

DESIGN AND FABRICATION OF SOLAR POWERED EGG INCUBATOR



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**A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF PRODUCTION
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REQUIREMENT FOR THE AWARD OF THE DEGREE OF BACHELOR OF
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SUPERVISOR: ENGR. DR. E. M. ETUK

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CERTIFICATION

This is to certify that this study was carried out by **God'stime Ozomah** with matriculation number **ENG1905884** in the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City in partial fulfillment of the requirement for the Award of Bachelor of Engineering (BEng.) in Production Engineering.

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DEDICATION

I dedicate this project to God Almighty, my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this program and on His wings only have I soared. I also dedicate this work to my parents Mr. and Mrs. Samuel and Irene Ozomaah who has encouraged me all the way and whose encouragement has made sure that I give it all it takes to finish that which I have started.

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My gratitude goes to God Almighty for allowing me to complete my degree programme.

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ABSTRACT

Poultry farming is a crucial agricultural sector that provides protein and economic opportunities, particularly in rural communities. However, small-scale poultry farmers often face challenges in egg incubation due to unreliable electricity and the high costs of conventional incubators. This study explores the design, fabrication, and evaluation of a solar-powered egg incubator tailored for small-scale poultry farmers. The proposed incubator harnesses renewable solar energy to maintain optimal incubation conditions, ensuring stable temperature, humidity, and automated egg turning.

The research employs a systematic approach, including component selection, design calculations, computer-aided design (CAD) simulations, and prototype fabrication. The incubator is designed to be cost-effective, energy-efficient, and scalable, making it accessible to farmers in off-grid areas. Performance tests demonstrated that the incubator maintained an internal temperature range of 37–38°C, achieving a hatchability rate of 91% and fertility rate of 95%. Computational Fluid Dynamics (CFD) analysis validated its thermal efficiency and air circulation patterns.

The results indicate that solar-powered incubation is a viable alternative to conventional methods, reducing dependency on fossil fuels while enhancing productivity. This study contributes to sustainable poultry farming by offering a practical, environmentally friendly, and economically viable solution for small-scale farmers. Further research is recommended to explore large-scale applications and the integration of automated control systems.

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CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Poultry farming plays a pivotal role in agriculture, serving as a vital source of protein in the form of eggs and meat. For many rural communities worldwide, small-scale poultry farming is not only a source of nutrition but also a means of generating income and supporting livelihoods. Traditionally, hens have been responsible for naturally incubating eggs, but this method is not efficient for medium to large-scale operations. The natural process limits the number of eggs a hen can incubate at once, and the hatching success rates are often inconsistent.

To overcome these limitations, egg incubators were introduced, offering a technological solution that allows farmers to create a controlled environment for optimal hatching. Modern incubators precisely regulate temperature, humidity, and egg turning, ensuring better hatching success rates and allowing farmers to hatch eggs consistently throughout the year.

Despite the clear benefits of egg incubators, small-scale poultry farmers often struggle to access this technology due to its high upfront costs and dependence on reliable electricity. In rural and off-grid areas, consistent access to electricity can be a challenge, making conventional incubators unsuitable for many small-scale farmers. Additionally, even in areas with access to electricity, power outages and unstable supply increase operational costs, reducing profitability for small-scale operations, especially in developing nations.

As a result, there is a growing demand for an affordable, sustainable, and reliable solution that can help rural farmers scale up their poultry farming operations without the barriers of expensive equipment and unreliable electricity.

Solar-powered egg incubators offer a promising solution by harnessing renewable solar energy, which is readily available in regions with abundant sunlight. By using solar energy, these incubators can operate independently of the electrical grid, reducing costs and making them accessible to small-scale poultry farmers in remote areas. Solar-powered incubators not only address the challenge of unreliable electricity but also help make poultry farming more feasible and scalable for rural communities, enhancing their economic prospects and food security.

In addition to their economic advantages, solar-powered incubators contribute to global sustainability efforts by reducing reliance on fossil fuels and lowering carbon emissions. Solar energy is a clean, renewable resource that minimizes the environmental impact of agricultural operations. By integrating solar energy into poultry farming, farmers can reduce their carbon footprint, aligning with the global push toward environmentally sustainable agricultural practices.

With the increasing emphasis on sustainable farming methods, the adoption of renewable energy technologies is becoming essential in agriculture. Solar-powered incubators represent an innovative solution that supports sustainable and resilient farming practices, particularly in regions with limited or costly energy supplies.

This study seeks to address the need for a **sustainable, affordable, and reliable solar-powered egg incubator** specifically tailored to the requirements of small-scale poultry farmers. While solar-powered incubators exist commercially, they are often expensive and not well-suited to the needs of small-scale farmers. This research aims to design a modular solar-powered incubator

that is adaptable, allowing farmers to scale its capacity based on their specific requirements and available resources.

The focus of this study will be on designing and fabricating an incubator that is both technically efficient and economically viable. It will explore key operational aspects such as temperature management, humidity control, and automated egg turning, all while ensuring the system is energy-efficient and easy to use. The study will also consider the environmental sustainability of the design, comparing its impact to conventional incubators that rely on grid power.

