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DESIGN AND FABRICATION OF A SOLAR POWERED SMART POULTRY INCUBATOR

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TITLE PAGE

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A PROJECT SUBMITTED TO THE DEPARTMENT OF PRODUCTION ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE AWARD OF POSTGRADUATE DIPLOMA (PGD) IN PRODUCTION ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY

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CERTIFICATION

This is to certify that this project work: "Design and Fabrication of a Solar Powered Smart Poultry Incubator" was carried out by Metuaghan Onoriode Martins with matriculation number PG/ENG2415361 of the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City in partial fulfillment of the requirement for the Award of Postgraduate Diploma (PGD) in Production Engineering.

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DEDICATION

This project is dedicated to Almighty God for His guidance, wisdom, and strength throughout the course of this work.

I also dedicate it to my parents, my brothers and sisters, my wife and children, whose love, encouragement, and unwavering support have been a great source of inspiration. Special appreciation goes to the lecturers and mentors who contributed to my academic growth, and to my friends and colleagues for their cooperation and motivation during the research period.

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Finally, I extend heartfelt appreciation to my family for their unwavering love, understanding, and financial support, which provided a strong foundation for the successful completion of this work.

ABSTRACT

This project presents the design and development of a solar-powered smart poultry incubator aimed at improving hatchability through stable environmental control. The system integrates a forced-draft air circulation mechanism, a microcontroller-based temperature and humidity regulation unit, and an automatic egg-turning system to simulate natural incubation conditions. Solar energy, supported by photovoltaic cells and a DC battery bank, serves as the primary power source to ensure reliability in areas with unstable electricity supply. Experimental trials indicate that the implemented control system maintains consistent thermal and humidity conditions essential for healthy embryo development, resulting in improved hatching efficiency. The overall design contributes to sustainable poultry production by offering an affordable, energy-efficient, and locally adaptable incubator solution for small-scale and rural poultry farmers.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

An incubator is a mechanical facility or machine which provides fertilized eggs or poultry birds with controlled environment suitable for eggs hatchability or birds survival at an early stage. As part of a controlled environment for eggs or poultry birds in an incubator, moist and warm air, temperature (*Gutiérrez et al., 2019*) and relatively even exposure of the eggs to hatching conditions are significant operational factors. as the embryo emerges into a chick in the short period of 21 days. The egg incubator is designed with the aim of achieving high hatchability of healthy chicks. The incubator simulates the avian incubating method and keeps the eggs within 37.5^0C and in the correct humidity for the incubation (*Osanyinpeju et al., 2018*). Beyond poultry applications, an incubator may serve other specialize purposes which include specimen culture as executed in scientific research and supporting infants in medicine.

An incubator basically regulates temperature and humidity and other conditions to achieve optimal environment. In poultry farming, mimicking natural conditions of eggs and chicks' development has been made possible through the artificial simulation using mechanical devices like the incubator (*Kone et al., 2024*). Incubator for egg hatching has made a great impact in agriculture by stimulating economic growth and enhancing foreign exchange earnings for a developing country like Nigeria. Owing to the positive gains of improvising such a device as an incubator for poultry farming, a considerable increase in the production of chicken, ostrich, duck, guinea fowl, turkey and their meats and eggs to the food industry is highly prospective. However, many farmers especially in rural communities who venture into artificial incubation of birds are significantly affected by poor power supply and or availability in a country like Nigeria. This has necessitated the need to explore alternative and sustainable energy sources such as the use of photovoltaic cells and solar battery to harness sun (solar) energy to power such incubators for a more profiting poultry farming (Benjamin and Onye, 2012). Beside the energy needs and requirements for artificial incubation, the process of operation of many existing incubators still remains a tedious task to behold as human efforts is still very required to control the operation of the device. The considerable human effort in the operation of conventional incubators often result in poor condition control which compromises the sustainable development of the eggs leading to low hatch output, loss of eggs and or chicks. It is a daunting task for man to have an accurate prediction and set in place the prevailing weather or incubator conditions necessary for the good hatchability of eggs under incubation process, hence the need for the use of smart devices which can readily set into action the conditions required for the proper functioning of the incubator. A typical modern incubator is shown in Figure 1.1.

Figure 1.1 Egg Incubator (*Brinsea, 2024*)

A smart device such as a smart incubator allow for the automated control of incubation environment such as temperature, and humidity levels to reproduce ideal brooding conditions (Ohpagu and Nwosu, 2016). The smart or automatic incubator will therefore ensure good monitoring of breeding which tends to artificially replicate traditional egg breeding conditions which rely on nature as carried out by mother hens. In the incubation process, for example it is required that the air inside the incubator is neither too dry nor too humid. To keep a stable humidity level, it is necessary to moisturize the system approximately every 2 days and during the incubation process, the eggs surfaces should be relatively exposed to the prevailing incubator conditions necessary for hatching (Morin, 2024). Efficient incubation system requires the followings:

All bird eggs require five environmental conditions to be controlled to enable the correct development of the embryo:

i. The egg must be maintained at the right temperature to enable the metabolic processes within the developing embryo to occur at the correct rate.
ii. The egg must be frequently turned and carefully positioned so that the embryo passes through fresh nutrients in the white of the egg, while forming in the correct position for hatching.
iii. The egg loses water through pores in the shell. The humidity of the air around it must be controlled to ensure the right amount of water is lost over the incubation period.
iv. The egg "breathes" so there must be a supply of fresh air to provide oxygen and to remove waste carbon dioxide. Eggs are susceptible to infection so the incubator must provide a clean, disinfected environment.

Owing to the need to ensure compliance and achieve the aforementioned it is pertinent to adopt more sophisticated method which can efficiently make the incubator function optimally to get the operational conditions for hatching of the eggs right. This cannot be achieved by mere making the incubation smart but by ensuring there is no interruption to operation of the incubation device arising from epileptic or absence of power supply which then also necessitates the use of alternative energy source such as solar power for the operation of an incubator. 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 in a place like Nigeria (Osanyinpeju *et al, 2018*).

1.2 Statement of the Problem

An incubator is a mechanical device with artificially controlled environment for growth and development of entities in various sub areas such as agriculture, medicine and laboratories. Conventional poultry farming incubation in Nigeria for egg grooming and hatching of eggs is froth with some anomalies due to poor incubation environment control arising from human efforts put in inaccurately to simulate the natural condition of the incubation process. Many existing incubators are grid powered, somewhat sophisticated and costly that local poultry farmers could barely afford them and even in the event of owning the facility, its successful operation may be impeded by the incessant power outage often experienced in Nigeria. These shortcomings have necessitated the need to build a local but sustainable smart and solar powered incubator which can automatically simulate optimal incubation process conditions with the use of alternative power supply for efficient operation and suitable for use by rural and urban farmers in Nigeria.

1.3 Aim and Objectives of the Project

The aim of this project is to design and fabricate a solar powered smart poultry incubator suitable for use by rural-urban poultry farmers in Nigeria.

The objectives of this research project are to:

1. study and highlight operational conditions of a poultry incubator.
2. design a proof of concept of a solar powered smart poultry incubator
3. fabricate the proof of concept of a solar powered smart poultry incubator.
4. test and carry out performance of the developed solar powered smart poultry incubator.

1.4 Significance of the Project

This project is significant in various respects which include high output yield of chickens. The egg incubator can help farmers to incubate eggs to produce large numbers of chickens for food sustainability in Nigeria. The development of a smart incubator can improve the incubation of hen eggs. The development and use of solar powered egg incubators will boost long chicken production which will also be amenable to local farmers in rural and urban areas of Nigeria. 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. The ability to produce locally made incubators will boost the Nigerian local content initiative and also create jobs, food sustenance and income for producers and consumers. This project will serve as a precept for an extensive and intensive research on incubation process and incubator production.

1.5 Scope of the Project

This research project is focused on the design of poultry incubator for the incubation of chicken eggs. The proposed development of a proof of concept is based on adaptive design method which tend to emphasize making observations and inferences from existing incubators with an intent to modify and or optimize the incubation system. This project will also explore the use of alternative energy source bordering on the use of solar energy with the use of photovoltaic cell, dc battery and associated solar facilities. The design calculations will be based on the operational conditions of the incubator. The key operational variables of the incubator include the internal temperature which is 37.5 to 38^0C, the humidity of the incubating chamber which is 65% and the turning mechanism which turns at specific times. Simulation of the working environment will be carried out by applying the calculated parameters in a CFD simulation. The incubator will be modelled to generate the fabrication drawings.

CHAPTER TWO

LITERATURE REVIEW

2.1 Etymology of Artificial Incubation

The art of incubator by artificial means has been known overtime of years which is an ancient practice but has been employed on a commercial scale only within the last 60-70 years (Akanji and Duvuna, 2012). The Chinese developed the first incubator at least as early as 246 B.C. (Bari, 2008) by using a mud barrel, heated with charcoals which brought about embryonic development. The eggs were turned by hand. These early incubation methods were often practiced on a large scale, a single location perhaps having capacity of 36,000 eggs (Joe, 2007). The Egyptians were the first artisans to construct large scale incubators which were made from brick and heated by fires built in the same rooms where the eggs were incubated. The first large incubators in the United States were built in 1895 by Charles Cyphers (Parkhurst and Mountneyb (2012), It was a 20,000 eggs capacity room type incubator for duck eggs.

2.2 Principle of Hen Egg Incubation

Incubation entails the development of embryos with respect to hens by providing the eggs with the correct, environment for the developing chick. A vital factor of incubation is the constant temperature required for the embryo development over a specific period. The humidity is also critical. The incubator or incubating machine is used for the artificial control of environment necessary for embryo development. Depending on complexity, an incubator will give varying degrees of control over temperature, humidity, egg turning, fresh air flow and hygiene, while providing a secure place for the eggs. Controlled environment is the action word which recommends that after 18 days of incubation, the temperature should be between 38^0C to 37^0C until the chicks are hatched (Kyimpong and Forson, 2017). Brisnea (2024) describes some basic principles of hen egg incubation with respect to the prevailing environment as follows:

1. Temperature: Ideal storage temperature of eggs under incubation is between 12ºC and 15ºC (50 – 69ºF). Too high a storage temperature and some incubation can commence but at the wrong rate. This will decrease the chances of the embryo developing normally. If storage temperature is below freezing the cell structure of the egg can break down and prevent the embryo developing.
2. Humidity: The best humidity level at which to store eggs is between 75 to 85% RH to avoid significant drying out of the egg before incubation.
3. Time in Storage: Depending on species, it is preferable that eggs should not be kept for more than 7 days prior to incubation. Between 7 and 14 days' hatchability begins to decrease considerably. Vitamins decay and membranes breakdown in time and so the embryo can often suffer early mortality.
4. Turning During Storage: Eggs should be turned once a day, 45 degrees each way, back and forth through 90º during the storage period. Insufficient turning can cause the yolk to float and touch membranes near the shell. If the embryo touches the membrane, it may stick and prevent growth once inside the incubator.
5. Cleanliness: Cracked, mis-shaped and heavily soiled eggs should be discarded (if possible). Soiled eggs may be cleaned using a brand egg wash solution. It is essential to wash eggs in solution that is significantly warmer than the egg so that expansion in the egg causes flow out through the pores rather than dirty water flowing inwards.

