacity of air ($KJ/Kg\,K^{-1}$)

ΔT = temperature difference (K)

The total heat required to raise the temperature of the air from 25 °C to 38 °C is calculated as 3713.07J

The quantity of heat required to raise temperature of the air from 25°C to 38°C in Watts is calculated as follow:

Since the air in the incubator need to be change about eight times a day or once every 3 hours for adequate ventilation i.e. after 3 hours the all the air would be empty and another quantity of air would flow into the incubator through the ventilation hole.

T_{safe} =Safe time require to empty all the air in the chamber in seconds =3×60×60 =10800 seconds

$$\dot{Q}_{air} = \frac{\text{the total heat required to raise the temperature of the air from 25 to 38°C}}{\text{Safe time require to empty all the air in the chamber in seconds}} \quad (4)$$

$$\dot{Q}_{air} = \frac{3713.07}{10800} = 0.3438\ W$$

Design of ventilation holes

From Theraja and Theraja [43]

Angular speed of the fan in rev/sec = V_{fan}= 0.05revs/seconds (5)

Taking the diameter of fan as 250mm

Radius of the fan=r=(d/2)=(250/2)=0.125mm (6)

Speed of fan in m/s= V_{fan} = =ωr=0.05 × 2 × π × 0.125=0.0393m/s (7)

Total cross-sectional area of the ventilation holes =A_t

Volume airflow rate through the ventilation hole= total cross-sectional area of the ventilation holes × speed of fan = $A_t \times V_{fan}$ (8)

Volume of the incubator chamber =total volume of the air in the chamber = $0.2359 m^3$. (9)

Safe time require to empty all the air in the chamber= T_{safe} =3hours= 10800seconds

$$\text{Volume airflow rate} = \frac{\text{Total volume of air in the chamber in m3}}{\text{Safe time require to empty all the air in the chamber in seconds}} \quad (9)$$

$$= \frac{Vchamber}{Tsafe} = \frac{0.2359}{10800} \quad (10)$$

Equating equation 8 and 9, we have

$$V_{fan} \times A_T = \frac{Vchamber}{Tsafe} = 0.00002184 m^3/s \quad (11)$$

$$A_T = \frac{Vchamber}{Tsafe \times Vfan} = \frac{0.00002184}{0.0393} = 0.0005557m \quad (12)$$

Since A_T =Total cross-sectional area of the ventilation hole= πr^2 (13)

$$A_T = 0.0005557 = \pi r^2 \quad (14)$$

Where, r = the radius of the ventilation hole

$$r^2 = \frac{0.0005557}{\pi} = 0.0001769 \quad (15)$$

$$r = 0.01330\text{m or } 13.30\text{mm} \quad (16)$$

Total Heat Loss through the Walls of the Incubator

The formula used to calculate heat loss by conduction was:

$$R = \frac{L}{AK} \quad (17)$$

$$Q = \frac{-\Delta T}{\sum RTH} \quad (18)$$

$\sum R_{TH}$ = the overall conduction thermal resistance

ΔT = temperature difference (K)

A = surface area of the incubator walls (m^2)

L = thickness of the incubator walls (m)

K = thermal conductivity of each wall (W/mK^{-1})

Q_{cond} = the rate of conduction heat loss through each wall

The calculated value of the rate of heat loss by conduction through the walls is 59.77 W

Heat Loss by Air Convection on the Outer Surface of the Walls

The formula used to calculate the heat loss by convection was:

From Mahesh [44],

The Grashof number for fluid (air) for the wall =

$Gr_{LT} = \frac{g\beta(TS - T\infty)(LcT)^3}{v^2}$ (19)

Where, g=acceleration due to gravity (m^2/s)

β = inverse of the mean film temperature (K^{-1})

ΔT=difference in temperature between the wall surface and the ambient air (K)

Lc =characteristic length of the wall (m)

v = kinematic viscosity of air (m^2/s)

From Mahesh [44], the Rayleigh number for fluid (air) on the outer wall= Ra= $Gr_L \times Pr$ (20)

