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# Development of Thermoelectric Egg Incubator Integrated with Thermal Energy Storage System

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**Abstract:** Egg incubation plays an important role in the poultry production system especially during the day-old chick development. In Nigeria, poultry production is a lucrative business but lack of commercially owned hatchery machines hinders the expansion and make poultry products for instance day old chicks costly more especially in the northern part of Nigeria. In this paper, the egg incubation system was designed with two (2) operating modes of heat sources namely: a thermoelectric module used for daytime operation and a thermal storage system containing phase change materials (PCM) which supplied heat to the system for nighttime operation. The solar PV arrays were designed to be the primary energy source for generating of electricity, which was supplied to heat sources for providing fertile eggs with five (5) egg trays that contains 60 eggs each per hatching process. The result revealed that temperature inside incubation chamber and relative humidity (RH) were controlled under optimum environmental conditions for hatching 36-39°C and 56-80% respectively to stimulate embryonic growth. As a result, the system achieved and maintained an optimum incubating temperature in the range of 36-39$^{o}$C and the relative humidity (RH) of 60-80% over the incubating period of 21 days.

## 1. Introduction

Modern agriculturists are now using new technologies in order to improve yields and preserve their agricultural products. Poultry farming is one of the entrepreneur systems in agricultural practice where by meat and eggs, a guaranteed sufficient supply of brood chicks is essential. This cannot be achieved by natural incubation by means of broody hens sitting on clutches of eggs. An efficient and reliable hatching system with the aid of a new technology for hatching of fertile eggs is important is this called "***egg incubator***". Egg incubators is a machine used in the industry to provide a hatching process under optimum environmental conditions (temperature, egg turning and humidity) that is well controlled to stimulate embryonic growth until hatching [1]. The temperature and relative humidity (RH) inside the incubator must be controlled to optimum environmental conditions in the temperature range of 36-39°C and relative humidity of 60-80% [1-3]. The incubating temperature is the most crucial factor in incubating efficiency [1, 4]. To produce a large number of eggs, commercial egg incubator (CEI) must be used. In this type of incubator, a heating element is used as a heat source by directly converting electricity to thermal energy. Several types of the commercial egg incubator have been designed such as manually operated, partially-automatic and fully-automatic operations [2].

The forced-air egg incubator is an incubator which used fan to circulate the hot-air into the incubation chamber and provides the necessary stable heat level, suitable moisture level, and the maintenance of appropriate amounts of oxygen inside the incubator [5]. An egg-hatching incubator integrated with a conveyor rotation system has been designed and developed using an automatic controller for the maintenance of temperature and humidity [6].

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However, it cannot be used in remote areas not serviced by electricity supply infrastructure. Nowadays, a photovoltaic (PV)-powered chicken-egg incubator was constructed for use in the rural areas and a large-capacity battery was required for operating the system for 24 hours [7].

Another form of incubator which involves the conversion of waste heat into useful electricity can provide a method of heating and cooling by electricity called thermoelectric technology. Thermoelectric technology (TE) modules can be used for both power generation and solid-state refrigeration or heat pumps. A TE module has no environmentally harmful fluids like chlorofluorocarbons [8, 9]. Due the reliability and environmentally friendly energy conversion technology of thermoelectric technology systems, its arouse the attention of many researchers. Moreover, the system requires less maintenance, free from pollutants and usually its small in size [8, 10]. Therefore, this technology is among the technologies that help in solving global warming and climate change issues because of its improved total energy efficiency and reduced consumption of fossil fuels. Recently, it was found that egg incubators with TE modules as heat sources has high efficiency, resulting in low electrical fees per hatching period [11, 12].

Thermal energy storage (TES) is very essential system in many engineering applications. Among the practical problems involved in solar energy systems is the need to increase the reliability of the system by storing any power produced in excess of the energy load. The stored energy can be used whenever needed, such as during the night or on overcast days [13]. Similarly, practical engineering problems arise from the waste-heat recovery system where waste heat availability and utilization periods are different [14]. A phase-change material (PCM) is a latent-heat storage material used for TES. The PCM can store or release a large amount of heat during the phase change process. TES systems containing PCM in the solid-to-liquid phase have been considered as a potential candidate for solar energy systems. These types of TES systems have a small volume and work in the known melting and solidifying temperature ranges of the PCM [15], which is used in latent heat storage for several applications such as solar energy systems, heat pumps and spacecraft thermal control, as well as for cooling applications in buildings [16].