6. Collection of Eggs: Generally, the best time to collect eggs is before 9am, and to check again at lunchtime. Eggs left in the nest for much longer than 24 hours tend to be poor hatchers.
7. Egg Shape, Shell Texture and Quality: Some naturally misshaped eggs have lower than expected hatch rates. Undersize eggs often have a large yolk in proportion to the albumen. Large eggs can sometimes be 'double yolkers' which will not hatch. Misshaped eggs usually have faults in the shell.
8. In natural circumstances eggs warm up quite slowly. Incubators often warm up quickly, and so if placed in the incubator immediately the egg may suffer some thermal shock. If possible, the eggs should be brought up to temperature slowly.

2.3 Types of Incubators

Incubators may be classed as follows:

2.3.1 Still Air:

Still Air Incubators are the most basic form of incubator. A still air incubator is basically an insulated box consisting of a heating element, thermostat or temperature controller to control temperature, egg tray, thermometer to measure the air temperature, a tray for water. Some machines may have a hygrometer for humidity measurement and a turning mechanism for turning of eggs. The air inside a still air incubator is circulated by convection. As the air is heated it expands and rises to the top of the incubator. The amount of airflow achieved in a still air machine is therefore determined by the ratio of air temperature inside the box to outside. The lower the air temperature outside the box the greater the airflow inside. To achieve good air circulation, air inlets are usually positioned in the base and top of the incubator. Inside a still air incubator, the warm air moves towards the top so different temperatures will be recorded at different levels (see example in Figure 2.1). It is therefore important that a still air incubator is kept on a level surface and that eggs are all of similar size.

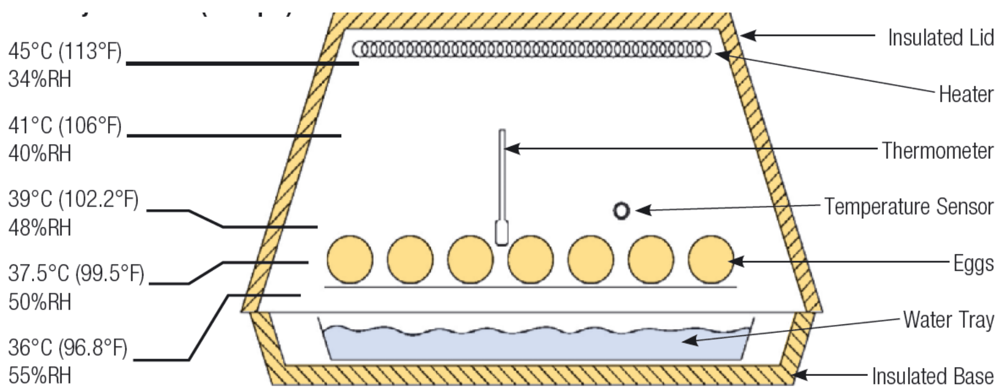


Figure 2.1 Still Air Incubator

2.3.2 Forced Draft Incubator

The forced draft machine was developed to overcome temperature gradient problems throughout the incubator. In a forced draft incubator, a fan is used to circulate the air, which gives a uniform temperature throughout the machine. The air temperature surrounding the egg is therefore constant and positioning of the thermometer and temperature sensor are less critical. Eggs, too, can be of differing size and set in trays at different levels. Using a forced draft incubator shown in Figure 2.2 also allows the accurate measurement and control of humidity.

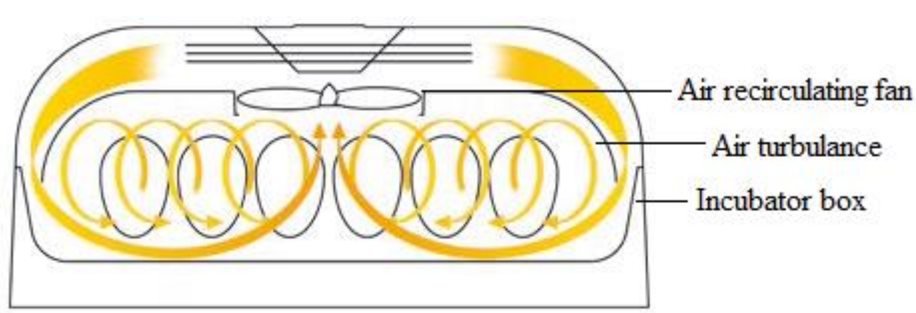


Figure 2.2 A schematic of a forced draft incubator.

2.3.3 Contact Incubators

Contact Incubation shown in Figure 2.3 mimics the natural incubation process that occurs in the nest. The most striking 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. Research studies carried out by J. Scott Turner at New York State University and the University of Cape Town has revealed major unsuspected differences in thermal behavior of eggs incubated by contact rather than convection.

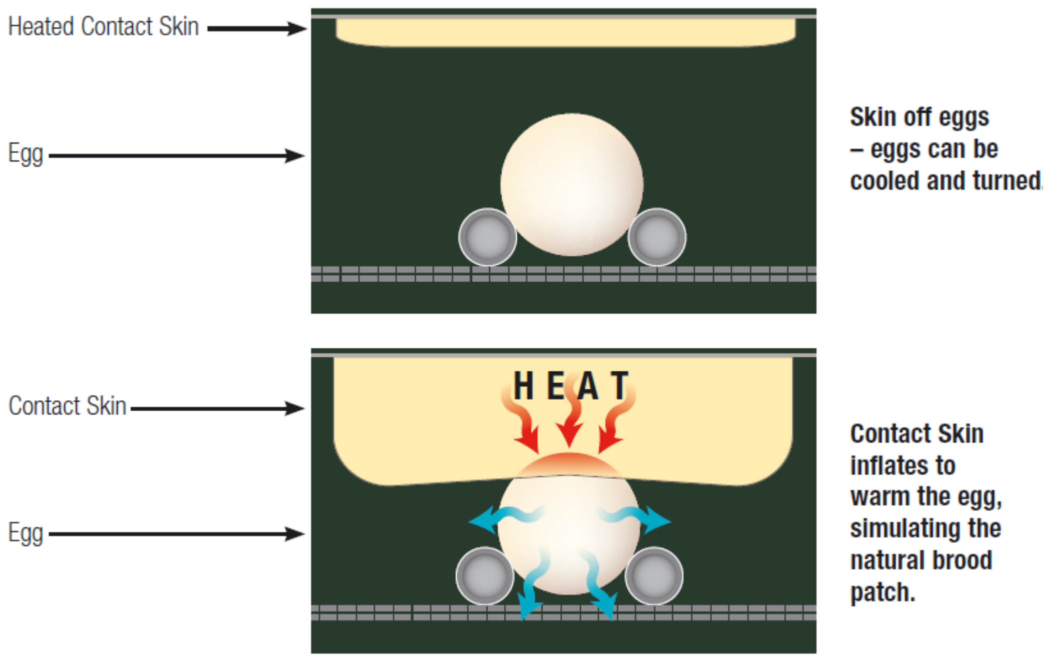


Figure 2.3 Contact type incubator

Crucially, eggs in a forced draft incubator have near uniform temperature throughout incubation; there will be some increase in embryonic temperature towards the end of incubation as a result of increased metabolism but otherwise the whole egg will remain near incubator air temperature. By contrast, eggs incubated naturally or by contact, have significant temperature differences. Heat is entering the egg over a relatively small brood patch, which is therefore warmer than other regions of the egg and is being lost from most of the remaining shell area, which is cooler. In contact incubation, the embryo temperature tends to fall at later stages of incubation as a result of the embryo's own blood circulation which becomes significantly more important than embryonic metabolism in determining temperature distribution and heat flow within the egg, quite contrary to previous understanding which assumed metabolism to be dominant and cause egg temperature to rise. The inevitable fact that the embryo grows larger and must move from its original position on top of the yolk sack downwards in the egg to cooler regions also tends to reduce embryonic temperature as incubation progresses.

2.4 Components of Solar Powered Smart Incubator

A solar powered smart incubator encompasses the use of renewable energy source to power a self-regulating egg incubator which mimics the natural egg incubation process. Renewable energy is energy generated from natural resources such as sun light, wind, rain, tide, geothermal, which are continually naturally replenished. The sun which is the source of solar radiation is a continuous fusion reactor. Solar energy is essentially black body radiation corresponding to a temperature of about 6000k and is therefore of high thermodynamic quality (Faninger, 2010). The basic components of a solar powered smart incubator include the followings:

1. **Heat source:** The heat source is required to heat up the incubator while the temperature sensor and switch connection monitors and regulates the heating process.
2. **Circulation fan:** The fan is used to ventilate the incubator and is connected to a timer and will operate periodically. This is to ensure that there is always enough oxygen supplied to the chicks and the carbon IV oxide produced by the eggs are evacuated from the incubator
3. **Humidity control system:** The water bath is used for humidity control and is fitted with a fan and a filter. The fan is meant to control humidity by spraying air laden with water into the incubator to keep it moist.

