# DEVELOPMENT OF A BIOGAS-POWERED POULTRY EGG INCUBATOR

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## ABSTRACT

This study advances the utilization of biogas energy for chick production. A wooden frame still-air incubator was developed, which uses biogas as a fuel to supply heat through a burner installed at the base. A no-load test was carried out during which incubator temperatures were calibrated against ambient temperatures when heat was supplied at various burner regulator knob positions. The results were used to develop a chart for incubator temperature control. Incubator temperature range (36-39.4°C) was successfully achieved at prevailing ambient temperatures by adjusting the knob position according to the chart. The temperature variation inside the incubator was not significant ($p > 0.05$). However, incubator temperature varied significantly ($p \leq 0.05$) with the time of the day. Relative humidity range (50-70%) was achieved by placing water pans on the floor of the incubator. The eggs were turned using a semi-automated device. Three incubation trials were carried out with 30 chicken eggs per experiment. The results showed that 23.9% of the fertile eggs were unhatched, 17.9% died at the embryonic stage while the hatchability (efficiency) of the machine was 59.7%. In conclusion, the developed incubator is feasible for poultry egg incubation.

**Keywords**: Incubator, Biogas, Chicken egg, Temperature, Relative humidity, Hatchability

## INTRODUCTION

Incubators are machines, which simulate the hen's role of providing fertile eggs with optimum environmental conditions (temperature, egg turning, relative humidity and ventilation) to stimulate embryonic development until hatching (French, 1997). Incubators may be classified as still air or forced air depending on how air is circulated. Still air incubators are the most common with the inside air circulated by convection but creating temperature strata when the air is heated. Incubation problems can be categorized into infertility of eggs, early and late term embryonic death and dead in shell (at time of hatching). Temperature is the most important factor in incubation efficiency. The growth processes in the development of the embryo are very sensitive and small deviations can cause development to progress out of sequence resulting in losses or deformities (Brinsea, 2014). Recommended temperatures vary between the two types of incubators: 37.5-39.4°C for still air incubators and 37.5°C for forced air incubators. Most of failed hatches can be due to the humidity not being set correctly. The ideal humidity level should be about 50-55% for the first 18 days of incubation, and for the last three days, about 65% (Gleaves, 1997). Proper ventilation is very important since the shells are porous and need to breathe. The best hatching results are obtained with normal atmospheric air, which usually contains 20-21% oxygen. The importance of egg turning during incubation has been well documented (Tona *et al.,* 2003; Abiola *et al.,* 2008). It enables proper formation of extra-embryonic membrane and facilitates the transfer of yolk nutrients to the embryo via the sub-embryonic fluid. Studies for effective hatchery operations have been well documented concerning nutrition of birds (Ayidin *et al.,* 2001; Adeyemo *et al.,* 2007), birds factors (Islam et al., 2008; Esen et al., 2010) and eggs factors (Elibol and Braket, 2008; Schmidt *et al.,* 2009; Moreki and Ditshupo, 2012; Ng'ambi *et al.,* 2013). Different types of small-scale poultry egg incubators with different heat sources have been developed. Some of these include: kerosene powered incubator (Ajayi *et al.,* 1997; Adewumi *et al.,* 2008), hurricane lantern incubator (Abiola, *et al.,* 2008), non-thermostatic controlled electric incubator (Ogunwande *et al.,* 2010) and passive solar powered incubator (Irtwange, 2003). However, because of the high cost of imported electric incubators and high cost of electricity tariff coupled with epileptic power supply in Nigeria, the development of incubators powered by renewable energy such as biogas should be suitable and acceptable for small-scale hatchery operations. In addition, such incubators will have

a multiplier effect through the effective recycling of organic waste to generate energy to boost chick production, generation of organic fertilizer for crop production, and reduction in environmental pollution.