Ultimately, this research will contribute to the growing body of knowledge on how renewable energy technologies can be successfully integrated into small-scale farming to enhance productivity, reduce environmental impact, and improve the livelihoods of rural farmers.

1.2. STATEMENT OF PROBLEM

Small-scale poultry farming is crucial for food security and income generation in developing countries, but egg hatching poses a significant hurdle. Many farmers struggle with unreliable or non-existent electricity, making traditional electric incubators impractical. Even when electricity is available, the high running costs of these incubators often eat into already slim profit margins. Traditional hen incubation, while low-cost, is inefficient, limiting the number of eggs hatched and tying up valuable resources. Furthermore, electric incubators, especially those relying on generators, contribute to environmental pollution, a growing concern. While solar-powered incubators exist, they are frequently too expensive or lack the scalability needed by small-scale farmers. This lack of affordable, reliable, and scalable incubation technology hinders productivity and limits the potential of small-scale poultry farming. Therefore, a modular, solar-powered egg incubator is essential. Such a device should be cost-effective for small-scale

farmers, technologically sound, and easily scalable to meet varying needs. Crucially, it must be environmentally sustainable, harnessing solar energy to eliminate reliance on fossil fuels. This innovation would empower farmers to improve hatching success rates, reduce operational costs, and embrace sustainable practices, ultimately strengthening their livelihoods and contributing to food security.

1.3. AIMS AND OBJECTIVES

1.3.1 AIMS

This research aims at designing and fabricating a sustainable solar powered egg incubator model for small scale poultry farmers.

1.3.2 OBJECTIVES

1. Carry out a study of different component of an egg incubator
2. Design calculation of operating parameter of the egg incubator
3. Simulation of the egg incubator components using computer aided design and analytical tool
4. Fabrication of the egg incubator machine
5. Evaluating the egg incubator economic and environmental sustainability

1.4. SCOPE OF THE STUDY

The scope of this study is centered on the design and fabrication of a modular solar-powered egg incubator tailored specifically for small-scale poultry farmers. This project will focus on developing an incubator that can operate efficiently in rural areas with limited or unreliable access to electricity by utilizing solar energy. The incubator will be designed to accommodate

the specific needs and constraints of small-scale farming operations, where affordability, simplicity, and reliability are paramount.

1.5 SIGNIFICANCE OF THE STUDY

This study is significant as it addresses key challenges faced by small-scale poultry farmers, particularly in rural and off-grid areas, by developing a sustainable, solar-powered egg incubator. The technological innovation proposed will provide an affordable and reliable solution to farmers who lack access to consistent electricity, thereby enhancing productivity, reducing operational costs, and increasing hatchability rates. Additionally, the study promotes environmental sustainability by leveraging renewable solar energy, reducing reliance on fossil fuels, and minimizing carbon emissions. Ultimately, this project contributes to improving food security, economic stability, and sustainable agricultural practices for small-scale farmers.

CHAPTER TWO

LITERATURE REVIEW

The purpose of this chapter is to review existing literature relevant to the design and fabrication of a sustainable solar-powered egg incubator for small-scale poultry farmers. This chapter provides a comprehensive analysis of the conceptual, theoretical, and empirical foundations of egg incubation technology, with a particular focus on sustainable and renewable energy applications. The review will help establish a knowledge base for the project by identifying existing technological advancements, challenges, and gaps in research related to solar-powered egg incubators.

The literature review is structured into four main sections. The conceptual framework (Section 2.1) explores fundamental concepts related to egg incubation, solar energy utilization, and sustainable design. The theoretical framework (Section 2.2) examines relevant theories that underpin the development and operation of incubators, such as thermodynamic principles and energy conservation. The empirical study framework (Section 2.3) reviews previous research studies and real-world applications of egg incubators, particularly those designed for rural and off-grid environments. Finally, the appraisal of reviewed literature (Section 2.4) provides a critical assessment of the gaps and limitations in existing research and highlights how this study will contribute to the body of knowledge in this field.

2.1 Conceptual Framework

This section details the conceptual framework underpinning this research, providing a comprehensive overview of the core concepts that guide the design and development of a sustainable solar-powered egg incubator for small-scale poultry farmers. The framework explores the intricate process of egg incubation, the effective utilization of solar energy within incubation technology, and the crucial aspects of sustainable design tailored specifically for the context of small-scale poultry farming. These interconnected concepts form the foundation upon which the research is built, ensuring a holistic and impactful approach to the project.

2.1.1 Egg Incubation Process: A Foundation for Success

Egg incubation is a delicate and precisely controlled biological process that provides the optimal environmental conditions necessary for embryonic development from fertilization to hatching. Understanding the intricacies of this process is paramount for designing an effective incubator. Several key parameters influence successful incubation, each requiring careful consideration and precise regulation:

- **Temperature:** *Temperature is arguably the most critical factor. Embryonic development is highly sensitive to temperature fluctuations. Optimal temperature ranges vary slightly depending on the species of poultry, but generally fall within a narrow window. Maintaining consistent temperatures within this range is essential for healthy development and high hatchability rates. Deviations from the optimal range, even by a degree or two, can lead to developmental abnormalities, reduced hatchability, or even embryo death. Therefore, precise temperature control mechanisms are crucial in any incubator design.*
- **Humidity:** *Appropriate humidity levels are also vital. Humidity plays a crucial role in regulating the rate of moisture loss from the egg. Insufficient humidity can lead to excessive water loss, resulting in a smaller chick and potentially hindering hatching. Conversely, excessive humidity*

can prevent adequate water loss, leading to a larger, weaker chick that may struggle to hatch. Maintaining the correct humidity level ensures proper embryonic development and facilitates a successful hatch.

