SMART EGG INCUBATOR MODEL FOR OPTIMUM AGRIBUSINESS PRODUCTIVITY.

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Abstract: *In this article, smart egg incubator model, an innovative thinking aimed at ensuring that egg incubator is adaptable to hatching different poultry eggs, incorporated with IoT technology for real time information communication with the farmer, was carried out. One of the highly demanded agro-product in Nigeria is poultry. Dependence on the natural means of hatching eggs for poultry production accounts for low productivity and is insufficient to meet growing demands, making the need for smart technologies that will aid in maximizing the yield necessary. More so, the epileptic nature of electricity power supply in the country is another factor hampering the productivity of poultry and by extension, the national economic development. Therefore, optimizing the conditions necessary for maximum production of poultry in the country, as to meet growing demands, becomes unavoidably relevant. These conditions: Ventilation, Temperature, Relative Humidity, regular positioning, and eggs turnings are kept at their optimal values to efficiently increase the hatchability rate. Temperature and humidity sensors are used to monitor and measure the temperature and humidity conditions respectively inside the incubator chamber. These values are sent to a microcontroller which then coordinates other component parts and mechanisms of the incubator to execute automated tasks to ensure the environmental conditions inside incubator chamber is within the acceptable optimum hatchability conditions of the eggs. A mobile application, that is, a GSM/IoT application is integrated with the incubator for the communication of relevant information to the poultry farmer on real time. A solar powered electricity supply is installed to forestall the problem of epileptic power supply and ensure the continuous operation of the incubator.*

Keywords: *Hatchability rate, egg incubation, IoT Technology, Adaptive, Agribusiness, economic development.*

1. Introduction

Egg incubation is the process by which eggs are kept warm under specific temperature and humidity so that the embryo inside can develop and hatch after a specific number of days (French, 1997). The most vital factors of incubation are constant temperature and humidity. Naturally, this process is carried out by the animal either by laying on the eggs, called brooding or burying it under the ground using geothermal heat or the heat generated from rotting vegetation, earth and other material, created to form a giant compost heap (Brinsea, 2014).

Nigeria has the largest annual egg production in Africa. Poultry production in Nigeria amounts to 300.00mt of meat and 650.00mt of eggs per year (FAO, 2019). Yet, this local production can only meet 30% of the demand for chicken eggs and meat. In Ghana, the demand for poultry meat is about 400.00 mt and the local production is just about 57.87 mt (Benjamin et, al, 2022 and Tanko, 2019). Artificial incubation technologies must come into play if this broiler production revitalization exercise is to yield effective results. According to Benjamin et, al, artificial incubators are used to hatch a larger number of eggs at a time. This increases the supply of day-old chicks and poultry product in general.

Artificial incubation is a technology that provides opportunity for farmers to produce chicks from eggs without the intervention of the mother hen. It is one of the fastest ways of transforming eggs to chicks. The most important difference between natural and artificial incubation is the fact that the natural parent provides warmth by contact rather than surrounding the egg with warm air. Each type of egg has different type of combination of environmental conditions for incubation. In this research, the incubator model is adaptable for the following egg types: Ostrich eggs, Chicken eggs, Quail eggs. Basically, the relationship between heat and temperature is fundamental to the design of the incubators.

2.0 Research Background

Day-old chicks, poultry meat and poultry eggs are in short supply in Nigeria and some parts of West Africa due to dependence on the natural incubation and/or inadequate number of artificial incubators called hatchers. In Nigeria it has received little attention and because of this most of the local farmers adopt the traditional method of hatching of birds. The need for a smart and adaptive form of hatching necessitated the idea of this innovative and robust model. This would reduce drudgery of the traditional hatching method which are uneconomical in term of large scale production.

Natural hatching takes a maximum of 12 to 15 eggs for a set of hatching which normally does not occur more than three times a year. This is highly inefficient and cannot meet up with the increasing demand for eggs and meat in a country with a high demand for poultry products like ours. Even if it is possible to separate the hen from chicks immediately after hatching, the hen is likely to stay up to 14 days before a new set of eggs are laid. This creates a kind of discontinuity in meat production and such delay can lead to shortage in the protein requirement of the society (Adewumi et al, 2015).