4. **Egg turning mechanism:** The turning mechanism is design to periodically turn the eggs by 45 degrees to ensure the proper development of the embryo and prevent it from sticking to the shell
5. **Solar panels:** A solar panel is a device that converts sunlight into electricity by using photovoltaic (PV) cells. PV cells are made of materials that generate electrons when exposed to light. The electrons flow through a circuit and produce direct current (DC) electricity, which can be used to power various devices or be stored in batteries. Solar panels are also known as solar cell panels, solar electric panels, or PV modules.
6. **Charge controller:** The charge controller is normally connected between the solar panel and the lead acid accumulator cells (battery) regulates the battery charging and protects the battery from overcharging and overload.
7. **deep cycle lead acid solar batteries:** A deep cycle battery is a lead battery designed to provide sustained power over a long period and run reliably until it is 80% discharged. Deep-cycle batteries are popular for off-grid or hybrid solar systems because they can be completely discharged and don't aren't damaged as quickly as normal batteries can be.
8. **Sensors and detectors**: various mechanisms of the incubator are controlled by sensors such as temperature and humidity probes, and motion sensors. When selecting and integrating sensors understanding their specifications is crucial to ensure optimal performance and compatibility is important. A typical IR sensor is shown in Figure 2.4

Figure 2.4 IR Sensor

9. **Arduino Uno**: this is a Microcontroller on which various automated operational components and sensor are actuated and collects feedback. An ATmega328P Arduino is shown in Figure 2.5. Its operating voltage is 5V. Digital I/O Pins is 14 (of which 6 provide PWM output) and Analog Input pins: 6. A Flash Memory is32 KB (of which 0.5 KB is used by the bootloader) and Clock Speed is 16 MHz.

Figure 2.5 Adruiono Uno

10. Servo Motors:

Servo motor shown in Figure 2.6 is used to control the position of objects, rotate objects, move legs, arms or hands of robots, move sensors etc. An Operating Voltage: 4.8V to 7.2V. Servo motors have three wires: power, ground, and signal.

Figure 2.6 Servo motor

11. Limit switch:

Limit switches are used to detect the presence or absence of an object. A limit switch shown in Figure 2.7 is an electromechanical device operated by a physical force applied to it by an object.

Figure 2.7 Limit Switch

12. Water Pump

A 12V DC water motor shown in Figure 2.8 is a versatile and compact device designed for low-voltage applications. It typically features a flow rate between 0.5 to 3 liters per minute and can handle pressures up to 3 bar.

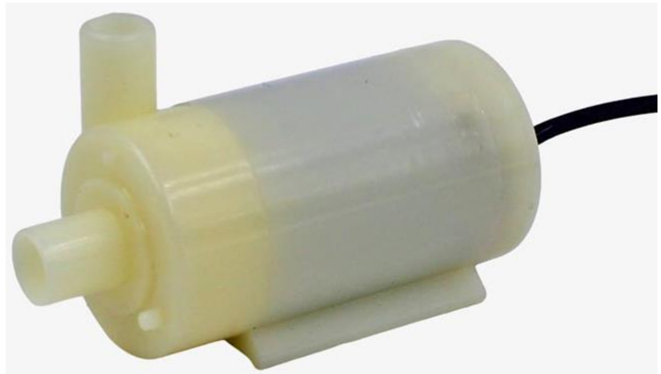


Figure 2.8 DC pump

13. Relay Module:

A 12V relay module shown in Figure 2.9 is designed to control high-voltage devices using a 12V DC control signal. It features electromechanical relays capable of handling currents up to 10A and voltages up to 250V AC or 30V DC. The module typically comes with multiple relays, ranging from 1 to 8, allowing for versatile switching capabilities. It is often used in automation systems and can be controlled by low-voltage signals from microcontrollers or other digital circuits. Indicator LEDs on the module provide visual feedback on the relay status.

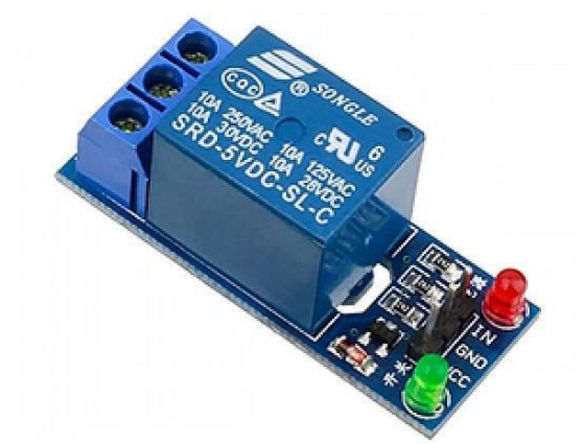


Figure 2.9 Relay Module

2.5 Review of Related Literature

Gutierrez et al., (2025) developed a hen eggs smart incubator for hatching system based on internet of things. The authors asserted that for hen breeders, hatching eggs in large quantities was a production problem, when they are incubated by hens. Their research paper described the development of an intelligent system for a hen egg incubator. The incubation system, based on Arduino, LabVIEW, Google Firebase and MIT App Inventor could control temperature, humidity and egg rotation automatically. In addition, the system could help farmers to monitor the intelligent incubator remotely. Successful hatched hen eggs were typically around 87.55%, 0.41% hatched defectively, 1.84% hatched but died at birth, and 10.20% not hatched, so an intelligent temperature and humidity control system was asserted by the authors to improve the successful hatching rate. The objective of the research was not to commercialize the work but to make it available for researchers and farmers so that they could replicate it and carry out experiments. In order to do this, the system was kept as simple as possible.

Kone et al., (2024) designed and fabricated an Iot-Based Intelligent Incubator shown in Figure 2.10.

Figure 2.10 Kone et al (2024) smart incubator

The intelligent egg incubator was designed to improve existing egg incubators to transform the traditional breeding method into a modern and advanced breeding method. To reduce the chore that traditional breeding methods can cause, the use of an automatic incubator was therefore recommended to ensure the best possible hatching rate. The authors asserted that automatic incubators allow for the control of temperature and humidity levels to reproduce ideal brooding conditions. The incubator was equipped with a Wi-Fi module via the ESP32, allowing the system to be manipulated remotely. The main objectives of the research were to design an egg incubation system that performs better than manual incubation. The proposed system was an innovation that makes it possible to monitor the temperature, humidity and movement of the egg inside the incubator which had a data acquisition system taking into account the physiological conditions of the eggs.

Osanyinpeju et al, (2018) carried out a research on the performance evaluation of a solar powered poultry egg incubator. The authors asserted that utilization of solar incubator would proffer solution to a major constraint of power inadequacy for commercial poultry egg incubation in Nigeria. In their work, a solar powered poultry egg incubator shown in Figure 2.11 was developed and the main components included incubating chamber, control system and solar powered system.

Figure 2.11 the Osanyinpeju et al (2018) solar incubator

The developed solar incubator was 610 mm × 607 mm × 1649 mm in size with a capacity for 150 eggs. This study conducted performance evaluation on the solar powered poultry egg incubator developed. The performance parameters of the proof of concept incubator included, hatchability, the percentage of chicks with unabsorbed yolk, fully developed chicks but not hatched and banger (exploded eggs) which were evaluated by loading total of 147 eggs for 21 days. Throughout the period of incubation, the temperature was maintained within the recommended range of 36 to 39^0C which was achieved with the aid of the temperature control system. The fertility of the eggs loaded was 64 % while the hatchability of the fertile eggs obtained was 44 %. The percentage of chicks that hatched, fully developed chicks but not hatched, chicks with unabsorbed yolk and banger (exploded eggs) were 44 %, 13 %, 40 % and 3 % respectively. The solar powered system proved to be a good source of power which could provide continuous supply throughout the period of the incubation without failing.

The study Yanti et al., (2022) was on the implementation of the internet of things in the duck egg incubator monitoring system. The use of IoT made it possible to design an IoT-based remote monitoring system in a duck egg incubator based on temperature and humidity sensors.

Unik, et al., (2021) used internet of things and automatics control system on quail egg incubator using human-centered design method. The authors also developed an intelligent quail egg incubation system that can be controlled remotely, and capable of controlling the temperature, heating source, humidity regulation, operation of the egg rack using to IoT sensors to optimize quail production.

Sanjayaet al., (2018) carried out a research on the development of quail eggs smart incubator for hatching system based on microcontroller and Internet of Things (IoT). The authors developed a smart incubator for quail eggs using an Arduino microcontroller-based system to control the temperature, humidity and egg rotation of the system. The system integrates a Python module and VNC software capable of monitoring the incubator remotely.

Rakhmawati et al, (2019) conducted a research on the thermal optimization on incubator using fuzzy inference system based IoT. The authors proposed an egg incubation system with the objective of optimizing the management of the temperature of the incubator through the use of the fuzzy inference system and the Internet of Things. The system could be controlled and monitored remotely via the internet.

Niranjan, etal., (2021) carried out works on the design and implementation of chicken egg incubator for hatching using IoT. The authors designed an egg incubation system that took into account temperature sensors, humidity, ventilation and an egg turning system using inexpensive materials. The developed system works with a solar panel, a water pump and a humidifier and an MCU node to control the system from the internet

Mujčić and Drakulić 92023) Designed and implemented a fuzzy control system for an egg incubator based on IoT technology. The authors set up a temperature control system through the use of a light bulb and a fan for an egg incubator.

Azahar, et al, (2020) designed an egg incubator capable of hatching eggs automatically using a temperature, heating and cooling control system inside the incubator. The system allowed operators to know if an egg is moving, however, it did not manage the rotation of the eggs in the hatching percentage.

Fiolana et al., (2019) developed an incubator which relied on artificial intelligence for its operation. The works offered a remote incubator monitoring and control system, capable of making the incubator temperature stable and uniform using genetic algorithms. The system also attempted to reduce unnecessary energy consumption. This system did not take into account the rotation of the eggs in its operation at the level of the incubator which played an essential role in the hatching percentage.

Afandi, et al., (2023) developed an incubator system for incubating eggs with the aim of managing temperature. The system was equipped with a LoRa wireless system to communicate with the incubator remotely so that the temperature can be managed remotely, the system did not take into account the rotation of the eggs in its operation at the incubator level.

In the works of Thet et al. (2019), the authors were interested in how to use renewable energies for example solar energy as a source of energy instead of traditional energy for the operation of a solar powered incubator. The new system was easy to use, inexpensive and easy to maintain, but there was no monitoring of incubation operational variables for egg grooming and hatching.

Mohd et el., (2019) developed a mechanized incubator. The authors were interested in how to rotate a large number of eggs using the DC motor and the DS1307 real-time clock and the SHT11 sensor. The objective was to spin a large number of eggs automatically. However, the system did not take into account the monitoring and status of the incubator.

Geneve. (2013) in his classroom chick hatch program guidebook identified that overheating of the egg in an incubator is much more critical than under-heating as it will speed up the rate of development causing abnormal embryos development in the early stages, and lower the percentage of hatchability. The production of chicks from a developing embryo is a very sensitive task which requires proper monitoring.

Wilson (1991) in his research on the physiological requirements of the developing embryo reported that the increase in temperature during incubation was very critical for chick embryos. Moreover, it was revealed that growth was retarded or ceased and the incidence of poor second quality chicks increased as the temperature was raised.