Additionally, the TE module was successfully tested as a new heating device in egg incubators, but it still used electricity from the national grid [11]. Furthermore, a large capacity battery was required for the PV-powered chicken egg incubator [7].

## 2. Materials and Method

### 2.1 Description of the System

The system consists of three components namely the egg incubation chamber, energy storage and the power supply units. The egg incubation chamber consists of five egg trays; each tray is holding 60 eggs and a relative humidity pan. The incubation chamber is constructed plywood with polystyrene as an insulation to reduce heat losses from the chamber while the inside is aligned with tarpaulin sheet for easy cleaning and to avoid moisture absorption by the wooden material. Each egg trays were connected together at one end by the means of a crank and link mechanism connected to the electric motor that could turn the trays at $45^{o}$ automatically. The turning mechanism is to avoid egg yolk sticking on the egg shell.

The power supply unit consists of four arrayed solar PV modules of 45 Watts and 12 Volts per module. The energy storage unit is made up of 2 lead batteries of 100Ah each, a charge controller and a 100Watts, 24 Volts solar powered inverter to convert direct current to alternative current from the PV panels. Heat supply in the incubation chamber is by 200 watts electric heater and electric motor used for turning mechanism of the egg trays powered by the photovoltaic modules. A thermostat was placed on upper end of the incubation chamber in order to regulates and controls the temperature of the incubation Chamber. An air vent allows air circulation within the egg chamber. A transparent glazing material is used as the door helps to monitor and inspect the incubator chamber from outside without opening the incubator door and to improve the thermal conductivity of the incubation chamber. A paraffin wax was used as the phase change material (PCM) so as to maintain the thermal energy storage (TES) was located at the bottom of the incubation chamber.

### 2.2 Materials' Selection

Materials used for construction of the system were selected based on cost, reliability, functionality and processability of the materials.

Table 1 shows the components of the system, materials used and reason(s) for selections.

### 2.3 Design Assumptions and Considerations

The design considerations that were used in the construction of the system are:

a. Number of eggs to be hatched which in the egg trays is 300 eggs;
b. Optimum incubation temperature of 37.5 $^0$C;
c. Relative humidity within the incubator of average of 65%; and
d. Reliability of the incubator.

**Table 1:** Materials Selected for Construction of the System

| Components | | Materials Selected | Reason(s) |
|---|---|---|---|
| Incubation Chamber | Glazing Door | Perspex glass | Cheap, ease to processing and strong |
| | Insulation | Polystyrene | Cheap and availability |
| | Chamber Cover | Plywood | Availability, reliability and ease processing |
| | Tray | Aluminum | Maintainability, strong and cheap |
| | Air Dust | Mild steel | Low cost and ease processing |
| | Thermal Storage material | Paraffin Wax | High insolation and absorption characteristics |
| Solar Photovoltaic | | Polycrystalline Silicon | High solar radiation absorption |

## 2.4 System's Components Design Calculations

### 2.4.1 Incubation Chamber

#### a. Heat Balance

The total heat required by the incubation chamber can be obtained using the relation given below by [17]:

$$Q_T = Q_a + Q_e + Q_s + Q_{pv} \tag{1}$$

Where:
$Q_a$ is the heat required by air in the incubation chamber and it is given as:

$$Q_a = \dot{m} C_a \Delta T \tag{2}$$

$Q_e$ is the heat requirement of incubation eggs and it is related as:

$$Q_e = m_e C_e \Delta T \tag{3}$$

$Q_s$ is the heat loss through the walls of the incubation chamber and is equated by:

$$Q_s = \frac{KA\Delta T}{l} \tag{4}$$

$\dot{m}$ is the mass flow rate of the air (Kg/hr);
$C_a$ is the specific heat capacity of the air (KJ/Kg$^o$C);
$m_e$ is the mass of the incubation eggs (Kg);
$C_e$ is the specific heat capacity of the incubation eggs (KJ/Kg$^o$C);
K is the thermal conductivity of the materials (W/mK); and
$l$ is the thickness of insulation material and plywood (m).