## MATERIALS AND METHODS

### Incubator Description

The still-air incubator, with 12.7 mm thick plywood framework also comprised a hatcher to make a single unit (Fig. 1). The internal dimensions were 406.4 mm × 406.4 mm (base) and 431.8 mm (height). It had two egg trays, upper and lower, each with internal dimensions of 394 mm × 394 mm at heights of 249 mm and 179 mm, respectively from the base. The distance between the trays was adequate to prevent the base of the upper tray from touching the eggs that may be set at the lower tray (Fig. 2a). Each tray had a capacity of 16 eggs. At each of the two side walls of the chamber were eight 12.7 mm holes drilled for ventilation (Fig. 2b). A metal plate (203 mm × 203 mm) ≈25% of floor space was fitted at the centre of the floor through which heat radiates into the chamber. The incubator had an underneath compartment partially covered, which also doubled as a stand; 152.4 mm high with 406.4 mm × 102.1 mm upper portion partially covered at the two sides while the back and front were completely covered. The uncovered lower portion was to allow fresh air for biogas combustion at the burner.

**Figure 1** The Developed Incubator (with the Front Doors Opened) and the Biogas Burner.

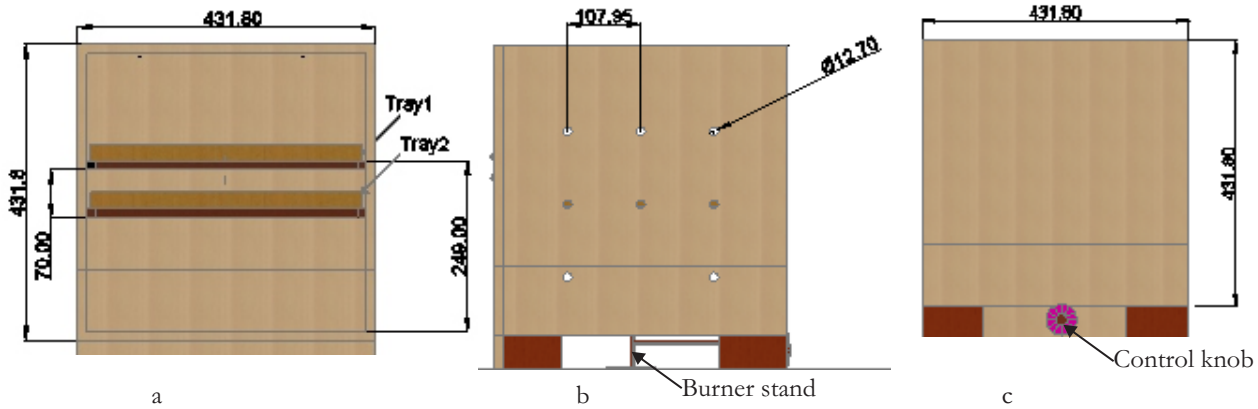


**Figure 2** a- Schematic View of: a- Front, b- Side and c- Back walls of the Incubator (All dimensions in mm).

**Biogas and Heat Supply**

Biogas for the incubation experiment was generated from a locally fabricated (2 $dm^3$ waste holder and 1.5 $dm^3$ gas holder) floating-drum plastic biodigester (Fig. 3) located about 3.5 m from the incubator. The biodigester was fed with about 40 $cm^3$ (at 8% total solids) disproportionate mixture of animal manures (cow dung, poultry and swine manures) at three days interval for continuous gas supply. The gas outlet from the biodigester was connected to the gas burner by a rubber hose.