Mauldin, (2003) in his research on the exchange of oxygen, carbon dioxide and moisture in the egg during incubation asserted that different incubator manufacturers have different means of circulating air: paddles, blades, and fans. In most cases, it was the pattern of airflow that was most important. The author further asserted that in a poorly maintained machine insufficient air is circulated through the mass of eggs resulting in hot and cold spots, which in turn creates slow hatches, reduced hatchability, and lower chick quality.

2.6 Literature Gap

Various literary works have been proposed to develop various kinds of incubators with emphasis of smart control, humidity, temperature and air flow control. It is however pertinent to note that majority of these research works are carried out in different regions which may often vary in their weather conditions and hence may affect operational variables control of these systems. This in turn affects the components selection and sizing. In view of this one may infer that the incubator system can be described as a tropicalized system which may be designed in accordance with the variation in weather conditions of a place. This research therefore puts into consideration the need to develop a smart egg incubation system that can be deployed in Benin City, Nigeria hence its components capacities will be estimated based on the prevailing weather conditions of Benin especially as the system is intended to use solar power as an alternative energy source. In addition, the present study puts into consideration the simultaneous control of the significant incubation variables of temperature, humidity and air flow which many previous research works to explore in that sense. The present research tends to also focus on the use of locally available materials selection and or design without putting much dependence on the acquisition of foreign made materials which many previous research works relied on.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

The proposed solar powered incubator prototype was constructed at the faculty of engineering workshop at the University of Benin. Materials proposed for its fabrication were sourced locally and they include following components.

i. Heat source (light bulbs)
ii. Temperature and humidity controller.
iii. Air recirculation fan
iv. Arduino Nano programmable board
v. Housing structure
vi. Egg turning mechanism
vii. Photovoltaic panel
viii. Solar battery
ix. Inverter
x. Charge controller
xi. Air inlet/outlet vent

3.2 Methods

The design approach for the solar powered incubator is adaptive. The design calculations are based on the operational conditions of the incubator. The key operational variables of the incubator include the internal temperature which is 38^{0}C, the humidity of the incubating chamber which is 65% and the turning mechanism which turns for 10seconds after every one-hour interval of time. Conceptual designs of the solar incubator are considered from which the most viable based on some design and operational criteria will be selected using a decision matrix. Simulation of the working environment was carried out by applying the calculated parameters in a CFD simulation. The incubator was modelled to generate the fabrication drawings.

3.3 Conceptual design

Two design concepts are considered which include the followings;

3.3.1 Concept 1

The first concept of solar powered incubator shown in Figure 3.1 had a fan fixed to the air inlet vent for forced draft supply only. The major disadvantage of the prototype is that it required additional electric power to power the draft fan which is not cost effective. The presence of a fan will also resist the heat production from the heat source making it lost heat fast and prolonging the time to attain the operating temperature.

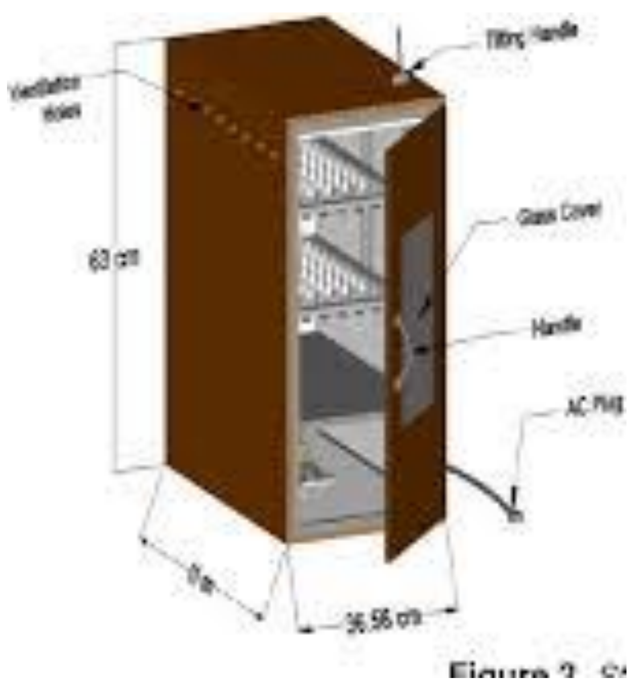


Figure 3.1 Forced draft solar powered incubator

3.3.2 Concept two

The second concept of solar powered incubator considered is shown in Figure 3.2. It comprises of a natural draft inlet into the incubating chamber. The use of natural draft ensures no additional load was on the battery.

Figure 3.2 Natural draft solar powered incubator

3.3.3 Decision matrix for selection of concept

The two concepts of solar powered incubator considered were compared based on some key criteria. The decision matrix for the two concepts is computed as shown in the Table 3.1.

Table 3.1 Decision Matrix

Criteria	Grade points	
	Concept 1 (forced draft)	Concept 2 (natural draft)
Convenient control	2	1
Accuracy in incubation variables control	2	1
Ease of operation	2	1
Energy requirement and sustainability	2	1
Ease of production	1	2
Simplicity	1	2
Total	10	8

From the decision matrix in Table 3.1 using simple aggregate score for the significant criteria considered, the concept 1 with a total weighted criteria average of 10 was met the minimum desired requirement for the design and operational function of the incubator. It was therefore selected as against the concept 2 with total weighted criteria average of 8.

3.4 Detail design

3.4.1 Incubation chamber

The incubation chamber comprised of fiber glass lagged metal compartment. The insulation is required to lower the rate of heat loss due to conduction while the air circulates inside the chamber. The sizing of the incubation compartment was carried out based on the number and sizes of eggs to be incubated. Data taken for weight and rectangular space occupied by an averaged sized egg is shown in Table 3.2. It is from such data that the sizing of the incubator chamber is evaluated.

Table 3.2 Average sizes of eggs

S/N	Weigh (g)	Volume occupied (m^3)
1	0.70	3.6×10^{-5}
2	0.68	3.6×10^{-5}
3	0.71	4.1×10^{-5}
4	0.72	4.5×10^{-5}
Average	0.70	3.95×10^{-5}

From the Table 3.2 it is estimated that a single egg could weigh about 0.70g and occupies a space of $3.95 \times 10^{-5} m^3$. it therefor means that 24 pieces of eggs as contained in a crate could occupy a space of $24 \times 3.95 \times 10^{-5} = 9.48 \times 10^{-4}\ m^3$ if standing alone but close together.

Also considering the space occupied by a hatched chick which was estimated as nearly 10% more than its equivalent egg from which it was hatched that is:

$$\frac{10}{100} \times 3.95 \times 10^{-5} + (3.95 \times 10^{-5}) = 4.345 \times 10^{-5}$$

Therefore, total space requirement for 106 chicken = $4.345 \times 10^{-5} \times 106 = 461.1 \times 10^{-5} m^3$

Since the space occupied by the chickens is more, then it is used as the design input for sizing the incubator compartment.

Possible dimensions of the chamber can be that of a cube say 0.13m by length, breadth and height., but recall, the area of floor is significant for the eggs and chicks.

Hence, should be increased to accommodate the 106 eggs and later chickens when hatched. Total space area of space occupied by the egg lying on its longest side of say 0.07m or say 0.1 for spacing and chicken movements, then 106 eggs will occupy $0.1 \times 0.1 \times 106 = 1.06 m^2$

If follows that the typical dimension of the floor could be say 0.5m by 0.5m

Height of incubator = 0.13 x 3 = 0.39m

Width of incubator = 0.5m

Length of incubator = 0.5m

Size of material for incubator casing

The casing design

Length of casing = L

Breadth of casing = B

Height of casing= H

Surface area of material of casing=Total Surface area of material of casing

Total surface area of the rectangular =

$L_1B_1+L_2B_2+L_3B_3+\ldots\ldots L_nB_n\ldots\ldots$ (3.1)

Where n = the nth term number of surface of the rectangular casing in arithmetic progression.

Area of rectangular cut out material= L x B (3.2)

Hence Surface area of the casing material= $[L_1B_1+L_2B_2+\ldots\ldots L_{n+1}Bn_{+1}\}$……… (3.3)

I.e. SA= TSA, where SA=surface area,

TSA= total surface area,

3.4.2 Air Volume and flow inside incubator

Given the volume of incubator as Vm3. this is also the amount of air that fills and recirculates the chamber per unit given time.

Air speed (Natural draft) = 1.2m/s

Heat Transfer Analysis inside the incubator

Required incubator temperature = 380C

Power of Heat element of bulb required to transfer heat = $\frac{Q}{t} = \frac{mc\Delta T}{t}$ (3.4)

The amount of heat entering incubator is given as

$Q = V \times \rho \times C_P \times \Delta T$ (3.5)

Where;

Q (J) = heat content of the air

V = the flowrate of the air (m3/s) = speed (m/s) x area of air inlet vent (m2)

ρ = density of air = 1.16kg/m3 @ 300C (from psychometric chart)

Cp = the specific gas constant for dry air = 1.005kJ/kgK) (from psychometric chart)

ΔT = the difference in temperature (K) between heat source and the ambient.

3.4.3 Heat Loss

The total heat loss in the incubator is the sum of the heat loss through radiation, conduction and convection and it is expressed as:

$Q_T = Q_{egg} + Q_{air} + Q_{cond} + Q_{conv} + Q_{rad}$ (3.6)

Where:

Q_T = total heat loss in the incubator chamber, W

Q_{egg} = heat energy required to raise the temperature of egg (Qe) from 25^0C to 38^oC, 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_{rad} = the heat loss by ventilation hole, W

In order to estimate the heat required, the energy needed to raise the trays, water, eggs, body, and the heat lost to the surroundings.