#### b. Egg Trays

The capacity of the incubator egg trays can be design by getting volume and area of the egg tray.

$$Volume\ of\ egg\ trays\ V = \frac{\pi d^2 hn}{4} \tag{5}$$

And;

$$Area\ of\ egg\ trays\ A = l_c b_c \tag{6}$$

Where:
$d$ is the diameter of the egg trays (m);
$h$ is the height of the egg trays (m);
$n$ is the number of the egg trays;
$l_c$ is the length of the incubation chamber (m); and
$b_c$ is the breadth of the incubation chamber (m).

### 2.4.2 Power Supply Unit

Solar photovoltaic (PV) module is an electronic device used to convert energy from the sun to useful energy and it is used for supplying power for the system. Before selecting a photovoltaic module for the system, the power output and number of the module were designed.

**a. Power Output of Solar PV Module**

The power output of the solar photovoltaic module ($P_{pv}$) can be obtained using the relation given by [18]:

$$P_{pv} = \frac{E_t \times PSI}{\eta_b \times K_{losses} \times H_{tilt}} \quad (7)$$

Where:
$E_t$ is the total daily energy of the system load (kWh/day);
PSI is the Peak Solar Intensity at the earth surface (W/m$^2$);
$\eta_b$ is the Efficiency of the System;
$K_{losses}$ is the determination factor due losses on the system such as dust, change in temperature and
$H_{tilt}$ is the average solar irradiance falling on the specific tilt angle.

The efficiency of the system can be found using the relation given by [19] as:

$$\eta_b = \eta_{inverter}\eta_{connection\ losses} \quad (8)$$

Where:
$\eta_{inverter}$ is the efficiency of the inverter (%); and
$\eta_{connection\ losses}$ is the efficiency of the system connection (%).
The determination factor can determine using equation given by [18] as:

$$K_{losses} = t_{manuf.}F_{temp.}F_{dirt} \quad (9)$$

Where:
$t_{manuf.}$ is the manufacturer's tolerance (%);
$F_{dirt}$ is the de-rating due to dirt (%); and
$F_{temp.}$ is the temperature de-rating factor which can be found using equation given by [20] as:

$$F_{temp.} = 1 - \left[\gamma(T_{cell,eff.} - T_{STC})\right] \quad (10)$$

Where:
$\gamma$ is the power temperature coefficient (%/$^o$C);
$T_{STC}$ is the standard temperature of the collector ($^o$C) and;
$T_{cell,\ effi.}$ is the average daily temperature which is given by [20] as:

$$T_{cell,eff.} = 25 + T_a \quad (11)$$

Where:
$T_a$ is the ambient temperature ($^o$C).

**b. Number of Modules**

The photovoltaic modules were arranged in series and parallel connections.

**A. Number of Modules in Series Connection**

The number of modules in series connection can be found using relation given by [21] as:

$$N_{ms} = \frac{V_{system}}{V_{module}} \quad (12)$$

Where:
$V_{module}$ is the nominal voltage of the module (V) and;
$V_{system}$ is the designed system voltage (V).

**B. Number of Modules in Parallel Connection**

The number of modules in parallel connection can be found using relation given by [21] as:

$$N_{mp} = \frac{P_{PV}}{N_{ms}P_{module}} \quad (13)$$

The number of modules of the system can be obtained by multiplying number of modules in series and that in parallel.

$$N_{mt} = N_{ms}N_{mp} \quad (14)$$

### 2.4.3 Design of Battery Bank

Battery bank is an essential component in smart grid design; it is where the solar irradiance absorbed by the solar photovoltaic modules being stored. The capacity of the battery bank can be obtained using the relation given by [22] as:

$$C_b = \frac{E_t N_c}{\eta_{inv.}V_n DOD_{max.}} \quad (15)$$

Where:
$N_c$ is the number of the autonomy days (days);
$\eta_{inv.}$ is the inverter efficiency (%);
$V_n$ is the nominal battery voltage (V) and;
$DOD_{max}$ is the maximum depth of discharging (%).