2.1 Statement of the Problem

Reliance on the natural means of hatching eggs for poultry production accounts for low productivity of poultry products and is solely insufficient to meet growing demands of the product. Besides, each type of poultry egg, such as chicken, ostrich or quail egg has different and specific combination of conditions of temperature, humidity and duration for incubation. These conditions must be adjusted to adapt to the type of egg. These backdrops have made the need for smart technologies that will be adaptive for hatching different types of eggs, in order to maximize the yield necessary. More so, the epileptic nature of electricity power supply in the country is another factor hampering the productivity of poultry and by extension, the national economic development. Figure 1 shows the architecture of the smart adaptive incubator model.

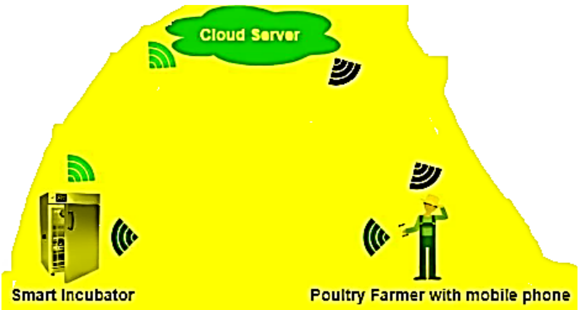

Figure 1: Architecture of the smart adaptive incubator model(source: Ajani A.S et al, 2020).

2.2 Research Aims and Objectives

The aim of this research is to model an improved IoT based egg incubator that can be adapted to incubate three different egg types, of Chicken, Ostrich and Quail eggs to ensure high productivity. To achieve this aim, the incubator model is proposed to:

i. Provide variable and adjustable temperature and humidity, by mere selection of egg type to enable the incubator to be adaptive for various types of eggs with different incubating conditions.
ii. Provide automatic temperature and humidity control, so as to ensure the temperature and humidity are maintained at the optimum incubating values.

iii. Provide GSM/IoT application functionality, for a tress free monitoring for and communication with the farmer.
iv. Provide a solar powered electricity supply source to forestall the problem of epileptic power supply of the national grid and ensure continuous operation.

2.3 Related Works

In artificial incubation, an Egg Incubator is used to provide the conditions that the brooder hen in nature gives to the eggs it broods on. These conditions need to be reproduced to nearly the same levels for the fertile eggs in the incubator to develop and hatch. The conditions that need to be controlled to ensure proper incubation of a fertile egg are temperature, humidity, turning of eggs and ventilation.

Ajani A.S et al, 2020 worked on design and construction of automated eggs incubator for small scale poultry farmers which has helped in improving and increasing the design methodology and hatching efficiency of incubator system. Nevertheless, this work is a small capacity egg incubator with a maximum capacity of 100 eggs and also did not incorporate IoT technology to ensure real time communication between the incubator and the user.

Benjamin Kommey et al 2022, designed a low-cost smart egg-incubator which aimed at increasing the hatchability of the incubator system and ensuring cost minimization in automated incubation using microcontroller which automatically adjust the incubator essential conditions to optimum information received about the conditions of the incubator from the temperature and humidity sensors. It considered the amount of electrical heat energy generated as given by the electrical power dissipated over time by the incubator and addressed the issue of the high cost of egg in Ghana by proffering more incubators as a solution. However, this work did not also include IoT technology for remote monitoring and does not pay attention to the incubator capacity as an essential factor of running cost minimization.

In the Design and construction of smart solar powered egg incubator based on GSM/IoT by Forson Peprah, et al, 2022, the abundance of solar energy was explored in order to forestall the problem of epileptic power supply with high hatchability rate and real time IoT enabled technology communication between the farmer and the incubator system. However, this work was done for only chicken egg. No reference was made to any other egg type and so it is not adaptive to other egg types.

3.0 Material and Method

Heat generation and regulation represent the major dynamics in the incubator and are very decisive in the incubation processes. This section presents the method of the research which involves the use of Feedback Control techniques in analyzing the system heat dynamics and generating the mathematical model of the heat. The physical model of the proposed smart adaptive incubator is shown in figure 2.