For Air

$$Q_a = 0.0942 \times 1.006 \times (37.5 - 25) = 1.184KJ$$

For Eggs

$$Q_e = m_e C_p \Delta T$$

The C_p of eggs = 4270*J/Kg* *(National Library of Medicine)*

The average mass of an egg is 60 *grams* or 0.06*Kg*

Therefore

$$Q_e = 0.06 \times 3.18 \times (37.5 - 25) = 2.385KJ$$

Energy required for 50 egg capacity

$$Q_{eT} = 3.15 \times 50 = 119.25KJ$$

Egg Trays

Egg trays are made significantly of PVC material

The weight of the egg tray from the mass properties evaluation from the CAD model is 242*grams* = 0.242*Kg*

C_p for PVC = 1.6*KJ/Kg*

$$Q_t = 0.242 \times 1.6 \times (37.5 - 25) = 4.84KJ$$

Heat loss through the walls

The walls of the incubator are cladded with 10mm hardboard insulation. Applying one dimensional heat transfer and assuming steady state conditions. The heat is transferred from the air to the insulation via conduction then to the through the insulation and to the steel via conduction

The heat flow via conduction is given by

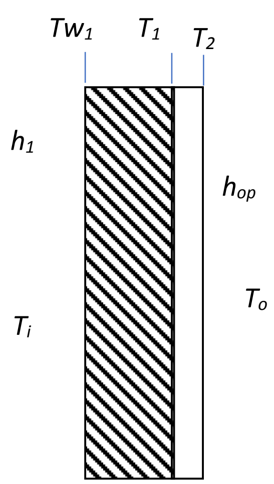
$q = \frac{(T_{hot} - T_{cold})}{R}$ with $R = \frac{k}{LA}$

The heat flow by convection or radiation is given by

$q = \frac{(T_{hot} - T_{cold})}{R}$ with $R = \frac{1}{hA}$

Thermal resistance Ra through a path a is given by the sum of the resistances of the interior film, each wall layer and the exterior film.

We consider the four walls and the glass door which has no insulation.



$h_i = 100\ W/m^2k$

$h_o = 10\ W/m^2k$

$A_{wall}=0.128m^2$

$A_{top/bottom} =0.105m^2$

$$AR_{Total} = A\left(\frac{1}{h_i} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{1}{h_o}\right)$$

For the side walls

$Q_w = UA_{wall}\Delta T$ where $U = \frac{1}{R}$

$$Q_w = 2 \times \frac{1}{0.155} \times 0.128 \times (37.5 - 25) = 20.64W$$

For top and bottom

$$Q_{tb} = UA_{tb}\Delta T$$

$$Q_{tb} = 2 \times \frac{1}{0.155} \times 0.105 \times (37.5 - 25) = 16.94W$$

For Glass door

$$U = \frac{k}{x} = \frac{0.9}{0.01} = 90$$

$$Q_{glass} = 90 \times 0.0748 \times (37.5 - 25) = 56.1W$$

Q loss from body is given by

$$Q_T = Q_w + Q_{tb} + Q_{glass} + Q_E$$

$$Q_T = 20.64 + 16.94 + 56.1 + 2.2 = 95.88W$$

Applying a safety factor of 10%

Therefore $Q_w = 1.1 \times 112.38 = 105.47W$

The heat energy required from equation (3.6) is evaluated as:

$$Q_T = Q_a + Q_{eT} + Q_{tT} + Q_{tm} + Q_w$$

$$Q_T = 1.185 + 119.25 + 4.84 + 5.76 + 105.47 = 241.344KJ$$

Thermal Analysis of the Incubator using computational fluid dynamics (CFD).

A steady state simulation to study the thermal and flow properties. The model was simplified to reduce the computational requirement. The temperature and velocity flow patterns are investigated to ensure the temperature and pressure of the system. The Fluid Subdomain was set as the volume domain inside the incubator as shown in Table 3.3.

Table 3.3 Thermodynamic properties of Air

Parameter	**Unit**	**Value**
Reference Axis		X
Boundary Layer		Laminar
Approximate Pressure	Pa	101325
Humidity	%	70
Turbulence Parameters		
Turbulence Intensity	%	0.1
Turbulence Length	m	0.00444

The Fluid selected was air (Ideal) and its thermodynamic properties are:
Path: Gases Pre-Defined

Specific heat ratio (Cp/Cv): 1.399

Molecular mass: 0.0290 kg/mol

The Boundary conditions were set to simulate the conditions of the incubator. An External inlet fan was used to simulate air flow inside the incubator. The axial 405F was used. The fan parameters are shown in Table 3.4. The pressure difference and volume flow rates were read from standard reference charts and Tables

Table 3.4 Fan parameters

Parameter	Unit	Value
Reference Axis		X
Volume Flow Rate	m^3/s	0.00013214529
Boundary Layer		Laminar

An environment out let was located at the base of the incubator to serve as outlet for the air. A volumetric heat source of 120 W was applied to two bodies at the top of the incubator. The heat source was set to always on. The goal of the simulation was to observe how long it would take to raise the average temperature of the incubator from 25^0C to 37^0C. The temperature plots and the velocity contours can be used to predict the performance of the system.

3.4.4 Humidity control

The humidity control inside the incubator entails the use of a water pump to periodically spray water inside the incubator to maintain an 80% humidity.

The pump is expected to spray a given amount of water with a pump power expressed as:

$$P_{h(kW)} = q \rho g h / (3.6 \times 10^6) \quad (3.7)$$

where

$P_{h(kW)}$ = hydraulic power (W) of the pump

q = flow capacity (m^3/s) of the water $= \frac{v}{h}$ = 0.0001m^3/s

ρ = density of fluid (water) (kg/m^3)

g = gravity (9.81 m/s^2)

h = differential head (m) =

3.4.5 Design for the solar power system

The solar power requirement of the incubator is dependent on the total electric power (w) requirement of the components in the incubator.

To estimate this the energy audit of the system has to be carried out and it includes the summation of the power rating of the:

Incubator bulb(s) and the water pump.

This power is supplied by solar components and estimates are as follows:

i. Solar panel capacity; this is the watts rating of the photo-voltaic cell (shown in Figure 3.3) required to charge the DC battery in watts-hour. It is expressed as

$$P_p = \frac{Battery\ energy}{charge\ time} \quad (3.8)$$

Figure 3.3 solar panel

The solar panel capacity is hinged on the hours of charge time required to charge a solar battery while also supplying power to make the components function.

ii. Battery Capacity; this the ampere-hour (A-h) rating of the solar dc battery (shown in Figure 3.4) required to carry the load units (the items to be powered). It is expressed thus;

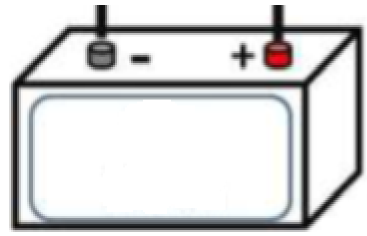


Figure 3.4 Schematic of a solar DC battery with positive and negative terminals

$$\text{Battery Capacity} = \frac{total\ load\ units\ (watts)}{operating\ voltage}\ \text{x desired operating time} \qquad (3.9)$$

iii. The inverter capacity

The inverter capacity is estimated as safety factor x dc load requirement (3.10).

iv. Sizing of the Solar Charge Controller

$$\text{Size of Solar Charge Controller in Amps} = \frac{solar\ panel\ wattage}{norminal\ battery\ voltage} \qquad (3.11)$$

The nominal battery voltage is taken as 12 V

3.4.6 Simulation of the turning mechanism motor torque

The turning mechanism shown in Figure 3.5 was also studied on linkage 3.10 and Solid Work to determine the motion properties of the mechanism and also to determine the required lengths of the link to get the desired tray angle which is between 30^0 to 45^0.

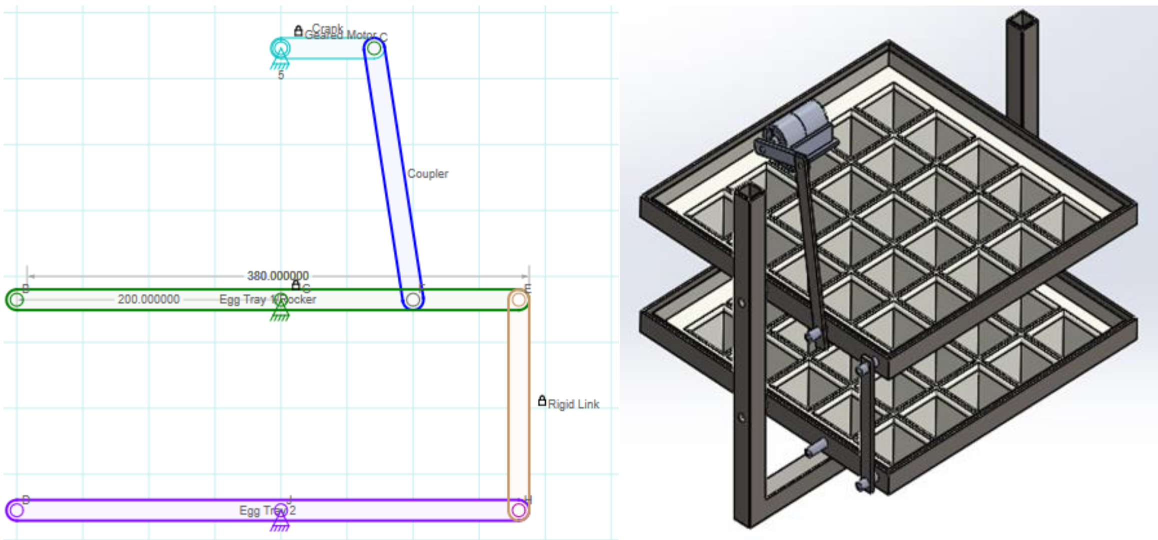


Figure 3.5 Egg turning mechanism in incubator

The turner mechanism consists of a geared electric motor, a crank rod, a connecting Rod and a rigid link connecting the trays. The trays are hinged to a horizontal member which allows them to rotate about the hinge axis. The system was then replicated in SolidWorks and analyzed. The mechanism is a four-bar chain and can be analyzed using methods for analyzing grashof' s four bar mechanism. Grashofs crank and rocker mechanism consists of the crank, coupler, rocker and the fixed link. The rule for this mechanism is that the sum of the longest and shortest link cannot be greater than the sum of the other two links if there must be relative motion. The fixed link is set based on the oven height and the spacing between the trays and the heat source dimensions at 173mm. The crank length is started at 60mm. This is a constraint and must be taken into account when selecting the size of the other members. With the rocker (tray) at ¼ the length of the total tray length.