- ***Ventilation:*** *Proper ventilation is essential for gas exchange. Developing embryos require a constant supply of oxygen and the removal of carbon dioxide. Insufficient ventilation can lead to a buildup of carbon dioxide, which is toxic to the developing embryo. Adequate ventilation also helps to regulate temperature and humidity within the incubator. The design of the ventilation system must balance the need for fresh air with the need to maintain stable temperature and humidity levels.*
- ***Egg Turning:*** *Regular egg turning is necessary, particularly during the early stages of development, to prevent the embryo from adhering to the shell membrane. Adherence can lead to developmental abnormalities and prevent the chick from hatching. Turning also helps to ensure uniform temperature and humidity distribution within the egg. The frequency and angle of turning vary depending on the species, but consistent and proper turning is crucial for successful incubation.*

Natural incubation, where hens brood eggs, provides these conditions instinctively. However, natural incubation is limited by the number of eggs a hen can brood and is susceptible to environmental variations. Artificial incubation, using specially designed machines, offers greater control over these parameters, allowing for the incubation of a larger number of eggs and minimizing the impact of external factors. This study focuses on developing an artificial incubation system powered by solar energy.

2.1.2 Solar Energy Utilization in Incubation: A Sustainable Solution

Solar energy, a readily available and renewable resource, offers a sustainable alternative to conventional energy sources for powering egg incubators. Harnessing solar energy for incubation is particularly advantageous in rural and off-grid areas where access to reliable electricity is limited or non-existent.

The integration of solar energy into incubation technology involves several key components and considerations:

- ***Photovoltaic (PV) Panels:*** *PV panels are the core of the solar energy system. These panels convert sunlight directly into electricity through the photovoltaic effect. The size and number of PV panels required will depend on the energy demands of the incubator, which in turn will be determined by factors such as incubator size, insulation, and the efficiency of the heating and ventilation systems.*
- ***Energy Storage (Batteries):*** *Solar energy is intermittent, meaning its availability fluctuates with weather conditions and time of day. To ensure consistent operation of the incubator, especially during periods of low or no sunlight, energy storage is essential. Batteries are commonly used to store the electricity generated by the PV panels, providing a backup power source when needed. The capacity of the battery system will depend on the incubator's energy consumption and the desired autonomy (the length of time the incubator can operate without sunlight).*
- ***Charge Controller:*** *A charge controller regulates the flow of electricity from the PV panels to the batteries. It prevents overcharging of the batteries, which can damage them, and ensures that the batteries are charged efficiently.*
- ***Heating and Ventilation Systems:*** *The electricity generated by the PV panels (or stored in the batteries) powers the incubator's heating and ventilation systems. Various heating methods can be employed, such as resistive heating elements or thermoelectric devices. The ventilation system typically consists of a fan that circulates air within the incubator, ensuring proper gas exchange. The design of these systems must be energy-efficient to minimize the overall energy consumption of the incubator.*
- ***Temperature and Humidity Control Systems:*** *Precise control over temperature and humidity is crucial for successful incubation. Sophisticated control systems, incorporating sensors and*

actuators, are used to monitor and regulate these parameters. These systems can be powered by the solar energy system, ensuring consistent and optimal incubation conditions.

By effectively integrating these components, solar-powered incubators offer a sustainable and reliable solution for egg incubation, particularly in regions with abundant solar resources but limited access to conventional electricity.

2.1.3 Sustainable Design for Small-Scale Poultry Farmers: A Holistic Approach

Sustainability is a central consideration in the design of a solar-powered egg incubator for small-scale poultry farmers. A sustainable approach encompasses several key aspects:

- **Energy Efficiency:** *Minimizing energy consumption is crucial for both economic and environmental sustainability. This involves optimizing the design of the incubator to reduce heat loss, using energy-efficient components, and implementing intelligent control systems.*
- **Cost-Effectiveness:** *The incubator must be affordable for small-scale farmers. This requires careful selection of materials and manufacturing processes to minimize costs without compromising performance or reliability. Exploring the use of locally available materials can further reduce costs and promote local economies.*
- **Ease of Maintenance:** *The incubator should be designed for easy maintenance and repair. Simple and robust components should be used to minimize the risk of failure and facilitate repairs. Providing clear instructions and readily available spare parts can further enhance maintainability.*
- **Scalability and Modularity:** *Small-scale farmers have varying needs in terms of incubation capacity. A modular design allows farmers to easily expand or reduce the size of their incubator as their needs change. This flexibility ensures that the incubator remains a valuable asset as the farmer's operation grows.*

- **Environmental Impact:** *Minimizing the environmental impact of the incubator is paramount. This includes using renewable energy sources (solar), selecting sustainable materials, and minimizing waste during manufacturing and operation. Considering the lifecycle environmental impact of the incubator, from material sourcing to disposal, is crucial for true sustainability.*
- **Social and Economic Impact:** *A sustainable incubator should contribute to the social and economic well-being of small-scale farmers. By improving hatchability rates and reducing operating costs, the incubator can increase farmers' income and improve their livelihoods. Empowering farmers with access to sustainable technology can also contribute to community development and food security.*

By integrating these principles of sustainability into the design and development process, this research aims to create a solar-powered egg incubator that is not only technologically sound but also economically viable, environmentally responsible, and socially beneficial for small-scale poultry farmers. This holistic approach ensures that the project contributes to a more sustainable and equitable future for poultry farming.