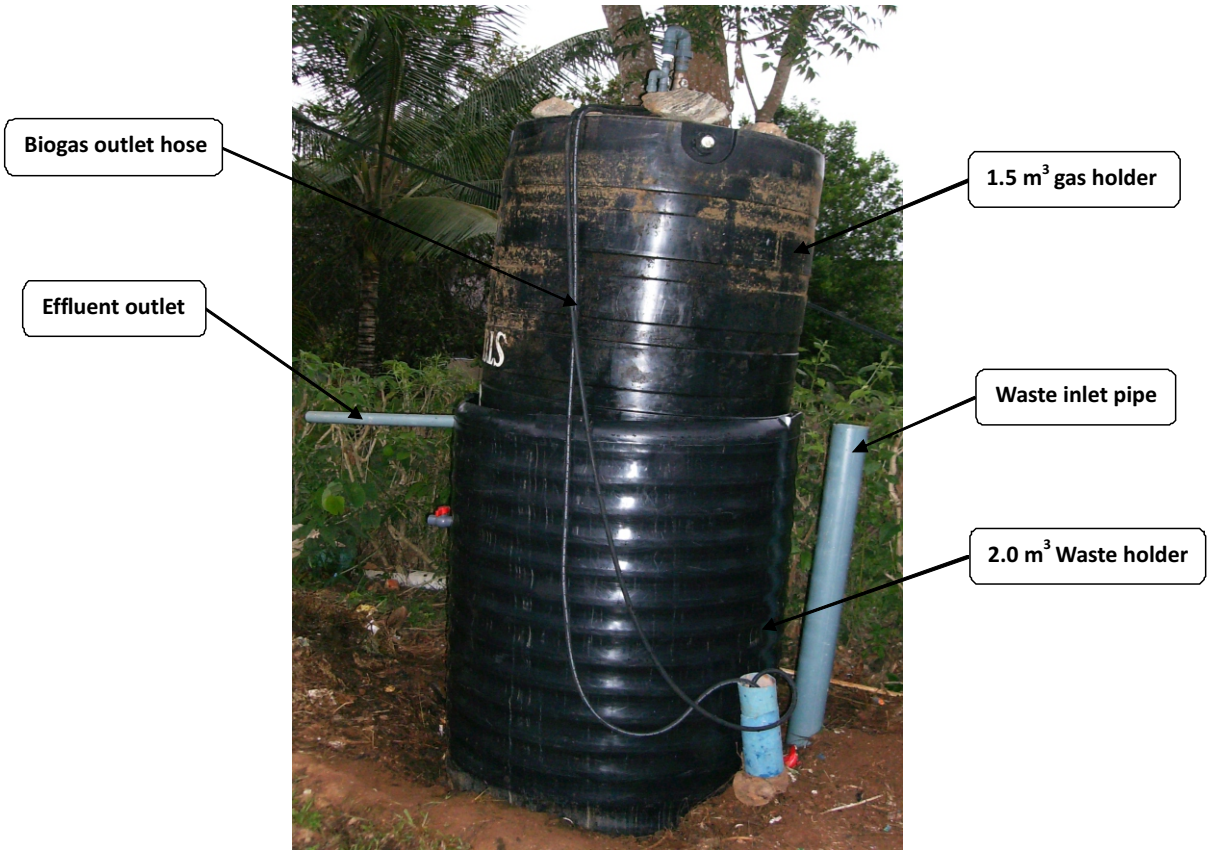


**Figure 3** Biodigester Used for Biogas Production.

A simple drying technology, consisting of dry charcoal briquettes loosely packed in a 300 mm long, 2.54 mm diameter pipe, was incorporated in the gas line to trap water vapour from the biogas. The saturated briquettes were replaced every four days with dry briquettes. The heating device for the incubator consists of a locally fabricated gas burner with an orifice of 3 mm and an adjustable height. The burner was positioned at the underneath compartment of the incubator. The head was adjusted to 38 mm vertical height from the centre of the metal plate. A hole was drilled on the back wall of the underneath compartment through which the burner regulator shaft was inserted and the cap (knob) fitted at the outer side tightly against the wall (Fig. 2c). With the installation, the gas flow could be regulated from the knob outside the wall. Whenever biogas is supplied, the flame from the burner heats up the metal plate, which in turn radiates heat into the incubator chamber.

**Temperature and Humidity Control: No Load Testing**

As was observed in a previous study (Ogunwande *et al.,* 2010), the temperature of the empty incubator chamber had a proportional relationship with the ambient temperature at any period of the day. This relationship formed the basis for calibrating the chamber temperature against the ambient temperature to produce a chart for temperature regulation. In still-air incubators, there is no fan to 'mix up' the air, therefore, stratification of air takes place - in other