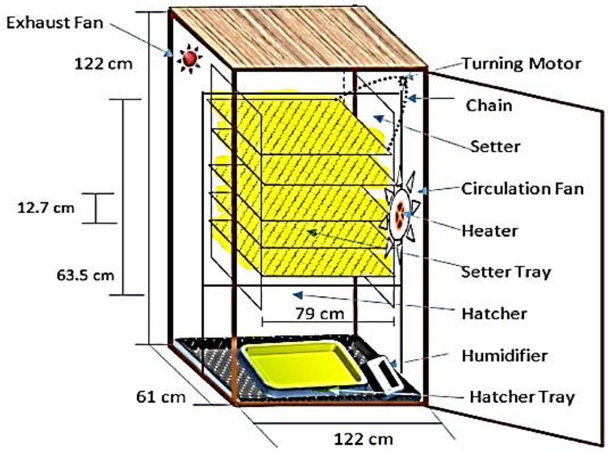

Figure 2: Physical model of the incubator chamber (French, 2017).

3.1 Mathematical Model of Heat Dynamics in the Incubator

Temperature is the most critical parameter among others in the incubation processes. Studies on the effect of incubation temperature show that temperature change influences embryo oxygen consumption and heat production during incubation (French, 2017). Heat energy is needed to raise the temperature of the incubator system to desired level. By definition, optimum incubation temperature is the temperature required for achieving maximum hatchability (French, 1997). According to French, the optimum temperature for successful incubation is 37.5°C. The amount of heat supplied by the heat source to the incubator is the governed by equation1.

Heat lost = Heat gained 1

The implication of equation 1 is that the heat supplied to raise the temperature of the incubator will be the heat gained to raise the temperature of the air, eggs, egg tray, incubator walls and the entire incubator ambience. Since the incubator will be mainly in a room, the average ambient temperature considered is 25°C.

Quantity of heat Q, supplied to the incubator system equals to the electrical energy generated by incandescent bulb. This quantity of heat can be determined by equations 2 and 3.

$$Q_s = E_s = V_s I_s t_s = V_s I_s \delta t_s \quad 2$$

$$or\ Q_s = E_s = P_s t_s = P_s \delta t_s \qquad 3$$

$$where: Q_s\ is\ the\ quatity\ of\ heat\ supplied\ by\ the\ source.$$
$$E_s\ is\ the\ electrical\ energy\ supplied\ by\ the\ source.$$
$$V_s\ is\ the\ electrical\ voltage\ supplied\ by\ the\ source.$$
$$I_s\ is\ the\ electrical\ current\ supplied\ by\ the\ source.$$
$$P_s is\ the\ power\ rating\ of\ the\ source, the\ incadescent\ bulb$$
$$t_s\ is\ time\ duration\ in\ seconds\ for\ the\ supply$$

Quantity of heat Q, gained by the incubator system can be determined equation 4.

$$Q_g = m_m C_m \delta T \qquad 4$$

$$where: Q_g\ is\ the\ quatity\ of\ heat\ gained\ by\ the\ incubator\ system.$$
$$m_m\ is\ the\ mass\ in\ kg\ of\ the\ material.$$
$$C_m\ is\ \ the\ specific\ heat\ capacity\ of\ the\ material.$$
$$\delta T = T_2 - T_1\ is\ change\ in\ temperature.$$

3.2 Temperature Dynamics in the Incubator

The flow of heat energy in the incubator system in terms of in temperature differential can be illustrated using the feedback diagram as shown in figure 3.

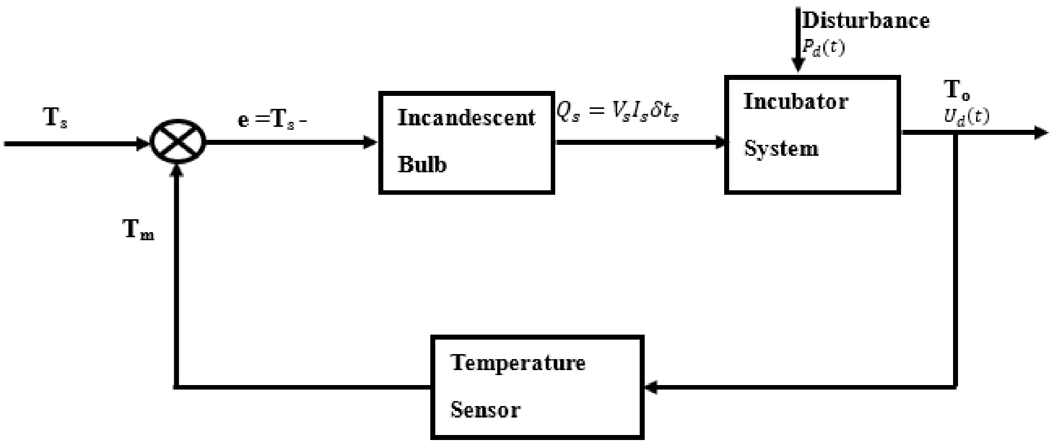

Figure 3: Illustrating heat Energy Dynamics in the incubator system using Feedback diagram