2.2 THEORETICAL FRAMEWORK

The theoretical framework provides a basis for understanding the principles and scientific theories that underpin the design and functionality of a solar-powered egg incubator. This section examines key theories related to thermodynamics, heat transfer, energy conservation, and incubation biology that influence the development of an efficient and sustainable incubator model.

Thermodynamic Principles and Heat Transfer Mechanisms The design of an incubator is primarily governed by the principles of thermodynamics and heat transfer. The first law of thermodynamics, also known as the law of energy conservation, states that energy cannot be

created or destroyed but can be transferred or converted from one form to another. In the context of an egg incubator, electrical energy from the solar panels is converted into thermal energy to maintain the required incubation temperature.

Heat transfer mechanisms—conduction, convection, and radiation—play crucial roles in ensuring uniform temperature distribution within the incubator. Conduction occurs through the contact between incubator walls and heating elements, convection circulates warm air around the eggs, and radiation helps maintain steady heat levels. A well-insulated incubator minimizes heat losses and ensures energy efficiency, which is vital for small-scale poultry farmers operating in areas with limited resources.

Incubation Biology and Embryo Development The theoretical understanding of embryo development is essential for designing an effective incubator. The incubation period for poultry eggs varies, with chickens requiring approximately 21 days. During this period, precise temperature regulation (typically around 37.5°C), humidity control (50-60% initially, increasing to 65-75% before hatching), and egg turning (at least three times daily) are necessary to ensure optimal embryonic growth and hatchability rates.

Scientific research highlights that deviations in incubation conditions can lead to developmental abnormalities or embryo mortality. Therefore, integrating automated temperature and humidity regulation systems powered by solar energy enhances the reliability and effectiveness of the incubator.

Solar Energy Conversion and Photovoltaic Technology The operation of a solar-powered incubator is grounded in the principles of photovoltaic technology. Solar panels absorb sunlight and convert it into electrical energy, which is then stored in batteries or used directly to power

heating elements and control systems. The efficiency of solar energy conversion depends on factors such as solar panel orientation, exposure to sunlight, and battery storage capacity.

A theoretical analysis of photovoltaic performance helps optimize the system design to ensure continuous operation even during low sunlight conditions. Integrating energy storage mechanisms, such as lithium-ion or deep-cycle lead-acid batteries, ensures stable power supply for uninterrupted incubation.

Environmental and Economic Sustainability Theories Sustainability is a key aspect of this project, aligning with environmental and economic sustainability theories. The triple-bottom-line approach emphasizes social, environmental, and economic benefits. By reducing reliance on fossil fuels and utilizing renewable solar energy, the incubator contributes to environmental conservation while lowering operational costs for small-scale farmers.

The theory of appropriate technology also applies to this study, advocating for the development of solutions that are cost-effective, easy to maintain, and adapted to the needs of local users. A solar-powered egg incubator designed with locally sourced materials and simple automation mechanisms aligns with this principle, ensuring accessibility and practicality for small-scale poultry farmers.

By incorporating these theoretical foundations, the study aims to develop an incubator that is not only technologically advanced but also sustainable, affordable, and efficient for rural poultry farmers. The integration of thermodynamic principles, biological incubation science, and renewable energy technology provides a comprehensive foundation for the proposed design.

2.3 EMPIRICAL STUDY FRAMEWORK

This section delves into the empirical study framework, which provides a foundation for the research by examining existing literature and real-world applications of solar-powered egg incubators. The review focuses on case studies, experimental research, and documented findings related to incubation technology, with a particular emphasis on energy efficiency, hatchability rates, and the economic and environmental feasibility of solar-based solutions. Analyzing these studies allows for the identification of best practices, success factors, challenges, and limitations, ultimately informing the development of an optimized and sustainable incubator model specifically tailored for small-scale poultry farmers. This framework serves as a crucial guide for the project's objectives, ensuring the design and fabrication of an incubator that is both practical and impactful.