words, the temperature increases with height. Because heat was supplied at the centre of the chamber floor, there was need to measure and evaluate the temperatures at different locations within the chamber with a view to determining uniformity or otherwise. Temperature was measured at different locations (on the vertical and horizontal planes) using a digital thermometer with thermocouple probes. On the vertical plane, temperature was taken at 150 mm (bottom vertical; BV), 220 mm (middle vertical; MV) and 290 (top vertical (TV) from the base while on the horizontal plane, 85 mm (front horizontal; FH), 210 mm (middle horizontal; MH) and 335 mm (back horizontal; BH) from the front wall. The temperature measurements taken at the three points from each plane were averaged. The average of the vertical and horizontal temperatures was recorded as the incubator temperature for the corresponding ambient temperature. The burner regulator knob was initially graduated at 10° or 15° interval from 0 to 150° in a clockwise direction to control the valve opening for gas flow. At position 0°, the valve was fully closed and no gas was supplied to the burner. At any knob position (KP), the incubator temperature was recorded against the corresponding ambient temperature. The data was collected at 2 h interval in a 24 h period for 3 days for each KP. A trial and error method was used to obtain KPs that produced high and low chamber temperatures (about 55°C and 32°C, respectively) beyond the incubation range of 37.2-39.4°C. Afterwards, four other KPs were selected (arbitrarily) in between and their incubator temperatures were calibrated against the ambient temperatures as described. A linear model was fitted to the temperature data obtained from each KP to generate an equation (Table 1). The linear curves as shown in Fig. 4 were used to regulate the chamber temperature during incubation. Based on the prevailing ambient temperature, incubation temperature can be obtained by adjusting to the corresponding KP.

Relative humidity regulation was achieved based on the recommendation by Smith (2000) on still-air incubators and as used successfully by Ogunwande *et al.* (2010). Water pans with total surface area equivalent to one-half and two-thirds the floor surface area were placed on the floor of the incubator to raise the relative humidity to the range of 50-60% and 61-70%, respectively. Relative humidity was measured using a digital hygrometer.

**Table 1.** Regression Equations showing the Relationship between Incubator and Ambient Temperatures from Model Fit according to Knob Position

| Knob position | Linear equation | $R^2$ |
|---|---|---|
| 80° | $y = 0.7457x + 16.061$ | 0.7557 |
| 88° | $y = 0.6789x + 19.265$ | 0.6090 |
| 90° | $y = 0.7325x + 18.57$ | 0.6885 |
| 100° | $y = 0.8977x + 15.306$ | 0.8905 |
| 110° | $y = 0.9651x + 14.445$ | 0.8795 |
| 125° | $y = 1.3682x + 7.0047$ | 0.9186 |

y: incubator temperature, x: ambient temperature.