$$Rocker + Coupler > 233mm$$

$$Rocker = 380/4 = 95mm$$

$Coupler\ length > 233 - 95 = 138mm$

Consider a four-bar mechanism shown in Figure 3.6

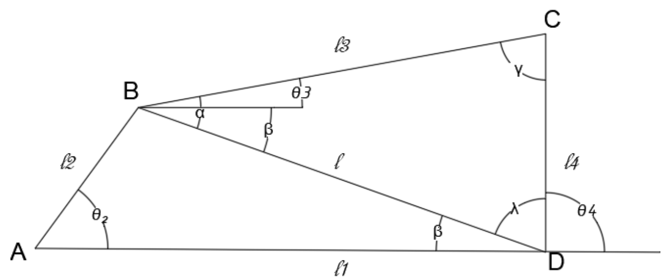


Figure 3.6 Four bar mechanism

Using cosine rule to analyze the triangle ABD, we have *l* as:

$$l = \sqrt{{l_2}^2 + {l_1}^2 - 2l_1 l_2 \cos\theta_2} \tag{3.12}$$

Using sine rule we can obtain the value of the angle *β*

$$\beta = \sin^{-1}\left(\frac{l_2 \sin\theta_2}{l}\right) \tag{3.13}$$

Similarly, using ΔBCD, we can obtain the values of *α* and *λ*

$$\alpha = \cos^{-1}\left(\frac{l^2 + {l_3}^2 - {l_4}^2}{2 l l_3}\right) \tag{3.14}$$

$$\lambda = \sin^{-1}\left(\frac{l_3 \sin\alpha}{l_4}\right)$$

$\theta_3 = \alpha - \beta$, and $\theta_4 = \pi - \lambda - \beta$

Displacement in the x and y directions can be obtained by resolving the forces to their orthogonal axes

$$l_2 \cos\theta_2 + l_3 \cos\theta_3 = l_1 + l_4 \cos\theta_4 = C_x$$

$$l_2 \sin\theta_2 + l_3 \sin\theta_3 = l_4 \sin\theta_4 = C_y$$

$B_x = l_2 \cos\theta_2$ and $B_y = l_2 \sin\theta_2$

With these equations the position of the links at any point of the crank rotation is defined. With the values for crank angle from 0^0 to 360^0. Values for both linear and angular displacement can be generated to define the position of the link at any point in time as shown in Figure 3.7.

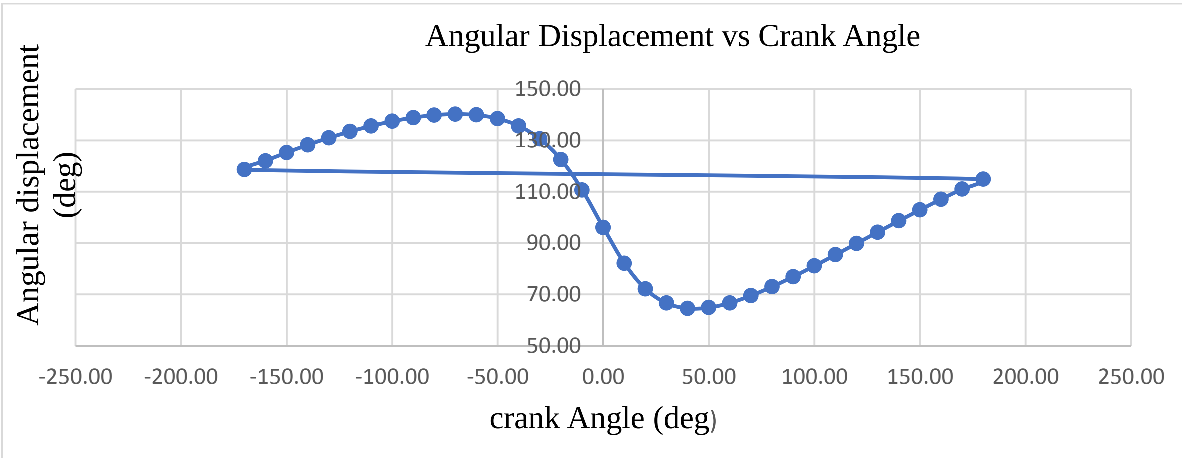


Figure 3.7 Turning mechanism path

The objective of the motion study was to determine the torque the motor would require. A design study using different coupler lengths and pin positions to determine the position that would obtain a 45-degree angular displacement was carried out. The conventional and acceptable speed of 2.5r/min was used to simulate the movement. The simulation was run for one complete revolution. One complete revolution will take

$$\frac{60secs}{2.5r/min} = 24seconds$$

The initial values were speed = 2.5r/min, crank Length = 80mm, connecting rod length = 220mm

initial crank angle set at 86°, pin position = 94mm from tray center pin should be equal to ¼ of the tray length. The goal of the simulation is to monitor the angular displacement of the tray and the motor torque.

Motion study settings

Gravity was set in the negative Y direction at 9.806m/s^2. General contact set was set with the parameters Table 3.5

Table 3.5. Contact parameters.

Parameters	Unit	Value
Dynamic Friction Coefficient μ_k		0.1
Dynamic Friction Velocity v_k	mm/s	10.6
Static Friction		
Dynamic Friction Coefficient μ_k		0.15
Dynamic Friction Velocity v_k	mm/s	0.10

A rotary motor of 2.5r/min at the crank pin was used to supply motion to the mechanism as shown in Figure 3.8.

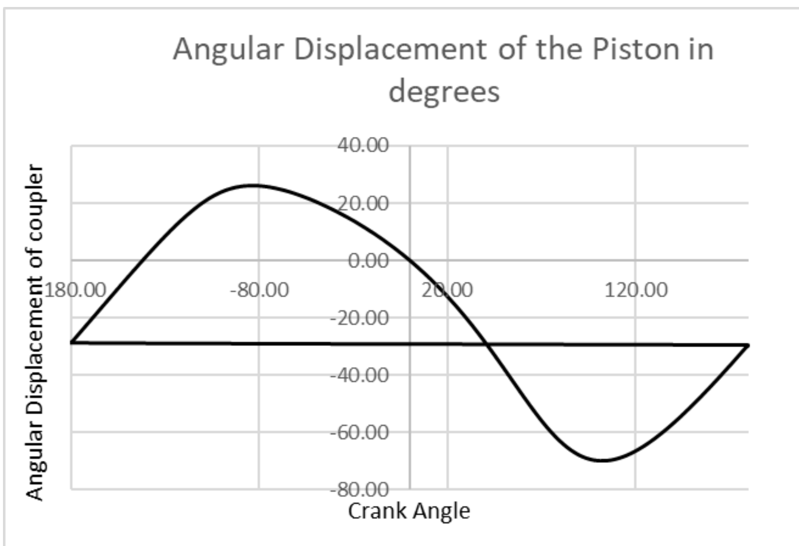


Figure 3.8. Motion description of the mechanism

The mean position in the graph is at -28.76. The maximum displacement from this mean position is 25.97 deg. This yields an angular displacement of 54.73 degrees upwards and 32.10 degrees after 180 degrees' rotation of the crank rod. The mechanism satisfies the turning requirement to ensure the proper development of the embryo.

The maximum torque required from the plot is 1Nm.

Calculating the motor power required.

$Torque \times FOS$

Selecting an FOS of 3, The torque is 3Nm and a crank radius of 70mm. The power is calculated thus

$$Power = \frac{Torque \times Crank\ radius}{Power\ factor \times Mechanical\ Eff\ of\ gearbox}$$

with a power factor of 0.8 and Mechanical Efficiency of 0.9.

$$Power = \frac{3 \times 0.07}{0.8 \times 0.9} = 0.291W$$

A 0.3W motor could be selected for the mechanism

3.5 Production Process

The solar powered incubator was fabricated at the faculty of engineering workshop using various production techniques. The procedure of production for some components include the following

i. The structural frame of the solar dryer; this was made from metal which were cut and welded together.

ii. The solar incubator compartment was made from:

   a. Galvanized metal sheet.

   b. Transparent glass sheet of 4mm thickness as an inspection window

   c. The casing box lagged with plywood to prevent or minimize heat losses

3.6 Bill of Engineering Materials and Evaluation (BEME)

The BEME of the solar powered incubator is shown in Table 3.6

Table 3.6 Bill of Engineering Materials and Evaluation of solar powered incubator

S/No	Items	Description	Quantity	Dimension	Unit cost	Total cost
1	Mild steel sheet metal		1 roll			
2	Mild steel rod		1	1m		
3	Electric pump		1			
4	Copper tube		6			
5	Electric bulb		1 roll			
6	Angle bar		1.5meter			
7	Bolts and nuts		lot			
8	Hollow square pipe	Mild steel	1/2 inch	1m		
9	Wirings/Electricals		Lump			
10	Paint	Liquid based	1 liter	1 can		
11	Fins					
12	Water reservoir		1			
13	Solar panel		1			
14	Solar battery		1			
15	Inverter		1			
16	Charge controller		1			
17	Arduino programmable board					
18	Miscellaneous				10000	10000
19	Workmanship				15000	15000
20	Total					96400

The graphic view of the produced solar incubator is shown in the Figures 3.9.

3.7 Test procedure

The solar powered incubator operational test was carried out by putting a given number of weighed eggs inside and switching it on. The operational test was carried out daily for a period of 21 days equivalent of the incubation period of eggs at which they become hatched to produce chickens. The environmental conditions and conditions of the incubator were also recorded before the incubation process commenced and during the incubation period. The device temperature and humidity were measured and taken periodically using thermometer and hygrometer. Values recorded were compared with ambient conditions of the environment. This was to ascertain the energy propagation taking place inside the device and the test was carried for the period incubation. On completion of the hashing of eggs inside the incubator, the chickens' conditions were monitored and analyzed accordingly. The test data recorded for the test were temperatures, relative humidity, time and weight. The equipment used for taking measurements of the solar incubator test include the followings;

i. Solar seaward 200R temperature meter ±(1% to 1^0C)

ii. Solar seaward 200R, 100-1500 W/m^2 for solar irradiance

iii. Extech 3-in-1 humidity meter. ±4%RH (from 10% to 70%RH)

According to (Ogunwande et al; and Gbabo et al). the biological performance parameters of the incubator is determined using the following formulae:

$$\% \text{ Fertility of eggs} = \frac{number\ of\ fertile\ eggs}{total\ number\ of\ eggs} \times 100\% \tag{3.15}$$

$$\% \text{ Hatchability of the fertile egg in the chamber} = \frac{number\ of\ hatched\ eggs}{total\ number\ of\ fertile\ eggs} \times 100\% \tag{3.13}$$

$$\% \text{ of hatchery waste (unhatched chicks)} = \frac{waste\ of\ chicks\ that\ did\ not\ hatch}{total\ number\ of\ fertile\ eggs} \times 100\% \tag{3.16}$$

$$\% \text{ of developed but unhatched} = \frac{number\ of\ chicks\ developed\ but\ unhatched}{total\ number\ of\ fertile\ eggs} \times 100\% \tag{3.17}$$

Operational test of the incubator was also carried out to determine the transient nature of heat and air flow in the incubator.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The test results recorded are shown in the Table 3.4 and the appendix 1 of this literature.