2.3.1 Case Studies on Solar-Powered Egg Incubators:

A growing body of research demonstrates the viability of solar-powered incubators as a practical alternative to conventional electric incubators, especially in rural and off-grid areas where access to reliable electricity is limited or non-existent. Numerous studies conducted across diverse geographical locations have evaluated the performance of these incubators, highlighting their potential for energy efficiency, cost savings, and improved hatchability rates compared to traditional methods or electric incubators reliant on generators. These case studies often document successful implementations integrating automated temperature and humidity control systems, as well as hybrid solar-battery systems to enhance reliability and ensure consistent operation even during periods of low solar irradiance. Specific examples of key case studies will be examined [*Here, you would insert specific citations and brief summaries of relevant case studies, including location, incubator design, performance metrics, and key findings. For instance:*]

- Example 1: A study conducted in [Location] by [Authors] investigated the performance of a solar-powered incubator using a [Specific Technology, e.g., parabolic trough collector] and found that it achieved hatchability rates comparable to electric incubators while significantly reducing operating costs.
- Example 2: Research in [Location] by [Authors] explored the use of a hybrid solar-battery system in a small-scale incubator, demonstrating its ability to maintain stable temperature and humidity levels even during extended periods of cloudy weather.

2.3.2 Analysis of Incubation Technology:

Beyond case studies, the empirical framework will also analyze the fundamental principles of incubation technology, including the critical parameters that influence successful hatching. This will involve a review of the literature on:

- **Temperature and Humidity Control:** Maintaining optimal temperature and humidity levels is crucial for embryo development. The review will examine different temperature control mechanisms, including passive and active systems, and their suitability for solar-powered incubators. The influence of humidity on hatchability and the methods for maintaining appropriate humidity levels within the incubator will also be explored.
- **Ventilation and Airflow:** Proper ventilation is essential for gas exchange and preventing the buildup of harmful gases within the incubator. The study will analyze different ventilation strategies and their impact on hatchability. The design considerations for natural and forced ventilation systems in solar incubators will be reviewed.
- **Egg Turning Mechanisms:** Regular egg turning is necessary to prevent the embryo from adhering to the shell membrane. The review will examine various egg turning

mechanisms, including manual and automated systems, and their feasibility for integration into a solar-powered incubator.

2.3.3 Economic and Environmental Considerations:

The empirical framework will also assess the economic and environmental implications of solar-powered egg incubators. This will include:

- **Cost-Benefit Analysis:** A comparative cost analysis will be conducted, comparing the initial investment and operating costs of solar incubators with those of traditional electric incubators and traditional hen incubation. The long-term economic benefits of reduced energy costs and increased hatchability will be evaluated.
- **Environmental Impact:** The environmental advantages of solar-powered incubators, such as reduced reliance on fossil fuels and lower carbon emissions, will be quantified and compared to conventional methods. The lifecycle environmental impact of the incubator components, including solar panels and batteries, will also be considered.

2.4 APPRAISAL OF REVIEWED LITERATURE

This section provides a critical appraisal of the reviewed literature, synthesizing the findings and highlighting key insights gained from the empirical study framework. It assesses the strengths and weaknesses of existing research and identifies areas of consensus and divergence. This appraisal serves to contextualize the current project within the broader body of knowledge on solar-powered egg incubation and justifies the specific research approach adopted.

2.4.1 Strengths and Weaknesses of Existing Research:

The reviewed literature reveals a significant body of research supporting the viability and benefits of solar-powered egg incubators. The strengths of this research include:

- **Demonstrated Feasibility:** Numerous case studies have demonstrated the technical feasibility of solar-powered incubation, showcasing successful implementations in diverse climates and contexts.
- **Energy Efficiency:** Many studies highlight the potential for significant energy savings compared to conventional electric incubators, especially in off-grid or grid-limited areas.
- **Improved Hatchability:** Several studies report comparable or even improved hatchability rates with solar incubators compared to traditional methods or electric incubators using generators.
- **Environmental Benefits:** The environmental advantages of reduced reliance on fossil fuels and lower carbon emissions are well-documented.

However, the reviewed literature also reveals some weaknesses and areas requiring further investigation:

- **Cost-Effectiveness:** While operating costs are often lower, the initial investment cost of solar incubators can be a barrier for small-scale farmers. More research is needed on cost-effective designs and financing options.
- **Scalability:** Many existing solar incubator designs are not easily scalable to accommodate the varying needs of small-scale farmers. Research on modular and adaptable designs is crucial.

- **Reliability:** Maintaining consistent temperature and humidity levels can be challenging, especially in regions with fluctuating solar irradiance. Further research on robust temperature control systems and energy storage solutions is needed.
- **Limited Data on Long-Term Performance:** Long-term performance data on solar incubators, including durability and maintenance requirements, is often limited. More longitudinal studies are needed to assess the long-term viability of these systems.
- **Socio-Economic Impact:** While some studies touch upon the socio-economic benefits of solar incubators, more in-depth research is needed to fully understand their impact on small-scale farmers' livelihoods and communities.

2.4.2 Key Insights and Emerging Trends:

The review of literature reveals several key insights and emerging trends in solar-powered egg incubation:

- **Hybrid Systems:** The integration of hybrid solar-battery systems is becoming increasingly common to enhance reliability and ensure consistent operation even during periods of low solar irradiance.
- **Automated Control:** Automated temperature and humidity control systems are crucial for maintaining optimal incubation conditions and improving hatchability rates.
- **Passive Heating and Cooling:** Research on passive heating and cooling strategies, such as insulation and ventilation design, is gaining traction as a way to improve energy efficiency.