The selected battery in this design was lead acid battery made from Hoppecke Solar Power with nominal voltage of 12V and capacity of 140Ah. The number of batteries used in this system can found using the equation given by [19] as:

$$N_{b_{requ}} = \frac{C_b}{C_{selected}} \quad (16)$$

Where:
$C_{selected}$ is the capacity of the selected battery.

Like in solar PV modules, the batteries are also connected in series and parallel arrangement, the number of batteries connected in series can be obtained using the relation given as:

$$N_{b_{series}} = \frac{V_{system}}{V_{battery}} \quad (17)$$

Similarly, the number of batteries connected in parallel can be obtained using the relation given as:

$$N_{b_{parallel}} = \frac{N_{b_{requ}}}{N_{b_{series}}} \quad (18)$$

## 3. Results and Discussion

The egg incubator was tested to evaluate the performance of the system, the tests were done March, 2021. The Preliminary test were conducted on the egg incubator, this test was done to ascertain the efficiency of the system when the eggs were not loaded to the egg incubator. Thermostat was used to control the temperature of the incubator. When the temperature in the incubating chamber increases to about 39°C as shown in figure 1, the thermostat is to switch off and shut the air duct so as to stop the hot air from the thermal storage unit from flowing into the incubating chamber so that the temperature does not go past 39°C to avoid cooking of the eggs. Similarly, when the temperature falls below 35°C, the thermostat is to switch on and start allowing hot air to pass to the incubating chamber since a lower temperature than this will slow the chick's metabolic rate.

The hygrometer is a simple tool for measuring the amount of humidity in the incubator. The evaporative moisture pan in the incubating unit is used to provide the required humidity. When the hygrometer reading is more than 60%, the evaporative moisture pan is removed from the incubating unit. Similarly, when the hygrometer reading is below 60%, the evaporative moisture pan is returned. 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.

Table 2 shows the temperature of the incubation chamber with respect time. The result shows that the initial temperature in the chamber was 26°C and it took the incubator about 15 minutes to attain the minimum recommended temperature (36°C). After reaching the required temperature less energy was required to maintain heat in the chamber.

Figure 3 shows the effect of ambient temperature on the daily instantaneous temperature of the incubation chamber of the egg incubator. On day 1 (01/03/2021) the value of the temperature of the incubation chamber at 8:00 was 36°C while the value of the ambient temperature measured and recorded was 26°C. The temperature of the incubation chamber was maintained constants up to 11:00 when its value rise to 37°C while the ambient temperature as attained 29°C. The value of the temperature of the incubation chamber was then maintained till 13:00, at 14:00 its value was 38°C and this value was stretched till 16:00. The value of the temperature of the incubation chamber was 39°C between 17:00 and 18:00. At 19:00 the temperature of the incubation chamber drops to 38°C which was steady till 20:00. It was observed that the ambient temperature increases in value from 8:00 to 18:00 and at 19:00 the ambient temperature starts to drop simultaneously with the temperature of the incubation chamber. On day 1, the temperature of the incubation chamber varied from 36 and 39°C while the ambient temperature varied from 26 to 33°C.


**Figure 1:** Incubating Eggs before and after hatching with temperature reading.

**Table 2:** Temperature Variation of the Incubation Chamber against Time

| S. No | Temperature °C | Time Taken (Seconds) | S. No | Temperature °C | Time Taken (Seconds) |
|---|---|---|---|---|---|
| 1 | 26 | 0 | 7 | 32 | 310 |
| 2 | 27 | 12 | 8 | 33 | 407 |
| 3 | 28 | 39 | 9 | 34 | 591 |
| 4 | 29 | 123 | 10 | 35 | 846 |
| 5 | 30 | 183 | 11 | 36 | 904 |
| 6 | 31 | 249 | 12 | 37 | 1085 |