Where, Pr=Prandtl number for fluid (air) on the outer wall

Gr = Grashof number for fluid (air) on the outer wall

Ra = Rayleigh number for fluid (air) on the outer wall

From Mahesh [44], Nu =$0.59Ra^{1/4}$ (21)

Where, Nu=Nusselt number for fluid (air) on the outer wall

Ra= Rayleigh number for fluid (air) on the outer wall

From Mahesh [44], The average convective heat transfer coefficient for the wall=$hc = \frac{NuKair}{Lc}$ (22)

Q_{conv} = hc A (T_S -T_∞) (23)

Where, Q_{conv} = the convective heat transfer on the wall of the incubator

hc= The average convective heat transfer coefficient for the wall

A= area of the outer wall

T_s =temperature of the wall surface,

T_∞ =air temperature

Q_{conv} = the heat loss through air convection, W

The calculated value of the rate of heat loss by convection (Q_{conv})= 13.1893 W

Quantity of Heat Loss by Ventilation Hole

Quantity of heat loss by ventilation hole was calculated using $Q_V=\rho V\Delta T$ (24)

Where, V= Ventilation rate (m^3/s) = $0.00002184 m^3$ /s (25)

ρ at 38.5°C was found to be 1.135kg/m^3

∴ Q_V = 1.135×0.00002184×(38.5-25)=0.0003346W (26)

Heat Production by Eggs

Heat production due to the metabolic activities of the eggs was estimated using the average of Lourens *et al.* [15] heat production rate of 137mW for small egg and 155mW for big egg. A heat production rate of 146mW was used for the design.

Therefore the heat generated by one egg due to metabolic activities = 146mW (27)

The heat generated by 150 eggs due to the metabolic activities = W= 146mW × 150 (28)

W= 21.9W (29)

Total heat loss in the incubator system

Total heat loss in the incubator system = Q_{LT}

$Q_{LT} = Q_{egg} + Q_{air} + Q_{cond} + Q_{conv} + Q_v$ (30)

Where,

Q_{LT} = total heat loss in the incubator chamber, W

Q_{egg} = heat energy required to raise the temperature of egg (Q_e) from 25°C to 38°C, W

Q_{air} = heat energy required to raise the temperature of air from 25°C to 38°C, W

Q_{cond} = the heat loss through the walls by conduction, W

Q_{conv} = the heat loss through air convection, W

Q_v = the heat loss by ventilation hole, W

Q_{egg}= 43.64 W, Q_{air} = 0.3438 W, Q_{cond} = 59.77 W, Q_{conv} = 13.1893 W, and Q_v = 0.00032225 W

Q_{LT} = 43.64 W + 0.3438 W + 59.77 W + 13.1893 W + 0.00032225 W

Q_{LT} = 116.94 W

Heat generated by 200 eggs due to the metabolic activities, W

The heat generated by the 200 eggs due to the metabolic activities = W_{egg}

W_{egg} = 29.2 W

Minimum quantity of heat required to balance the heat losses in the incubator system

Minimum quantity of heat required to balance the heat losses in the incubator system = $Q_{LT} - W_{egg}$

= 116.94 − 29.2 = 87.74 W

Minimum quantity of heat required to balance the heat losses in the incubator = 87.74 W. A heat source (electric bulb) with power rating 100 W was used to balance the heat loss in the incubator system. From the analysis Q_{TL} (Total heat loss) was 85.44W hence the design was viable.