- Focus on Small-Scale Farmers: There is a growing recognition of the specific needs and constraints of small-scale poultry farmers, leading to the development of more tailored and affordable solutions.

2.4.3 Justification for the Current Research Approach:

The appraisal of the reviewed literature highlights the need for further research on cost-effective, scalable, and reliable solar-powered egg incubators specifically designed for small-scale poultry farmers. This project addresses this need by focusing on:

- Modular Design: Developing a modular design that can be easily scaled to meet the varying needs of small-scale farmers.
- Cost Optimization: Prioritizing cost-effective materials and manufacturing processes to make the incubator affordable for small-scale farmers.
- Sustainable Materials: Exploring the use of locally sourced and sustainable materials to minimize environmental impact.
- Performance Evaluation: Conducting rigorous testing and evaluation to assess the incubator's performance in terms of hatchability, energy efficiency, and reliability.

By addressing these key areas, this project aims to contribute to the development of a practical and impactful solution for small-scale poultry farmers, promoting food security, economic empowerment, and sustainable agricultural practices. The reviewed literature provides a valuable foundation for this research, guiding the design, fabrication, and evaluation of the proposed solar-powered egg incubator.

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 the following components.

- i. Heat source (light bulbs)
- ii. Temperature and humidity controller.
- iii. Water pump
- iv. Housing structure
- v. Egg turning mechanism
- vi. Photovoltaic panel
- vii. Solar battery
- viii. Inverter
- ix. Charge controller
- x. 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 38⁰C, 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 Table 3.1.

Table 3.1 Decision Matrix

Criteria	Grade points	
	Concept 1 (with forced draft)	Concept 2 (without forced draft)
Cost of production	1	2
Energy requirement	1	2
Ease of production	1	2
Ease of operation	1	2
Bulkiness/space	1	2

requirement		
Simplicity	1	2
Total	6	12

From the decision matrix in Table 3.1 using a simple aggregate score for the significant criteria considered, the concept 2 with a total weighted criteria average of 12 was selected as against the concept 1 with total weighted criteria average of 6, hence the concept 2 was selected.

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 x 10 ⁻⁵
2	0.68	3.6 x 10 ⁻⁵
3	0.71	4.1 x 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 $3.95 \times 10^{-5} \text{m}^3$. it therefore means that 24 pieces of eggs as contained in a crate could occupy a space of $24 \times 3.95 \times 10^{-5} = 9.48 \times 10^{-4} \text{m}^3$ 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 24 chicken = $4.345 \times 10^{-5} \times 24 = 1.0428 \times 10^{-3} \text{m}^3$

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

Considering additional space for free movement of the chicks before evacuation, say doubling the total required space, then the required size of the incubation chamber = $2.0856 \times 10^{-3} \text{m}^3$

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 24 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 24 eggs will occupy $0.1 \times 0.1 \times 24 = 0.24 \text{m}^2$

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

Height of incubator = $0.13 \times 3 = 0.39\text{m}$

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 =

$$L_1B_1 + L_2B_2 + L_3B_3 + \dots + L_nB_n \dots \quad (1)$$

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

$$\text{Area of rectangular cut out material} = L \times B \quad (3)$$

$$\text{Hence Surface area of the casing material} = [L_1B_1 + L_2B_2 + \dots + L_{n+1}B_{n+1}] \dots \quad (2)$$

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 the incubator as $V\text{m}^3$. 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 = 38°C

$$\text{Power of Heat element of bulb required to transfer heat} = \frac{Q}{t} = \frac{mc\Delta T}{t} \quad (4)$$

The amount of heat entering incubator is given as

$$Q = V \times \rho \times CP \times \Delta T \quad (5)$$

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)

C_p = 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:

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

Where:

Q_T = total heat loss in the incubator chamber, W

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

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

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

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

Q_{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 = 4270J/Kg

(National Library of Medicine)

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

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

$$242\text{grams} = 0.242Kg$$

C_p for PVC = 1.6KJ/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 clad 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

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

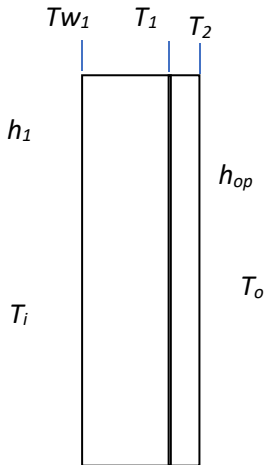
The heat flow by convection or radiation is given by

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

Thermal resistance R_a 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.



$$h_i = 100 \text{ W/m}^2\text{k}$$

$$h_o = 10 \text{ W/m}^2\text{k}$$

$$A_{wall} = 0.128 \text{ m}^2$$

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

$$k_1 = 0.022 \text{ Wm}^{-1}\text{k}^{-1}$$

$$k_2 = 237 \text{ Wm}^{-1}\text{k}^{-1}$$

$$L_1 = 0.01 \text{ m}$$

$$L_2 = 0.002 \text{ m}$$

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

$$R_{Total} = \left(\frac{1}{100} + \frac{0.01}{0.22} + \frac{0.004}{237} + \frac{1}{10} \right) = 0.155A$$

For the side walls

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

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

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%

$$\text{Therefore } Q_w = 1.1 \times 112.38 = 105.47W$$

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 (C_p/C_v): 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 25⁰C to 37⁰C. The temperature plots and the velocity contours can be used to predict the performance of the system. The goals monitored during the simulation are presented in the Table 3.5. the results of the thermal simulation of the incubator is presented in the result section.