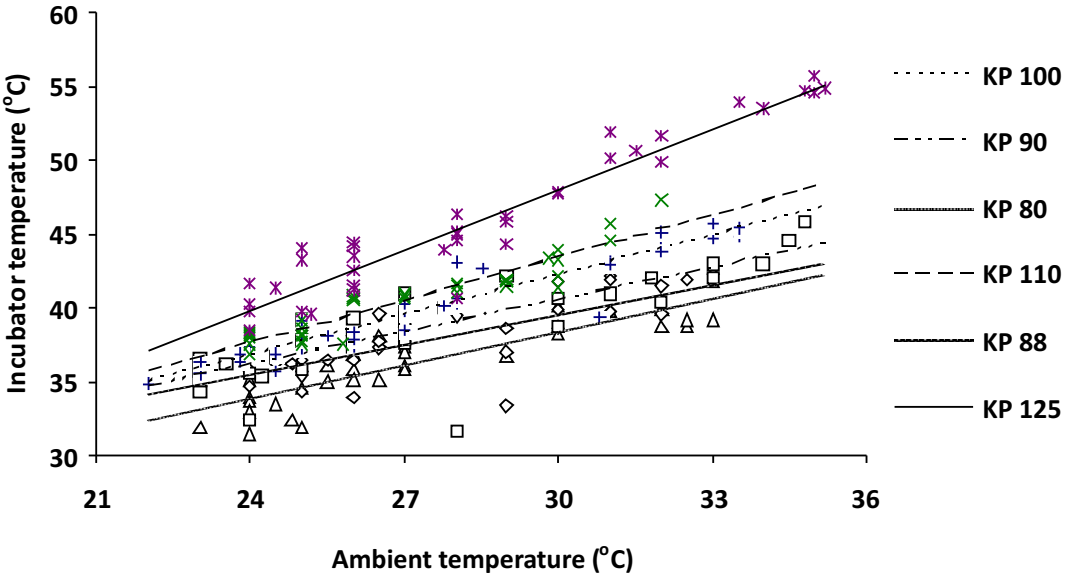


**Figure 4** Calibration Curves of Chamber Temperature Against Ambient Temperature.

## Egg Turning

A semi-automated turning mechanism (Ajayi *et al.,* 1997; Ogunwande *et al.,* 2010) was adapted for turning of the eggs during incubation. All the eggs were set on the sides and were turned 180° at the same time without opening the incubator door, with the use of a solid crate placed inside each egg tray. The crate was partitioned into sixteen egg spaces using the data (weight; 62.1 ± 3.64 g, length; 59.1 ± 1.73 mm, breadth; 44.3 ± 0.92 mm and circumference; 69.6 ± 1.44 mm) obtained from 25 randomly sampled chicken eggs. At any point in time, one end of the crate flushes with a wall of the tray, leaving a clearance equal to half the circumference of an average egg between the opposite end of the crate and wall of the tray. A rope was tied to the two opposite sides of the crate and extended outside through the walls of the incubator and used to draw the crate either side to turn the eggs.

## Incubation of Eggs

Thirty hatchable chicken eggs carefully selected, weighing ≈ 62.3 g each were purchased from a poultry farm in Ile-Ife. The eggs had been laid not more than five days (Schmidt *et al.,* 2009) and stored with pointed end down (Moreki and Ditshupo, 2012) at between 70 and 80% relative humidity and between 20 and 25 °C. The eggs were set at 15 eggs per tray in the two trays at room temperatures and placed in the incubator; thereafter heat was increased gradually to avoid heat shock to the eggs. Constant biogas supply was ensured for continuous heat supply to the incubator. Chamber temperature and relative humidity was regulated as described earlier. During the periods of fairly stable ambient temperatures, the knob was always set at a position that would produce heat within the minimum and maximum incubation temperature range. Chamber temperature was measured at the two tray levels (front, middle and back for each level) at 2 am, 2 pm and 8 pm when ambient temperature had been previously observed to change significantly. Relative humidity was also measured alongside temperature. Candling of eggs was done on the 10th day to assess fertility and monitor the development of the embryos. The eggs were turned three times daily (as recommended by Abiola *et al.,* 2008) for the first 18 days to prevent the developing embryo from sticking to the shell and causing abnormal growth. On the 18th day, chamber temperature was reduced to between 35.5 and 37°C, relative humidity increased to between 60 and 70% and no further turning of eggs was carried out until completion of incubation. The incubation was repeated three times with 30 hatchable eggs at each trial and the same procedure adopted. The percent hatchability, which is also the efficiency of the incubator, was estimated using the equation:

$$Hatchability\ (\%) = \frac{total\ number\ of\ eggs\ hatched}{total\ number\ of\ fertile\ eggs} \times 100$$

**Statistical Analysis**

Incubator temperature data was subjected to statistical analysis using the GLM procedure of Statistical Analysis System (SAS, 2002) software. Three-way analysis of variance (ANOVA) was performed to compare variations among KPs, vertical and horizontal incubator temperatures. Furthermore, because the ambient temperature depends to a large extent on the time of the day, the ambient and incubator temperatures recorded at every 2 h interval were respectively compared throughout the 24 h period using one-way ANOVA to determine variations with time of the day. Where significance was indicated at $p \leq 0.05$, Duncan's Multiple Range Test was used to separate the means. Regression analysis was performed to establish linear relationships between chamber and ambient temperatures at respective KPs.