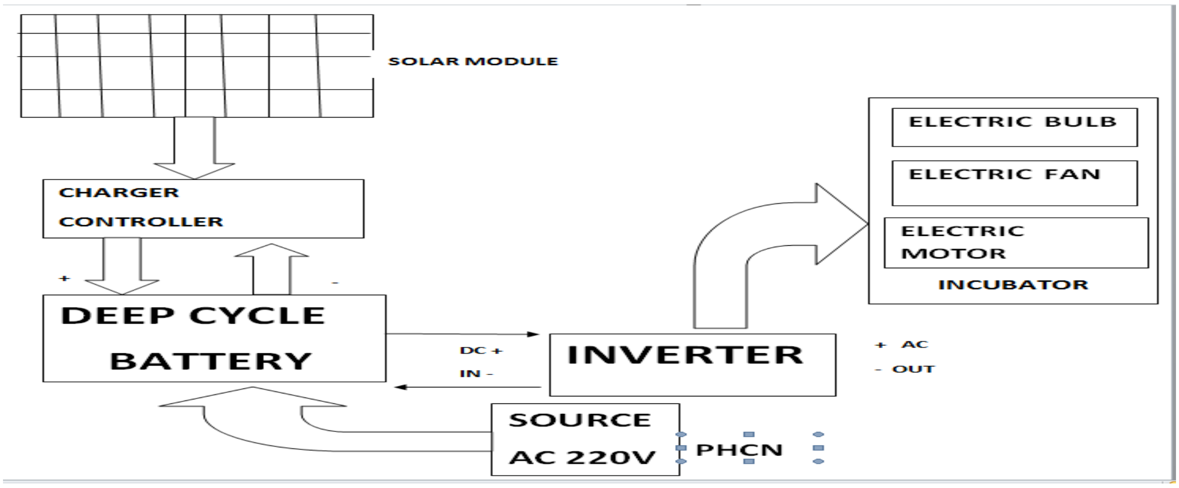

Fig. 1. Block diagram of the solar poultry egg incubator.

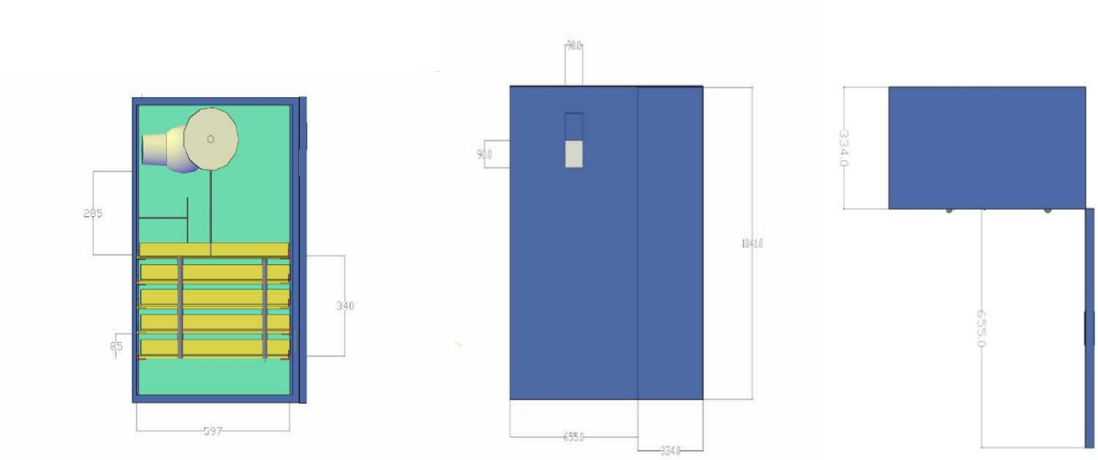

Fig. 2. The orthographic drawing of the designed solar powered poultry egg incubator using first angle projection.

Design of the Solar Powered System

The first step in designing a solar PV system for the egg incubator is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system which is as follows:

The electric loads in the incubator system are electric fan, electric motor and electric bulbs which are to be powered by the solar system.

Energy consumption of all loads in the egg incubator= $P_B T_B + P_M T_M + P_F T_F$ (31)

Where

P_B ,P_M and P_F are the power rating of the bulb, electric motor and electric fan respectively.

P_B ,P_M and P_F are taking as 1OOW, 20W and 1hp(750W) respectively.

Considering the starting torque of the electric motor where the electric motor draw a high inrush current during starting which is two times the operating electric current [45,46], the electric power of the electric motor was calculated as:

P_M =1hp×2 or (750 ×2 watts)=2hp or (1500watts)

Energy consumption of all loads in the egg incubator= 80×86400+10×86400+10×86400=8640000Joules
While T_B ,T_M and T_F are the time of usage of the bulb, electric motor, and the fan per day respectively.