3.3 Determination of Humidity

Humidity, which is the amount of water vapor contained in air, is another important condition required in egg incubation. Eggshells are porous in nature and water passes through them. This is why all eggs dry out slowly, whether incubated or not. A higher humidity level in the incubator ambience is an indication of slower drying out of water in the egg (Forson Peprah et al, 2022). Humidity must therefore be maintained at optimum level in order to achieve effective egg incubation. Optimum humidity keeps the egg from losing too much of moisture during the incubation process. The humidity required for the incubation of poultry eggs can be calculated as the mass of water vapor per unit volume of air (D., 1990), as shown in equation 5.

$$H = \frac{m_v}{V} \qquad 5$$

Besides, humidity also depends on mass flow of air, temperature and speed of the circulating air by the fan (D., 1990). The following expression can be used to determine humidity of the egg incubator system.

$$\rho_v V = m_v R_v T \qquad 6$$

And $m_v = \frac{\rho_v V}{R_v T}$ 7

Combining equation 2.4 and equation 2.7, we have equation 2.8

$$H = \frac{\rho_v}{R_v T} \qquad 8$$

$$where: H = \ Humidity, m_v = molar\ mass\ water\ vapour,$$
$$\rho_v = energy\ density\ or\ heat\ density, R_v = gas\ contant,$$
$$T = temperature, V = volumeof\ air.$$

3.4 Turning the Egg

Turning eggs at a defined time interval per day starting from day one to day 14 (in the case of Quail eggs) or day 17 (in the case of chicken eggs) in incubation maintains the embryo at the center of the egg shell, and keeps the embryo from sticking to the shell membrane (Okonkwo, 2012 & Abraham, 2014). In achieving this, incubators programming considers eggs turning 1-hour intervals in a day. The optimum turning angle is 45 °C.

3.5 Determination of Efficiency of the Incubator

Equation 2.9 shows the egg fertility rate. The factors that determine egg fertility are; (i) the source of egg and (ii) egg handling, and (iii) egg storage before incubation. The incubator does not influence these factors. Therefore, in determining the efficiency of the incubator, equation 10 is useful and other factors (optimum temperature, humidity and regular turning of eggs) that the incubator has to maintain for successful operation.

$$\text{Fertility Rate} = \frac{Number\ of\ fertile\ eggs}{Number\ of\ eggs\ Loaded} \times 100\% \qquad 9$$

Hatchablility Rate $= \frac{Number\ of\ \ eggs\ hatched}{Number\ of\ fertile\ eggs} \times 100\%$ 10

Table 1: Typical efficiency determination of incubator (source: Ajani et al, 2020)

Month	Tail Trail	Number of Eggs Set	Fertile Eggs	Infertile Eggs	Hatch Eg Eggs	Hatchabilty (%)
January	1	100	95	5	85	89.47
March	2	100	92 92	8	88	95.57
April	3	100	98	2	90	91.84
May	4	100	96	4	85	88.54
June	5	100	90	10	81 81	90.00
	Total	500	471	39	429 429	455.42
	Average	100	94.2	7.8	85.8	91.08

Without considering the heat diffusion, the temperature change per unit at heating time, t with a continuous heating source is given by equation 11. Obviously, 11 is a linear graph.

$$T_{(t)} = \frac{p_t}{\rho C_p} = \frac{\omega \varepsilon_o \varepsilon'' E^2\ t}{\rho C_p} \quad 11$$

$where: \omega = 2\pi f, \varepsilon_o = permittivity\ of\ air, \varepsilon'' = relative\ loss\ factor,$
$E = rms\ value\ of\ the\ electri\ field,$
$C_p = specific\ heat\ capacity\ of\ heating\ element,$
$\rho = heat\ density\ of\ the\ material, p = power\ rating, t = time$

With $\omega = 2\pi f, \varepsilon_o, \varepsilon'', E, C_p, \rho\ and\ p\ all\ constants, equation\ 11\ simplifies$ further $to\ equation\ 12.$

$$T_{(t)} = kt \quad 12$$

Where $\boldsymbol{K} = \frac{p}{\rho C_p} = \frac{\omega \varepsilon_o \varepsilon'' E^2}{\rho C_p} = contant$