## RESULTS AND DISCUSSION

**No-Load Test**

The ambient temperature ranged between 22 and 35°C during the calibration experiment. The results of the calibration showed that incubation temperature range (37.2-39.4°C) was attained successfully. The linear equations derived (Table 1) established a positive relationship between ambient and chamber temperatures with high $R^2$ values (0.60-0.92). Knob position was significant ($p \leq 0.05$) on incubator temperature (Table 2). Expectedly, chamber temperature increased as the valve opening increased (Table 3) but there was no significant ($p > 0.05$) difference in the heat produced by three KPs of 90°, 100° and 110° at any given ambient temperature. The comparison of temperatures along the vertical and horizontal planes in the chamber showed no significant ($p > 0.05$) variation (Table 2). This implied that fairly uniform temperature would be achieved at any location inside the chamber during incubation regardless of the KP. It was revealed that ambient and chamber temperatures varied ($p \leq 0.05$) with time of the day (Table 2). Some times of the day had fairly stable ambient temperature, which consequently reflected on the chamber temperature. For example, ambient temperatures between 2 and 6 am were the same ($p > 0.05$), similarly between 2 and 4 pm (Table 3). The same trend was experienced with the chamber temperatures in these periods.

**Table 2.** ANOVA Results showing the Effect of Variable Factors on Incubator Temperature

| Source | DF | SS | MS | *F*-value | Pr>F |
|---|---|---|---|---|---|
| KP | 5 | 15450.301 | 3090.060 | 48.303 | <.0001 |
| VP | 2 | 299.547 | 149.774 | 2.341 | 0.097 |
| HP | 2 | 229.734 | 114.867 | 1.796 | 0.166 |
| KP * HP | 10 | 697.884 | 69.788 | 1.091 | 0.365 |
| VP * HP | 3 | 121.723 | 40.574 | 0.634 | 0.593 |
| KP * VP | 10 | 324.809 | 32.481 | 0.508 | 0.886 |
| KP * VP * HP | 15 | 798.661 | 53.244 | 0.832 | 0.642 |
| Error | 1680 | 107473.795 | 63.972 | | |
| Corrected Total | 1727 | 126456.078 | | | |
| Time (ChamberT) | 11 | 13203.105 | 1200.282 | 18.187 | <0.0001 |
| Error | 1716 | 113252.974 | 65.998 | | |
| Corrected total | 1727 | 126456.078 | | | |
| Time (AmbientT) | 11 | 1481.843 | 134.713 | 38.358 | <0.0001 |
| Error | 204 | 716.455 | 3.512 | | |
| Corrected total | 215 | 2198.298 | | | |

ChamberT: chamber temperature, AmbientT: ambient temperature, KP: knob position, VP: vertical plane, HP: horizontal plane.

**Incubation**

The incubation experiments lasted 22-23 days (Table 4). The biogas burnt with a clear blue flame free of soot and the environment was well ventilated, indicating that the quality of the ambient air would not have been degraded during incubation. During candling, the fertile eggs showed embryos looking like large red spiders in the shells. The unfertile eggs obtained may have been due to old age of parent stock or wrong mating ratio (Wageningen and Meinderts, 1995). The grand mean of chamber temperatures measured at the two tray levels at the three periods in each day was estimated as the daily chamber temperature. Similarly, the mean of the relative humidity measured at the three periods in each day was taken as the daily relative humidity. The chamber temperature fluctuated within the incubation temperature range. The first 18 days had temperatures between 37.6 and 39.9°C while the remaining days had between 36.0 and 37.5°C (Fig. 5). Although there were some few cases of deviations from upper and lower temperature limits recorded during some periods of the day during incubation, these did not reflect in the mean values as they were compensatory.