Since the loads (electric bulb and electric fan) are required to be working for the whole day while the electric motor is to be rocking 2 seconds after every one hour throughout the whole day, then

T_B=24hours=86400seconds, T_M=2×24=48seconds,

T_F =24hours=86400seconds,

Energy consumption of all loads in the egg incubator= 100×86400+20×86400+1500×48=10440000Joules (32)

Sizing of the PV Modules (Solar Panel or Cell)

According to Osanyinpeju *et al.* [45] the average peak sunshine hour for the day in a particular place is an important parameter in designing the size of the solar panel and obtaining the wattage of the solar panel needed for powering a particular machine in that particular location. To calculate what size of solar panel that will be required for the solar poultry egg incubator this was determined as follow:

Size of solar modules in watts $= \frac{total\ daily\ energy\ requirement\ in\ Joules}{total\ seconds\ of\ sunlight\ during\ the\ day\ in\ seconds}$ (33)

During the course of study carried out by Osanyinpeju *et al.* [47] on the investigation of suitable time for the performance measurement and evaluation of mono-crystalline photovoltaic panels at Federal University of Agriculture, Abeokuta (FUNAAB), Alabata, Ogun State at a location where the designing of these solar panels were going to be installed the estimated average peak sunshine hour obtained for the locality was 6.4 hours.

So the average peak hour of sunshine was taken as 6.4 hours or 23040 seconds, we have:

$$Size\ of\ solar\ modules\ in\ watts = \frac{10440000}{23040} = 453.125\ Watts$$

or 453.125 J/s

480Watts power rating of solar panel would be needed.

Size of Batteries

To determine the size of the battery (total capacity) the equation below was used:

$$The\ size\ of\ battery = \frac{total\ energy\ requirement\ for\ period\ without\ sunshine}{Nominal\ battery\ voltage} \quad (34)$$

Taking the norminal battery voltage as 12Volts.

Since the sunshine hours is taking as 6.4 hours, the battery is required to store charge based on the remaining hour without light which is 17.6 hours.

Let total energy required for the whole day= E_{day}

Time which energy is required in the incubator per day=T_{day} = 24 hours=8640 seconds

Time without sunshine=T_{wo}=17.6 hours= 63360 seconds

The total energy required by the incubator for the period without sunshine is calculated as:

The total energy required by the incubator for the period without sunshine

$$= \frac{Eday \times Two}{Tday} = \frac{10440000\ Joules \times 63360\ seconds}{86400\ seconds} = 7656000\ Joules \quad (34)$$

The size of battery= $\frac{7656000}{12}$ = 638000 Ampseconds (35)

Since battery is size in AmpHours, therefore the size of the battery is:

Size of the battery = 638000 Amp [1/3600 hours] =177.22 AmpHours (36)

Beaule *et al.* [48] recommended that solar battery should not be discharged below 50% of its capacity for its long life span. Therefore the size of the solar battery was multiplied by 2.

The size of the battery=177.22 × 2

The size of the battery =354.44 AmpHours

Therefore, the size of the battery that would be needed is 400 AH.

Sizing of the Solar Charge Controller

To figure out what size of solar charge controller needed the following procedure was used:

Size of Solar Charge Controller in Amps=(solar panel wattage)/(norminal battery voltage)

The norminal battery voltage is taking as 12 V

$$Size\ of\ Solar\ Charge\ Controller\ in\ Amps = \frac{solar\ panel\ wattage}{norminal\ battery\ voltage} \quad (37)$$

$$Size\ of\ Solar\ Charge\ Controller\ in\ Amps = \frac{480}{12} = 40Amps$$

The size of the solar charge controller that would be needed is 40 Amps

Sizing of the Solar Inverter

Leonics (2013) recommended that for safety, the power rating of solar inverter should be considered 20-30% bigger in size than the total power rate value of all the loads (electric fan (20 W), electric motor 1hp (750 W) and electric bulb (100 W)) in the incubator in Watts at any instant.