Table 3.5 Gola Table of the CFD Simulation

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Total Temperature 1	[K]	322.614621 6	322.0557644	321.3812789	322.6146216
GG Av Velocity 1	[m/s]	0.06203989 7	0.061681718	0.061105224	0.062085119
GG Av Mass Fraction of Water 1	[]	0.01379681 9	0.013796819	0.013796819	0.013796819
GG Av Mass Fraction of Air 1	[]	0.98620318 1	0.986203181	0.986203181	0.986203181
SG Av Temperature (Fluid) 1	[K]	320.167858 6	319.4753546	318.734573	320.1678586
SG Mass Flow Rate 1	[kg/s]	- 0.00241676	-0.002417574	- 0.002418482	- 0.002416505
SG Av Velocity 1	[m/s]	1.60971978 1	1.60783351	1.605032436	1.610665889
SG Av Mass Fraction of Air 1	[]	0.98620310 1	0.986203101	0.986203101	0.986203101
VG Av Temperature (Solid) 1	[K]	336.590872 3	336.0263761	335.3568399	336.5908723

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 $= \frac{v}{h} = 0.0001 m^3/s$

ρ = density of fluid (water) (kg/m³)

g = gravity (9.81 m/s²)

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

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



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;

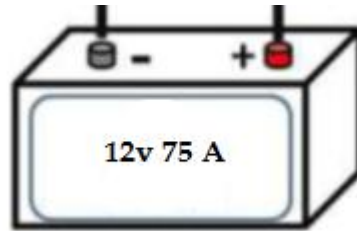


Figure 3.4 Schematic of a solar DC battery with positive and negative terminals

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

- 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

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

The nominal battery voltage is taking as 12 V

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 3.2

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

S/N o	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	Miscellaneous				10000	10000
18	Workmanship				15000	15000
19	Total					96400

The graphic view of the produced solar incubator is shown in Figures 3.3 and 3.4.

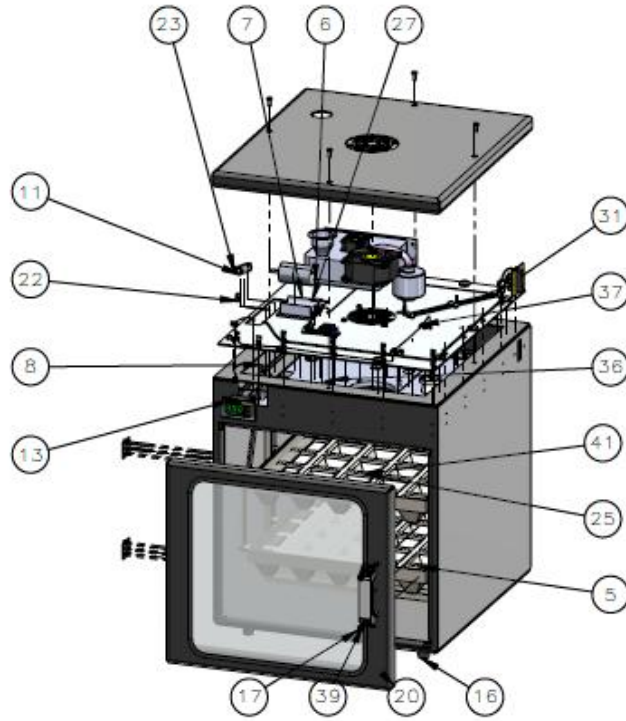


Figure 3.5 Unassembled drawing of the solar incubator.



Figure 3.6 Assembled drawing of the fabricated solar incubator.

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 \pm (1% to 1^oC)
- ii. Solar seaward 200R, 100-1500 W/m² for solar irradiance
- iii. Extech 3-in-1 humidity meter. \pm 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:

$$\% \text{ Fertility of eggs} = \frac{\text{number of fertile eggs}}{\text{total number of eggs}} \times 100\% \quad (3.12)$$

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

$$\% \text{ of hatchery waste (unhatched chicks)} = \frac{\text{waste of chicks that did not hatch}}{\text{total number of fertile eggs}} \times 100\% \quad (3.14)$$

$$\% \text{ of developed but unhatched} = \frac{\text{number of chicks developed but unhatched}}{\text{total number of fertile eggs}} \times 100\% \quad (3.15)$$

Operational testing 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)	T _a (°C)	T _{inc} (°C)	R _a (%)	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)	T _a (°C)	T _{inc} (°C)	R _a (%)	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)	23	95
Hatched eggs (Hatchability)	21	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	24	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.