**Table 3.** Duncan's Multiple Range Tests showing the Effect of Variable Factors on Incubator Temperature

| KP | Temp (°C) | VP | Temp (°C) | HP | Temp (°C) | Time | Temperature (°C) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Chamber | Ambient |
| 80° | 36.22[a] | BV | 39.25[a] | FH | 39.75[a] | 12 am | 37.61[a,b] | 29.27[d] |
| 88° | 37.97[b] | MV | 40.03[a] | BH | 39.80[a] | 2 am | 37.25[a,b] | 24.78[a] |
| 90° | 39.36[c] | TV | 40.65[a] | MH | 40.94[a] | 4 am | 37.30[a,b] | 24.65[a] |
| 100° | 40.23[c] | | | | | 6 am | 36.29[a] | 24.05[a] |
| 110° | 40.51[c] | | | | | 8 am | 37.81[a,b] | 25.21[a,b] |
| 125 | 46.01[d] | | | | | 10 am | 41.54[d,e] | 27.63[c] |
| | | | | | | 12 pm | 41.87[d,e] | 27.54[c] |
| | | | | | | 2 pm | 44.44[f] | 31.95[e] |
| | | | | | | 4 pm | 44.38[f] | 32.25[e] |
| | | | | | | 6 pm | 42.73[e,f] | 29.94[d] |
| | | | | | | 8 pm | 40.18[c,d] | 27.26[c] |
| | | | | | | 10 pm | 38.92[b,c] | 26.56[b,c] |

Means along column with same superscripts are not statistically different at $p \leq 0.05$.
KP: knob position, VP: vertical plane, HP: horizontal plane.

The deviations were mainly as a result of sudden or rapid change in ambient temperatures from recorded values or periods. Insignificant high temperatures were noticed at the later stage of incubation and were attributed to the heat generated by the developing chicks. The relative humidity also fluctuated within the incubation range during the experiments; 50.1 and 59.3% (first 18 days) and 60.1 and 70.8% (remaining days) (Fig. 6). No significant ($p > 0.05$) correlation was established between chamber temperature and relative humidity. Observations from the eggs showed that the few temperature deviations from normal may not have adversely affected the hatchability of the chicks as the fertile eggs still developed into fully grown chicks. It can be stated that the right temperatures during incubation enabled the metabolic processes within the developing embryo to occur at the correct rate. Also, the adequate relative humidity during incubation may have prevented the chicks from sticking to the shells.

**Table 4.** Incubation Results for 30 eggs at three trial experiments

| Parameter | | Experiment | | | Total |
|---|---|---|---|---|---|
| | | 1st | 2nd | 3rd | |
| Average egg weight (g) | | 60.9 | 63.6 | 62.6 | 62.3* |
| Unfertile eggs | | 9 | 6 | 8 | 23 |
| Fertile eggs | | 21 | 24 | 22 | 67 |
| Hatched chicks | Day 21 | 10 | 14 | 11 | 35 |
| | Day 22 | 1 | - | - | 1 |
| | Day 23 | 2 | 1 | 1 | 4 |
| Unhatched chicks | | 4 | 4 | 8 | 16 |
| Dead embryos | | 4 | 5 | 3 | 12 |
| Hatchability (%) | | 61.9 | 62.5 | 54.5 | 59.7* |