Considering the starting torque of the electric motor where the starting electric current is two times the operating electric current. The electric power of the electric motor is calculated as:

P_M =power of electric motor=1 hp×2 or (750 ×2 Watts)=2 hp or (1500 Watts)

The total power of loads in the solar incubator =P_T = 100+ 20+1500

The total power of loads in the solar incubator =1620 Watts

Since the total power of load needed by the egg incubator is 1620 W, therefore, a solar inverter that has at least 1620 watts continuous power rated would be selected.

The size of the solar inverter that would be needed is 2000 Watts

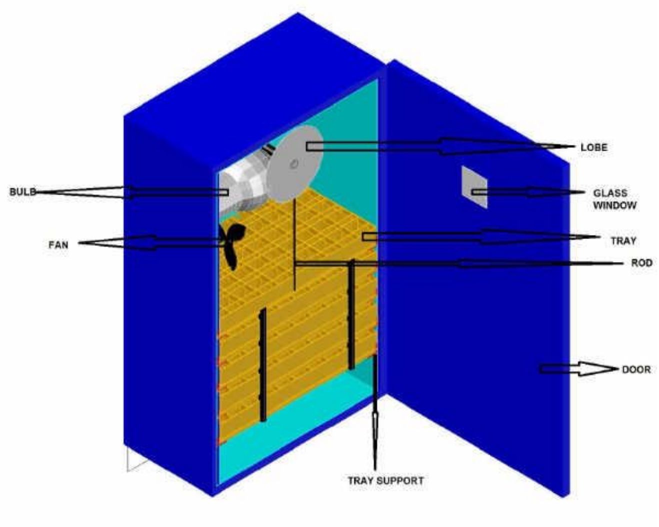

Fig. 3. Isometric drawing of the designed solar powered egg incubator.

Plate. 1. View of the Egg Incubator during Construction.

Preliminary test on the constructed solar powered poultry egg incubator

Preliminary test were conducted on the constructed egg incubator and the solar powered system and modification were made. This test was to ascertain the workability of the solar powered poultry egg incubator before loading any sets of eggs in it. 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.

Performance of the insulation of the developed solar powered poultry egg incubator on heat conservation before loading of eggs in the chamber

The egg incubator was lagged with fiber glass which helped to conserve heat in the chamber and minimize heat loss. The time taken to reach the recommended temperature for the incubation of egg was taken. Also the instantaneous temperatures with time were also read and recorded for using 100 W electric bulb as heater.

Thermostat was used to control the temperature of the incubator. Several readings were taken to test for the sensitivity and reliability of the instrument before loading the egg by comparing the values obtained to the values taken on the thermometer in the chamber. The thermostat was set to 39ºC and the sensor (probe) of the thermostat was suspended and positioned approximately mid way between the bulb and the bottom floor of the incubator exactly between tray supports 3 and 4 so as to take measured of the average temperature of the incubator system. For embryonic development of the fertile egg, temperature was taken serious and proper measured was set in place to have successful growth of the embryo during the course of incubation because it was the most critical parameter.

The effect of daily ambient temperature on the daily interior temperature of the incubator

The effect of daily instantaneous ambient temperature on the interior instantaneous temperature of the developed solar powered poultry egg incubator was monitored for a period of 4 days (19/12.2015 to 22/12/15) from 7: 00 to 18: 00 to ascertain its workability. The purpose of the test was to ensure that the temperature of the interior of the incubator work within the recommended temperature range for successful hatchability. The interior temperature of the developed solar powered egg incubator was measured using a thermostat while the ambient temperature of the incubator was measured using hygro-thermometer clock and sensor (probe). The thermostat was set to 39 ºC.

Plate. 2. View of the developed solar powered poultry egg incubator during construction.

Plate. 3. View of the developed solar powered poultry egg incubator during construction.

Plate. 4. View of the Synchronization of the Constructed Egg Incubator with the Installed Solar powered System in Operation.

Plate. 5. The Solar Panels during Installation.