Table 4.1 Values of ambient and room readings for solar incubator.

Time (hr)	Ta (^{0}C)	T_{inc} (^{0}C)	Ra (%)	R_{inc} (%)
1	31	38.5	70	67
4	32	40	68	66
8	30.8	37.8	70	68
12	30	37.8	69	65.8
16	32	37.8	65	65
20	31	37	69	66
24	30	38.5	70	68
Average	30.9	38..63	69.2	66.5

Table 4.2 Values of average, ambient and room readings for solar incubator.

Time (days)	Ta (^{0}C)	T_{inc} (^{0}C)	Ra (%)	R_{inc} (%)
1	31	38.5	70	67
2	32	40	68	66
3	30.8	36.85	70	68
4	30	37.8	69	65.8
5	32	36.8	65	65
6	31	38.2	69	66
7	30	36.5	70	68

8	32	40	68	66
9	30.8	36.85	70	68
10	30	37.8	69	65.8
11	32	36.8	65	65
12	31	37	69	66
13	32	40	68	66
14	30.8	37.8	70	68
15	32	40	68	66
16	30.8	36.85	70	68
17	30	37.8	69	65.8
18	32	36.8	65	65
19	31	37	69	70
20	32	40	68	69.5
21	32	38.5	65	71

Table 4.3. The biological performance of the loaded eggs.

Biological Performance parameter	**Evaluation**	**Percentage (%)**
Fertile eggs (Fertility)	19	95
Hatched eggs (Hatchability)	80	91
Chicks that hatched late	4	17
Chicks that were fully develop but unhatched	-	0
Hatchery waste (chick that did not hatch)	3	13
Total number of eggs loaded	106	100

The result of data collected for ambient temperature T_a, ambient relative humidity R_a, incubator temperature T_{inc} and relative humidity of incubator R_{inc} in a given time T is presented in Tables

4.1. and 4.2. The test values were plotted on a graph in Figure 4.1 and 4.2. The daily ambient and incubator temperatures were compared as shown in Table 4.1 and the graph in Figure 4.1. The relative humidity of the incubator and that of the ambient were also compared as shown in Table 4.2 and the graph in Figure 4.2.

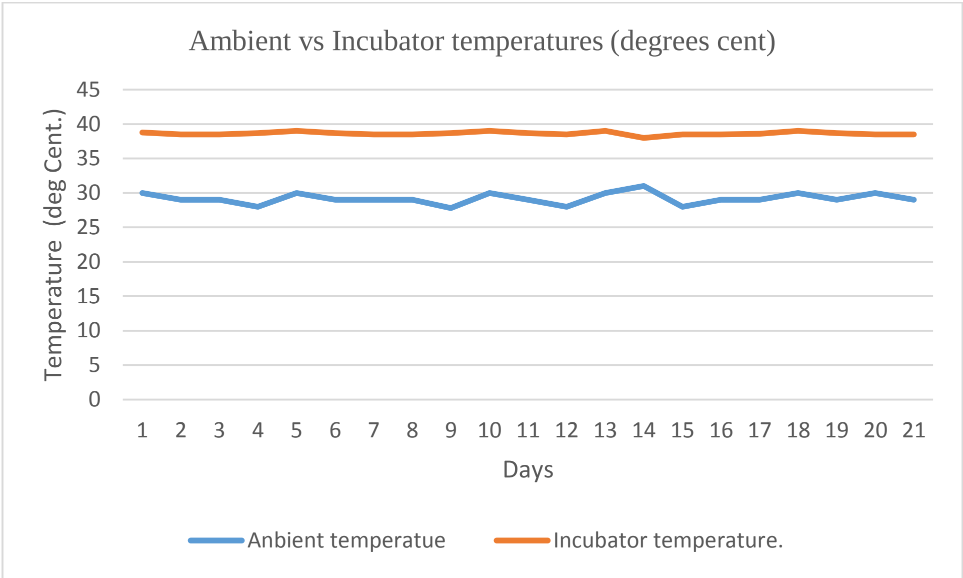


Figure 4.1 Temperature measurement of Ambient and incubator.

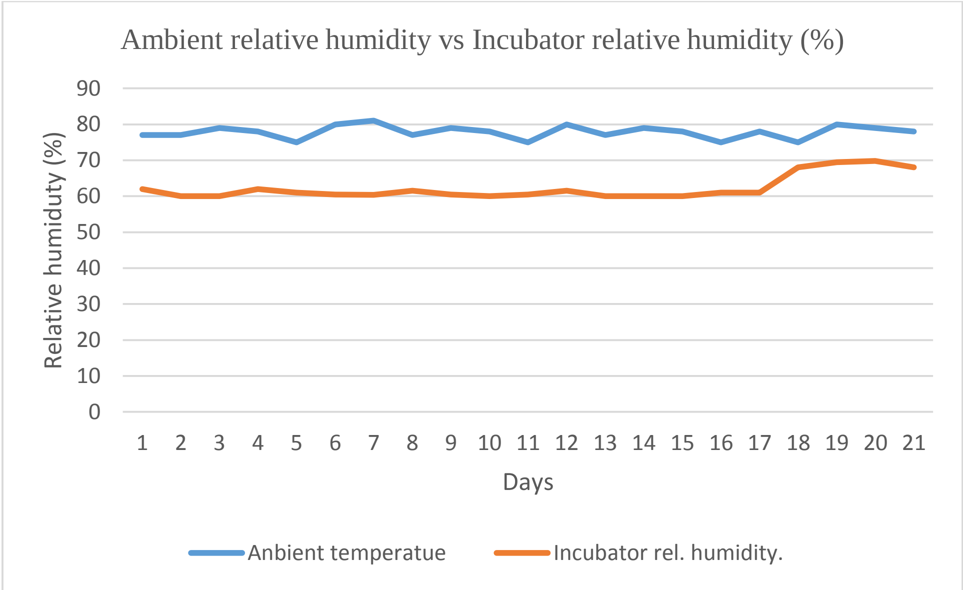


Figure 4.2 Relative humidity of Ambient and incubator

Thermal Analysis

The velocity isolines and contour plots for the thermal analysis of the incubator are presented in Figures 4,3 and 4.4 respectively.

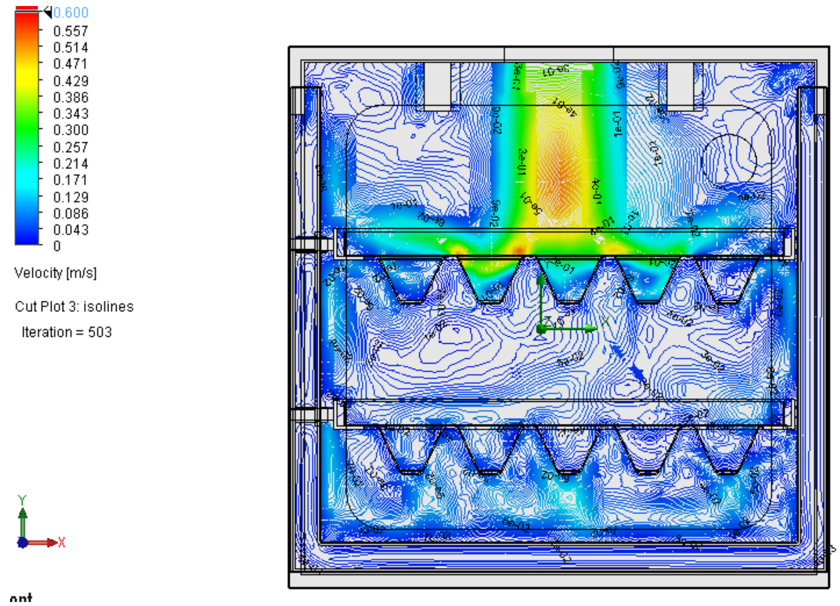


Figure 4.3 Velocity Isolines

The velocity of 0.3m/s seconds at entry and reduces 0.05m/s. The bodies in the incubator cause a reduction in the kinetic energy of the air. This gives sufficient time for the air to gain temperature.

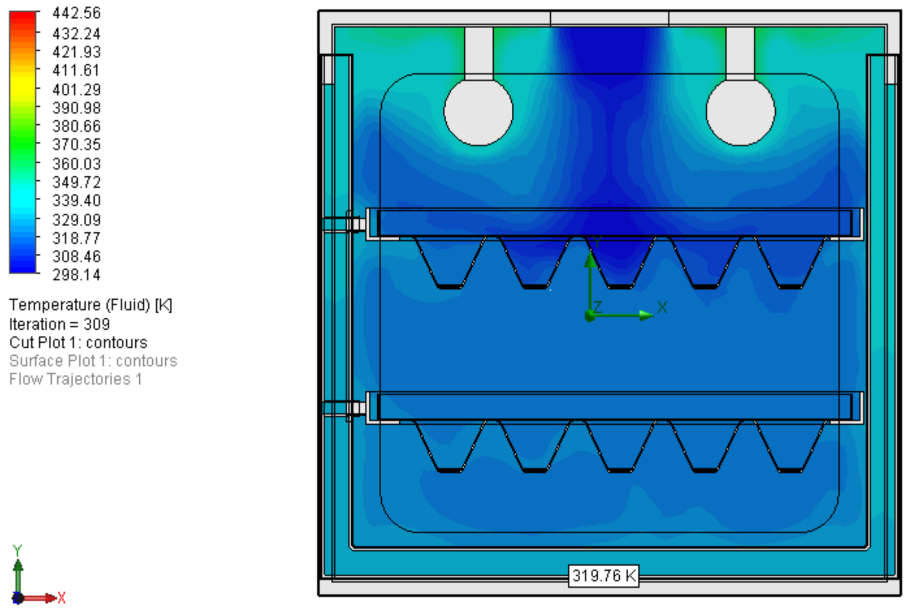


Figure 4.4 Contour plots showing Temperature distribution in the incubator

The temperature plot shows how the temperature distribution in the incubator. The critical areas around the trays show that the temperatures are at 310.37 K or 37.10^{0}C. The isolines contour plot shows. The plot shows that the air around the walls are at a higher temperature due to transfer of heat between the walls and the air due to the insulation/cladding on the walls.

The isoline contour plots show that the temperature ranges from 308.98 – 319.77 K. We see the maximum temperature plots emanating from the volumetric heat source each rated at 60W. The temperature varies across the height of the incubator. It can be seen that the fresh charge is at room temperature. The air circulates around the incubator gaining heat in the process. The contour plot of the air velocity in shown in Figure 4.5.