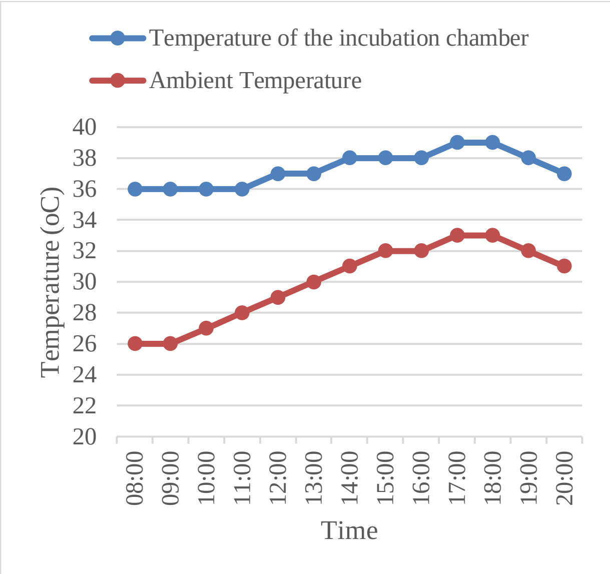


**Figure 2:** Effect of ambient temperature on the daily instantaneous temperature of the incubation chamber of the egg incubator for day 1

From figure 3, on day 2 (02/03/2021) the value of the temperature inside the chamber at 8:00 and 9:00 were 36°C while the value of the ambient temperature measured and recorded were 25 °C and 26°C, respectively. The temperature inside the chamber of the incubator was 37°C between 10:00 to 12:00 noon and 13:00 its value was 38°C. At 14:00 the value of the temperature inside the chamber rose to 39°C which was maintained as time proceeded till 17:00. At 18:00 the temperature inside the chamber drops to 38°C which was steady till 19:00. The ambient temperature increases in value from 8:00 to 17:00 and at 18:00 the ambient temperature starts to drop simultaneously with the interior temperature. On day 2 the interior temperature varied from 36 and 39°C while the ambient temperature varied from 25 to 31°C.

On day 3 (03/03/2021) values of the temperature inside the chamber at 8:00 was 36°C while the value of the ambient temperature measured and recorded was 27°C. The temperature of the incubation chamber was 37°C between 9:00 and 11:00 and between 12:00 to 14:00 its value was 38°C. At 15:00 to 17:00, the temperature inside the chamber drops to 38°C and to 37°C at 19:00 which was steady till 20:00. The ambient temperature increases in value from 8:00 to 16:00 and at 17:00 the ambient temperature starts to drop. On day 3 the interior temperature varied from 36 and 39°C while the ambient temperature varied from 27 to 32°C (Figure 4).

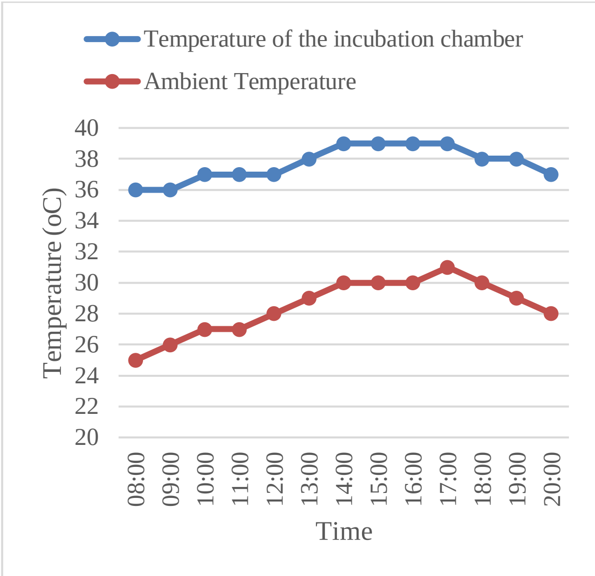


**Figure 3:** Effect of ambient temperature on the daily instantaneous temperature of the incubation chamber of the egg incubator for day 2