VII. Results and Discussions

Table 1 shows the instantaneous interior temperature of the incubator with time to determine the effectiveness and heat conservation of the fiber glass used as insulation. The result shows that the initial temperature in the chamber was 24oC and it took the incubator 19 minutes and 28 seconds to attain the minimum recommended temperature i.e. 36oC. Afterward the heater was tripping off and lighting up to maintain the attained temperature. The thermostat acted as breaks and makes device. The time taken to attain the recommended value of temperature was minimized because of the effectiveness of the fiber glass used as insulation. After reaching the required temperature less energy was required to maintain heat in the chamber.

TABLE I. The Instantaneous Interior Temperature Of The Incubator With Time To Determine The Effectiveness And Heat Conservation Of The Fiber Glass Used As Insulation

S/N	Temperature, °C	Time, seconds	S/N	Temperature, °C	Time, seconds
1	24	0	8	30	200
2	25	7	9	31	418
3	26	32	10	32	527
4	26	90	11	33	658
5	27	139	12	34	800
6	28	167	13	35	958
7	29	179	14	36	1168

[a.] Day of record: 23/12/2015 at 6:30pm.

Table 2 shows the effect of daily instantaneous ambient temperature on the daily instantaneous interior temperature of the developed solar powered poultry egg incubator. On day 1 (19/12/2015) the value of the interior temperature at 7:00 was 36 oC while the value of the ambient temperature measured and recorded was 25.8 oC. The interior temperature of the incubator was maintained as time proceeded till 11:30 when it value rose to 37 oC while the ambient temperature as attained 29.3 oC. The value of the interior temperature was then maintained till 13:00, at 13:30 its value was 38 oC and this value was stretched till 16:00. The value of the interior temperature was 39 oC between 16:30 and 17:30. At 18:00 the interior temperature drops to 38 oC which was steady till 19:30. It was observed that the ambient temperature increases in value from 7:00 to 17:30 and at 18:00 the ambient temperature start to drop simultaneously with the interior temperature. On day 1 the interior temperature varied from 36 and 39 oC while the ambient temperature varied from 25.8 to 32.8 oC. The average interior and ambient temperature between 7:00 and 19:30 were 37.3 and 29.9 oC, respectively.

On day 2 (20/12/2015) the value of the interior temperature at 7:00 and 7:30 were 36 oC while the value of the ambient temperature measured and recorded were 23.9 and 24.4 oC, respectively. The interior temperature of the incubator was 37 oC between 8:30 and 11:30 and between 12:00 noon and 13:00 its value was 38 oC. At 13:30 the value of the interior temperature rose to 39 oC which was maintained as time proceeded till 17:00 while the ambient temperature as attained 33.5 oC. At 17:30 the interior temperature drops to 38 oC which was steady till 19:30. The ambient temperature increases in value from 7:00 to 17:00 and at 17:30 the ambient temperature start to drop simultaneously with the interior temperature. On day 2 the interior temperature varied from 36 and 39 oC while the ambient temperature varied from 23.9 to 33.5 oC. The average interior and ambient temperature between 7:00 and 19:30 were 37.8 and 29.1 oC, respectively.

On day 3 (21/12/2015) values of the interior temperature at 7:00 and 12:00 noon were 37 oC while the value of the ambient temperature measured and recorded were 25.5 and 28.5 oC, respectively. The interior temperature of the incubator was 38 oC between 12:30 and 13:30 and between 14:00 and 18:00 its value was 39 oC. At 19:00 the interior temperature drops to 38 oC which was steady till 19:30. The ambient temperature increases in value from 7:00 to 17:30 and at 18:00 the ambient temperature start to drop. On day 3 the interior temperature varied from 36 and 39 oC while the ambient temperature varied from 25.5 to 33.5 oC. The average interior and ambient temperature between 7:00 and 19:30 were 38.0 and 29.5 oC, respectively.

On day 4 (22/12/2015) value of the interior temperature at 7:00 and 12:00 noon were 36 oC while the value of the ambient temperature measured and recorded was 24.3 and 29.6 oC, respectively. The interior temperature of the incubator was 37 oC between 12:30 and 13:30 and between 14:00 and 19:30 its value was 38 oC. At 17:30 the interior temperature drops to 38 oC which was steady till 19:30. The ambient temperature increases in value from 7:00 to 17:00 and at 17:30 the ambient temperature start to drop. On day 4 the interior temperature varied from 36 and 38 oC while the ambient temperature varied from 24.3 to 30.3 oC. The average interior and ambient temperature between 7:00 and 19:30 were 37.0 and 29.9 oC, respectively.