*Average value

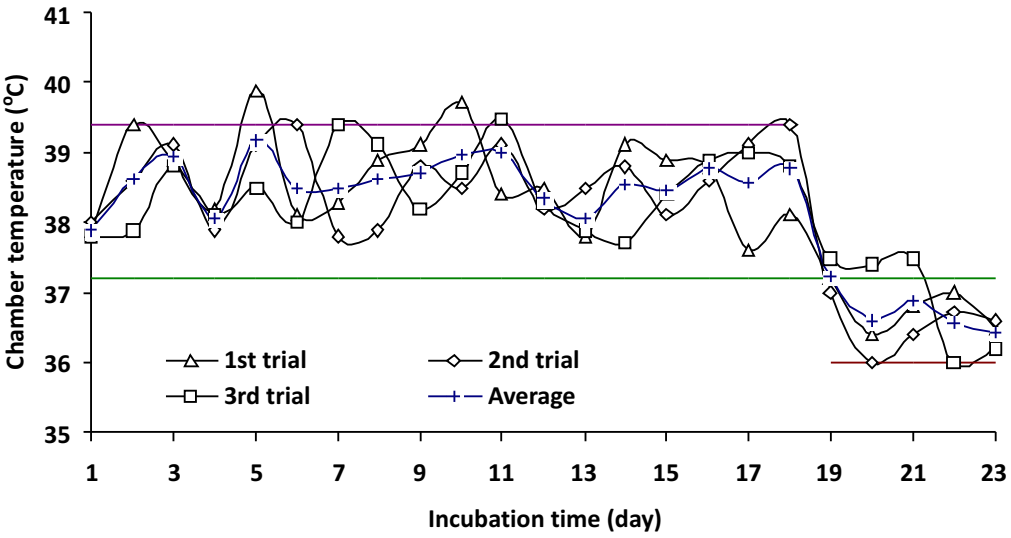


**Figure 5** Variation of Chamber Temperature During Incubation.

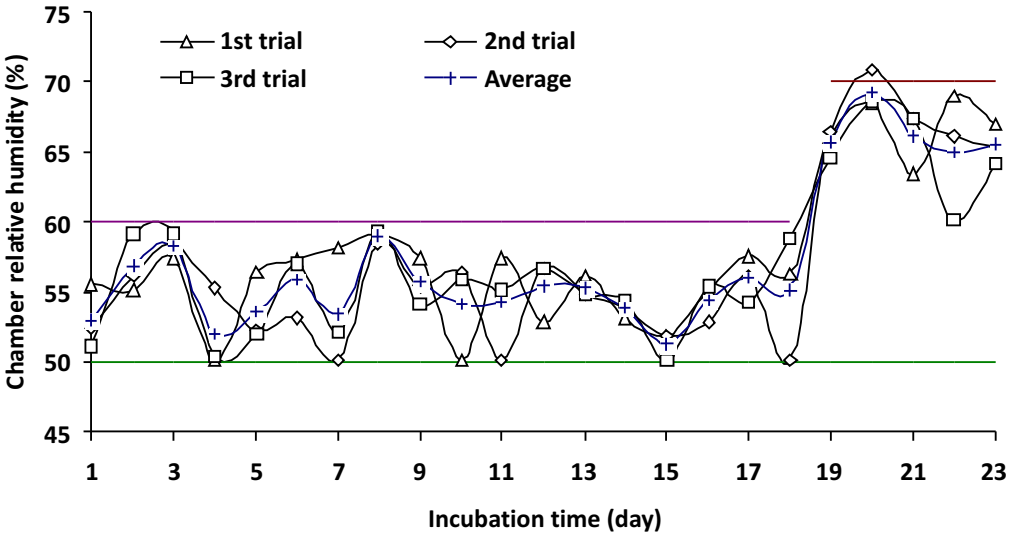


**Figure 6** Variation of Chamber Relative Humidity During Incubation.

The incubation results showed that all the fertile eggs did not hatch (Table 4). At 21 days of incubation, 47-66% of the eggs were hatched. By the 23rd day, more eggs (5-9%) had hatched. On the 24th day of each experiment, the remaining eggs were carefully broken from which fully developed but weak chicks and dead developing embryos were discovered (Table 4). The embryonic mortalities may have been due to the presence of bacterial or fungal infection on the eggs or in the chamber (Das *et al.,* 1994) or the presence of cracks (micro) on the egg shells through which the embryos may have been vulnerable. The developed but unhatched chicks may have been unhealthy (Gleaves, 1997) or have genetic weakness. The hatching of eggs beyond 21 days may have been due to the consistent temperature fluctuations during incubation and it was possible that if incubation had been extended beyond 23 days, some of the unhatched chicks may have hatched (as obvious from the growth stage of some of the unhatched chicks). The hatchability of 59.7% recorded (Table 4) was lower to values from previous studies probably because the operational conditions were significantly different. Ogunwande *et al.* (2010) achieved 61.5%, with temperature controlled through calibration; Abiola *et al.* (2008), 72.90%, when eggs were turned three times daily; and Moreki and Ditshupo (2012), 76%, with eggs stored four days prior to incubation. However, the machine has a good potential and can be improved upon for effective chick production.

## CONCLUSIONS

The percentage hatchability recorded showed that the developed incubator was feasible for poultry eggs incubation. The machine had a clean source of heat which was not detrimental to the health of the developing embryos. The materials of construction were readily available and affordable to an average farmer. The chamber temperature and relative humidity could be easily controlled through calibration. Turning of the eggs could be done without opening the incubator. The developed incubator, when standardized, promises to boost chick production by taking hatchery to the door steps of small-scale poultry farmers while promoting the generation and utilization of biogas energy for a clean and safe environment.

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