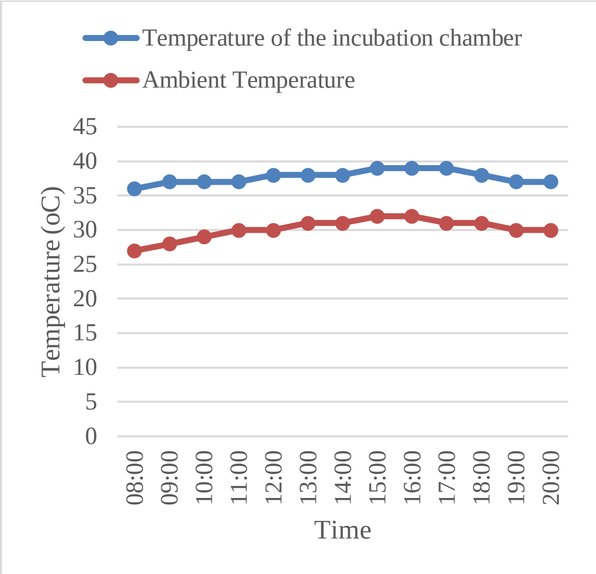


**Figure 4:** Effect of ambient temperature on the daily instantaneous temperature of the incubation chamber of the egg incubator for day 3

When the ambient temperature increases, the temperature difference between the ambient and temperature of incubation chamber reduces. Therefore, less heat lost from the incubation chamber through the incubator wall to the surrounding there by increasing the temperature inside incubation chamber. As the ambient temperature decreases the temperature difference between it and incubator temperature increases. However, more heat transfer from the incubator through the incubator wall to the surrounding thereby decreasing the temperature of the interior of the incubator. This was achieved with the aid of a temperature control system (thermostat) incorporated in the incubator system.

Figure 5 shows the effective of an average relative humidity of both incubation chamber and ambient relative humidity for the three days of the experiment. It was observed that the average relative humidity of the incubation chamber was ranged to be 56–80%, while ambient conditions were between 47–79% relative humidity. The results showed that steady incubation operating conditions could be achieved and maintained using solar energy for sustained egg incubation. Further test run of the incubator using fertilized poultry eggs recoded about 73.3% efficiency. The incubator was loaded with 300 fertilized eggs 220 of the number hatched while the remaining number could not hatch.

Main advantage of this incubation system over the conventional incubation system is that the incubating chamber condition is always constant at the appropriate temperature and humidity for hatching eggs as the supply of heat is on 24 hours service.

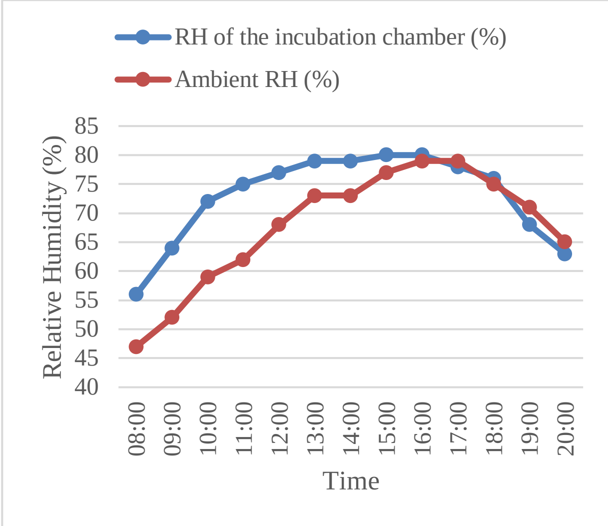


**Figure 5:** Effect of ambient relative humidity and relative humidity of the incubation chamber for the three experimental days

## 4. Conclusion

The egg incubation system powered by solar photovoltaics designed and developed was evaluated with fertile eggs, to ascertain its ability to incubate and hatch fertile eggs. The system was developed using available materials such as plywood, stainless steel, polystyrene, paraffin wax and solar generation and storage materials with Sunny Island charge controller 202-253V, 90A was used.

After the experimentation/testing of the system, percentage hatchability of the system was found to be 73.3%. It also revealed that temperature of the incubation chamber and relative humidity range of 36–39$^{o}$C and 56–80% could be maintained within the incubator. Observe that the difference between hatchability rate and fertility rate is not much at all. It means that under normal circumstances, the system under evaluation is highly suitable for incubation process.

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