Applying Laplace transform to 2.12, we have, $T_{(s)} = \frac{k}{s}$

And $T_{(s)} = \frac{p}{\rho C_p s} = \frac{\omega \varepsilon_o \varepsilon'' E^2}{\rho C_p\ s}$

Where s = complex frequency parameter

Considering a small change in unit heating time resulting in a small incremental change in temperature, then

$$\delta T = k\delta t \quad 13$$

Substituting 13 into 4, we have 14

$$Q_g = m_m C_m k \delta t \qquad 14$$

For air, K $= \frac{\omega \varepsilon_o \varepsilon'' E^2}{\rho C_p} = \frac{2\pi \times 50 \times 8.854x10^{-12} \times 1 \times 9^2}{1.293 \times 1.012} = 1.72 \times 10^{-10} F m^2 v^2 K J^{-1}$

Where, all the variables are as earlier defined in equation 4 in section 3.1. Equation 14 represent a linear relationship existing between heat and temperature in the incubator chamber.

4. Simulation Results and Discussion

In the course of simulation, the reference constants for incubator, materials, size and other instrument were selected. The thermographic properties of selected materials were inserted to the equation of the incubator model for simulation in order to predict the possible of construction. The required temperature ranges for effective incubation for the different type of eggs are shown in table 2.

Table 2: Type of Eggs showing different incubating conditions

S/NO	EGG TYPE	TEMPERATURE	HUMIDITY	PERIOD
1	OSTRICH	$36^{O}C – 37.5^{O}C$	20% - 30%	42 days
2	Chicken	$36^{O}C – 39^{O}C$	30% - 60%	21 days
3	Quail	$36^{O}C – 37^{O}C$	30% - 60%	18 days

4.1 Simulation Results

The heat dynamic model was converted into Matlab syntax and the simulation was carried out using Matlab software application. This result is shown in figure 4. This shows that the incubator functions normally with a linear graph showing a proportional relationship between heat, temperature and time of heating.

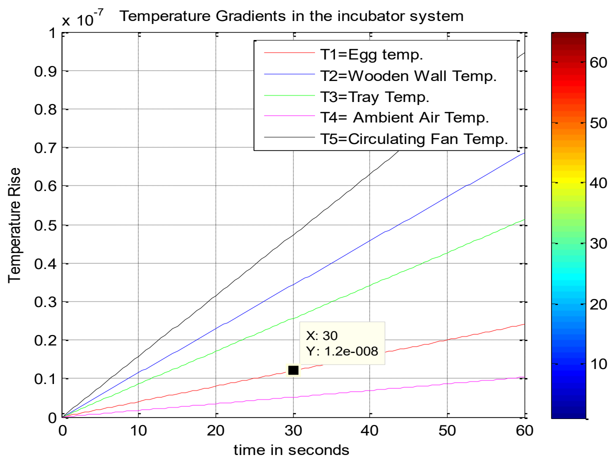

Figure 4: Heat and temperature dynamics in the incubator chamber.

5 Conclusion

Smart adaptive egg incubator model entails investigating heat transfer characteristics of Incubator chamber. Mathematical model of the dynamics of heat in the incubator chamber was generated and referenced. The thermographic properties of selected materials were inserted to the equation of the incubator model to predict the possible of physical construction in terms of material type, size and mass. From the calculation, the result showed that selected materials; such as zinc sheet, plywood and acrylic plastic sheet, were most suitable to construct the incubator cabinet. The error of temperature sensor was less than 1.1%, whereas error of humidity sensor was below 3.2%. These values validate the sensors used as acceptable instruments and measurements approach adopted in the model of the incubator was satisfactory. This incubator model will boost productivity of poultry farming in the country, thus meet the growing demand of poultry products. The percentage hatchability of the incubator is estimated to be above 94% based on the simulated result of the temperature dynamics.

From the simulated result and physical model, the smart adaptive incubator model was a success and has a capacity of 1500 eggs. The GSM/IoT and solar-powered features respectively, eliminate the stress of manual operation and epileptic power supply. More so, remote monitoring of the incubator has led to a reduction in the mortality rate of chicks and the operational cost associated with human labor. African governments, educational institutions and farmers can leverage on the technology offered by this smart adaptive egg incubator to enhance agribusiness productivity and national economic development.

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