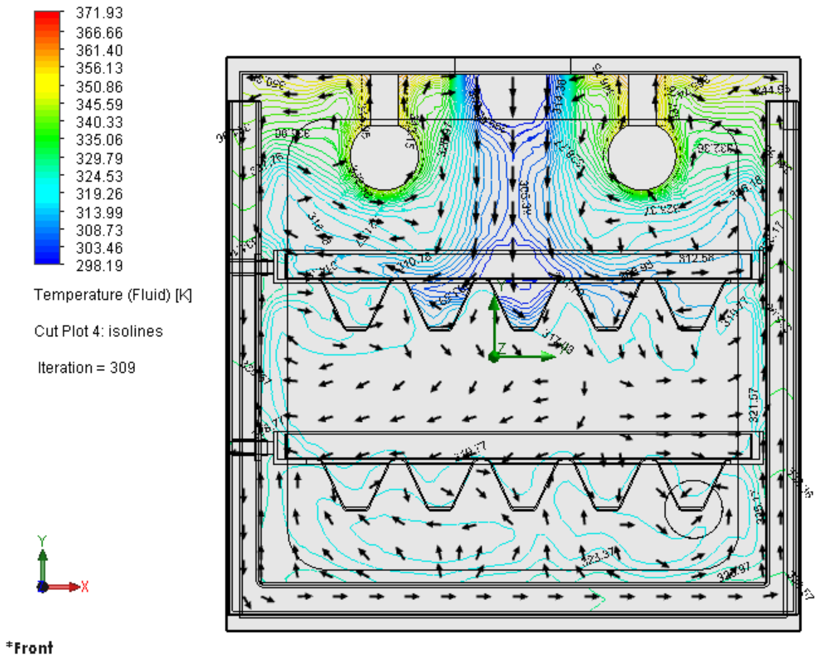


Figure 4.5 Contour plot of air velocity

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Total Temperature 1	[K]	303.0982528	302.5949441	302.0907037	303.0982528
GG Av Velocity 1	[m/s]	0.007967613	0.007708312	0.007169849	0.008175266
GG Av Temperature (Fluid) 1	[K]	303.0982527	302.594944	302.0907036	303.0982527
SG Mass Flow Rate 1	[kg/s]	-0.00015639	-0.000156393	-0.000156393	-0.000156393

The operational test outcome of the incubator showing temperature and air flow is presented in the Figure 4.6 and 4.7 respectively.

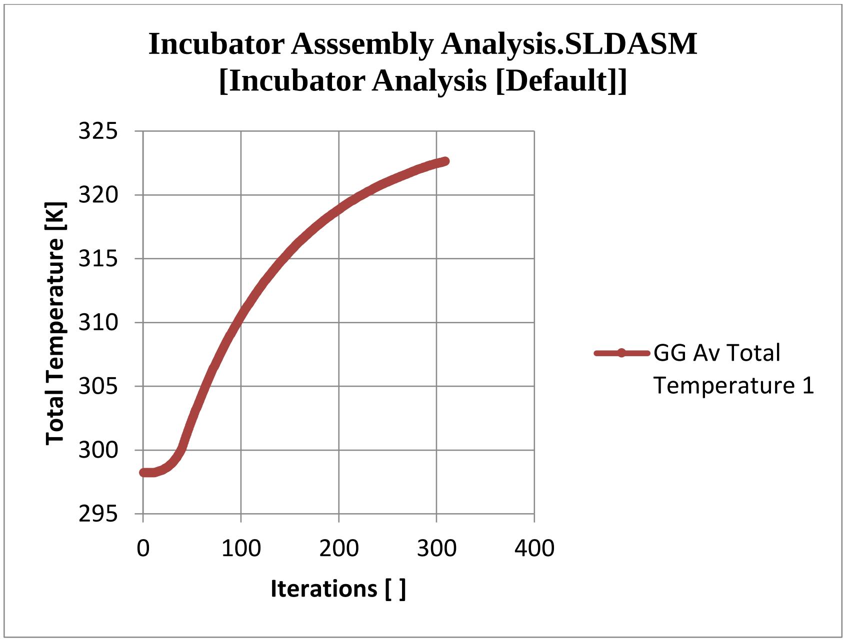


Figure 4.6 Heat flow pattern in the incubator

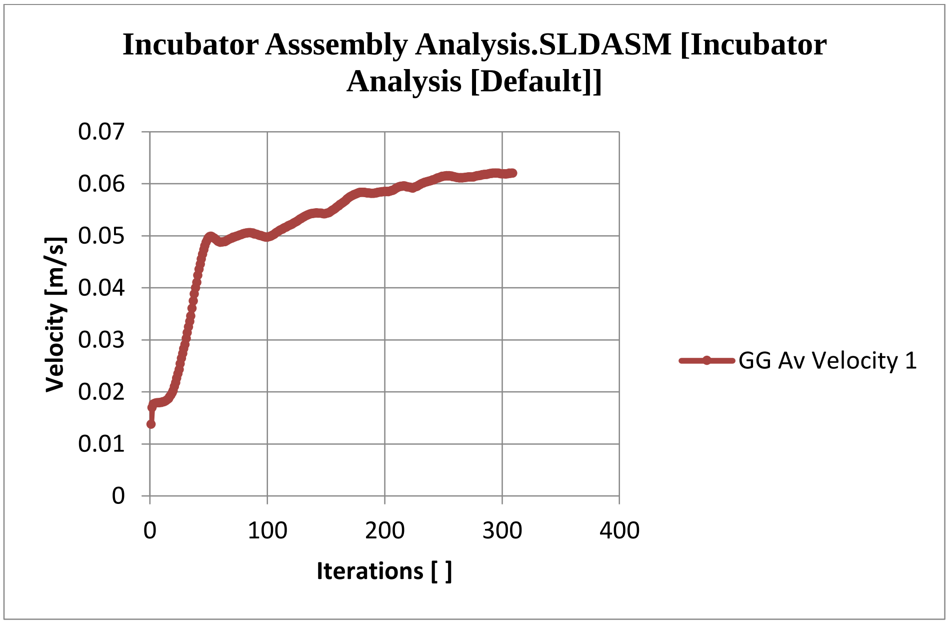


Figure 4.7 air flow pattern inside the incubator

4.2 Discussion of Results

The data recorded from the test showed that the daily average temperatures recorded for the ambient and incubator were 30.9 and 37.6 degrees centigrade respectively, while the daily relative humidifies recorded for were 69.2% and 66.5% for the ambient and incubator respectively. Inference from that considering the temperatures and humidity measurement in the Tables 4.1 and 4.2 is that temperatures inside the drying chamber were relatively higher than the ambient temperatures as shown in the graphs in Figure 4.1. This was due to the effect of the heat bulb which contributed heat to internal space and walls of the incubator. Also, the daily humidity measurement in the Table 4.2 showed that the humidity measurements for the ambient were a bit higher than that measured inside the incubator compartment as exemplified in the graph in Figure 4.2. This may have been due to the effect of the heated environment inside the incubator, brought about by the hot bulb.

Inference from the data in the Table 4.2 and Figure 4.2 also indicates that there was an increase in relative humidity of the incubator in the last 3 days of the test orchestrated by increased sprinkling of water inside the incubator.

The plot in Figure 4.6 show the gradual rise of the average temperature of the incubator. It can be seen that the air steadily gained the heat energy across several iterations. A peak average total temperature of 322K was reached over 350 iterations. The fan curves and the flow rate from the outlet surface shows that the outflow is less than the volumetric inflow. This causes slight turbulence within the volume enhancing the heat transfer.

The plot in Figure 4.7 shows the rise in the average velocity of the air from 0.015 to 0.063m/s. The increase in velocity is caused by the change in temperature causing the air to be lighter.

Furthermore, the forced inflow fan causes the inlet volumetric flow rate to exceed the outlet volumetric flow rate causing a slight increase in pressure and velocity

On the biological performance of the incubator, it was inferred from Table 4.3 that the highest

hatchability (91 %) was achieved after the incubation period. The high hatchability may have been due to the good control and maintain of heat near the eggs.

The solar system performance of the system was highly satisfactory as it was able to power the electric components within the operational test period of the facility.

CHAPTER FIVE

CONCLUSSION AND RECOMMENDATION

5.1 Conclusion

The present research centered on using solar power to power an incubator. This is a promising technology if properly developed from a prototype to a commercial product. The test data obtained from the experimentations revealed that air, humidity, temperature, nature of the material being used as insulator were necessary to establish the performance of the incubator. The solar powered incubator performance evaluation was conducted on the developed solar powered poultry egg incubator with a capacity of 24 eggs. The solar powered system provided uninterrupted power supply to the incubator throughout the period of incubation. The hatchability and fertility of the system were 91 % and 95%, respectively. The periodical turning of the eggs was carried manually to be economical on the facility development funds as well as the solar power requirement of the system. The system was able to maintain the interior temperature of the incubator between 37 and 38^{o}C throughout the incubation period with the aid of then temperature control system and the energy source employed. It was found that the incubator system is capable to incubate and hatch poultry eggs effectively.

From the results, it is imperative the tray areas will always have low values of air temperature if all conditions calculated are implemented. The temperature probes must be placed around the trays and not at the entry or close to the walls as the temperature in those regions are higher than the temperature around the trays.

5.2 Recommendations

Following the completion of the present research, the following recommendations were made;

i. Further research may be required to ascertain the degree of effects of variables which contributes to the overall incubation process of eggs using a solar drying device.

ii. Solar incubator device of this nature as exemplified with the present proof of concept can be commercially produced giving its effectiveness.

iii. Further research on this subject may be required to test the effectiveness of the solar incubator for higher amounts of eggs suitable for large scale commercial incubation.

REFERENCES

Akanji, A. M., & Duvuna, G. A. (2012). Development of poultry incubation systems in tropical environments. Nigerian Journal of Animal Production.

Brah, G. S., Sandhu, J. S., & Singh, A. (2005). Manual and automated incubation methods for poultry production. World's Poultry Science Journal.

Funk, E. M., & Forward, J. F. (1960). Design principles and performance evaluation of commercial incubators. Agricultural Engineering Research.

Haque, M. (2001). Humidity and temperature effects on hatchability of chicken eggs. International Journal of Poultry Science.

Turner, E. C., & Armstrong, J. D. (2007). Solar-powered agricultural devices for developing regions. Journal of Renewable Energy Systems.

Wilson, H. R. (1991). Effect of incubation environment on embryo development and hatchability. Poultry Science Review.