The result from day one to four pointed out that as the ambient temperature increased the incubator temperature also increased while as the ambient temperature decreased the incubator temperature decreased. When the ambient temperature increases the temperature difference between the ambient and incubator temperatures reduces. So less heat migrates from the incubator through the incubator wall to the surrounding there by increasing the temperature of the interior of the incubator. As the ambient temperature decreases the temperature difference between it and incubator temperature increases. However, more heat migrates from the incubator through the incubator wall to the surrounding thereby decreasing the temperature of the interior of the incubator. The study clearly shows that for the four days of the preliminary test the daily interior temperature was maintained between 36 and 39 oC while the ambient temperature ranged from 23.9 to 33.7 oC. This was achieved with the aid of a temperature control system (thermostat) incorporated in the incubator system.

Benjamin and Oye [6] carried out study on modification of the design of poultry incubation. They investigated variation in the interior temperature of the modified poultry egg incubator for two days where the data for the ambient temperature was not presented. They discovered that the interior temperature in the incubator chamber varied. The variation was linked to change in time and ambient temperature. Although it was predicted that the lower the ambient temperature the higher the temperature in the incubator chamber which is in negation to the results we obtained in the preliminary test carried out on our developed egg incubator. Programmed integrated circuit was used to keep the incubator temperature between 36 to 38 o C as reported by Benjamin and Oye [6].

The variation in both the interior temperature of the incubator and ambient temperature were observed in the study carried by Olasunkanm et al. [50] where both ambient temperature and interior temperature of the egg incubator were presented. In contradiction, Olasunkanm el al [50] results shows that the lower the ambient temperature, the higher the temperature in the incubator chamber. Although due to the action of programmed integrated circuit the internal temperature of the incubator was maintained between 37 to 38 o C as reported. The difference in results may be due to difference in localities.

Osanyinpeju et al. [7] accomplished work on performance evaluation on a developed solar powered poultry egg incubator. They obtained a first order model to predict the incubator temperature as a function of the ambient temperature which predicted the observed data well as proclaimed. The (R square-value) obtained was 0.9080 which revealed that there was a strong positive linear relationship between the ambient and interior temperature of the egg incubator. They testified that the ambient temperature of the egg incubator has great effect on the interior temperature making the interior temperature to be varied. It was observed by Ogunwande et al. [51] that the temperature of an empty incubator chamber has a proportional relationship with the ambient temperature at any period of the day.

Ogunwande et al. [12] succeeded in the development of a biogas-powered poultry egg Incubator. The incubator temperature was recorded against the corresponding ambient temperature. Linear equation was generated between the incubator and the ambient temperature with R-square value ranged from 0.6090 to 0.9186. During the experimental work the ambient temperature ranged from 22 to 35 o C while the incubator temperature ranged from 37.2-39.4 o C.

The preliminary test on the developed solar powered system poultry egg incubator indicates that the egg incubator works effectively within the recommended temperature required for successful hatchability with incubator temperature ranged from 36 to 39 o C while the ambient temperature ranged from 23.9 to 33.7 oC. The influence of the ambient temperature on the incubator temperature can be reduced by increasing the insulation of the incubator chamber thereby increasing the thickness of the wall of the incubator system.

TABLE II. THE EFFECT OF DAILY INSTANTANEOUS AMBIENT TEMPERATURE ON DAILY INSTANTANEOUS INTERIOR TEMPERATURE

Time	Day1(19/12/2015) Interior Temperature, °C	Ambient Temperature, °C	Time	Day2 (20/12/2015) Interior Temperature °C	Ambient Temperature, °C
7:00	36	25.8	7:00	36	23.9
7:30	36	26.5	7:30	36	24.4
8:00	36	26.7	8:00	37	24.4

8:30	36	26.8	8:30	37	24.4
9:00	36	27.4	9:00	37	24.7
9:30	36	27.1	9:30	37	25.2
10:00	36	27.4	10:00	37	25.5
10:30	36	27.7	10:30	37	26.5
11:00	36	28.3	11:00	37	27.1
11:30	37	29.3	11:30	37	28.6
12:00noon	37	29.5	12:00noon	38	29.2
12:30	37	29.9	12:30	38	29.7
13:00	37	30.4	13:00	38	30.5
13:30	38	31.1	13:30	39	31.3
14:00	38	31.5	14:00	39	31
14:30	38	31.7	14:30	39	31.8
15:00	38	31.9	15:00	39	31.8
15:30	38	32	15:30	39	32.3
16:00	38	32.8	16:00	39	32.5
16:30	39	32.6	16:30	39	32.7
17:00	39	32.6	17:00	39	33.5
17:30	39	32.7	17:30	38	32.2
18:00	38	32.3	18:00	38	32
18:30	38	31.7	18:30	38	31.3
19:00	38	31	19:00	38	31
19:30	38	30.3	19:30	38	29.5
AVE	37.3	29.9	AVE	37.8	29.1

	Day 3(21/12/2015)			Day 4(22/12/2015)	
Time	**Interior Temperature**	**Ambient Temperature**	**Time**	**Interior Temperature**	**Ambient Temperature**
7:00	37	25.5	7:00	36	24.3
7:30	37	26.1	7:30	36	25.4
8:00	37	26.2	8:00	36	25.5
8:30	37	26.2	8:30	36	25.7
9:00	37	26.4	9:00	36	25.8
9:30	37	26	9:30	36	26
10:00	37	27.3	10:00	36	27.3
10:30	37	27.5	10:30	36	27.6
11:00	37	27.5	11:00	36	27.6
11:30	37	28.0	11:30	36	28.3
12:00noon	37	28.5	12:00noon	36	29.6
12:30	38	29.1	12:30	37	30.2
13:00	38	29.2	13:00	37	30.2
13:30	38	30.3	13:30	37	32
14:00	39	30.4	14:00	38	31.9
14:30	39	31.2	14:30	38	32.3
15:00	39	31.5	15:00	38	32.9
15:30	39	32.3	15:30	38	33.1
16:00	39	32.6	16:00	38	33.7
16:30	39	33.3	16:30	38	33.4
17:00	39	33.5	17:00	38	33.7
17:30	39	33.5	17:30	38	33.5
18:00	39	32.4	18:00	38	33
18:30	39	31.6	18:30	38	32.3
19:00	38	30	19:00	38	31.6
19:30	38	29.6	19:30	38	30.3
AVE	38.0	29.5	AVE	37.0	29.9

[b] Day of record: 19/12/2015 to 22/12/2015.

Conclusion

A solar powered poultry egg incubator was designed and constructed using locally available materials. The developed solar incubator was 610 mm × 607 mm × 1649 mm in size with a capacity for 150 eggs. Preliminary test was also carried out on the developed solar powered poultry egg incubator before loading of the eggs. This study revealed that there was a strong positive linear relationship between the ambient and interior temperatures of the egg incubator which was in support of the result reported by Ogunwande et al. [12] and in contradiction to the results of Olasunkanm et al. [50] and Benjamin and Oye [6]. In spite of the fact that there were differences in results obtained all were able to achieve the recommended temperature require for hatchability with the help of temperature controller. This study testifies that the ambient temperature of the egg incubator has great effect on the interior temperature making the interior temperature to be varied. The outcome of the preliminary test indicate that the solar powered poultry egg incubator worked effectively within the recommended temperature for successful hatchability with incubator temperature ranged from 36 to 39 o C while the ambient temperature ranged from 23.9 to 33.7 oC. This indicates that the temperature control unit and the solar energy source are reliable and effective. The efficiency (hatchability) of the developed solar powered poultry egg incubator is 44 %.

Recommendations

For further study the thickness of the wall of the incubator should be increased so as the wall to accommodate more insulation. The increase in insulation would help to reduce the influence of the ambient temperature on the temperature of the incubator.

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