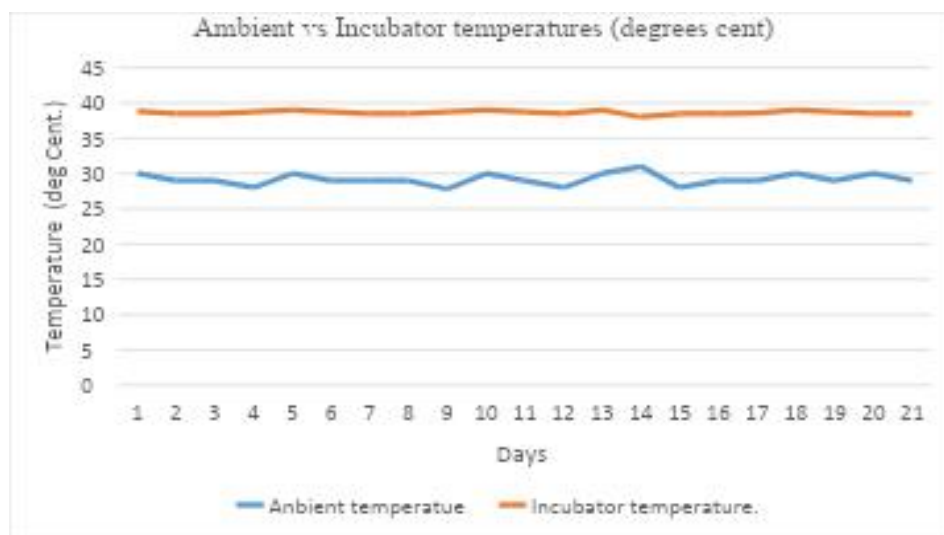


Figure 4.1 Temperature measurement of Ambient and incubator.

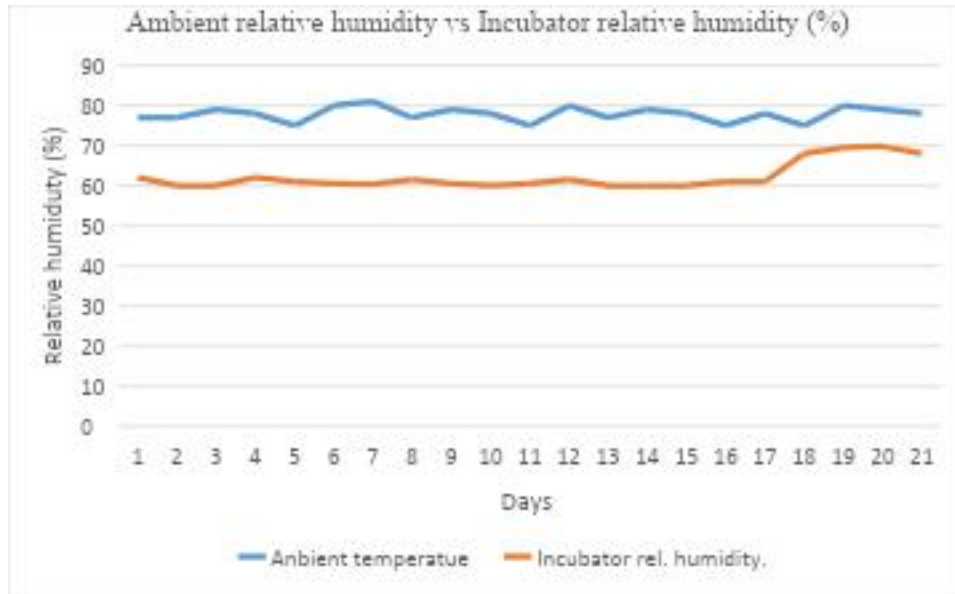


Figure 4.2 Relative humidity of Ambient and incubator

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.

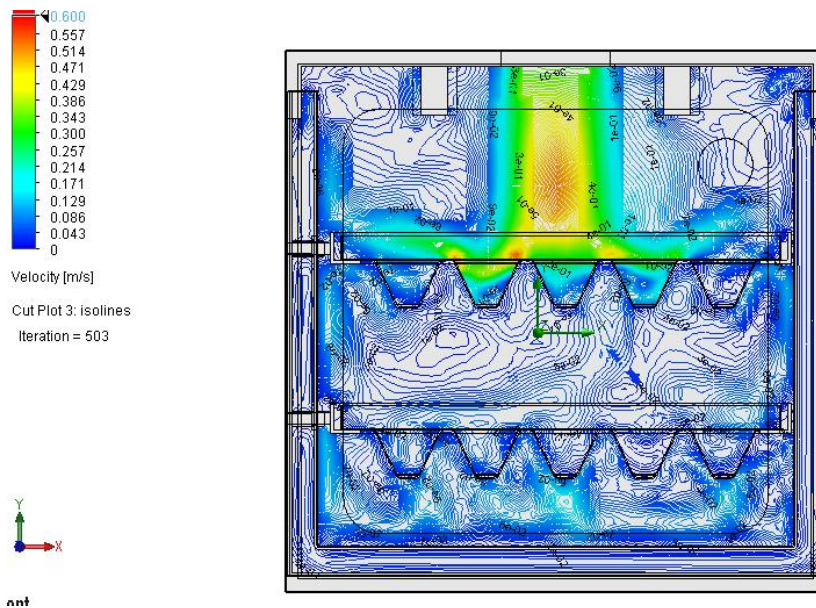


Figure 4.3 Velocity Isolines

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.

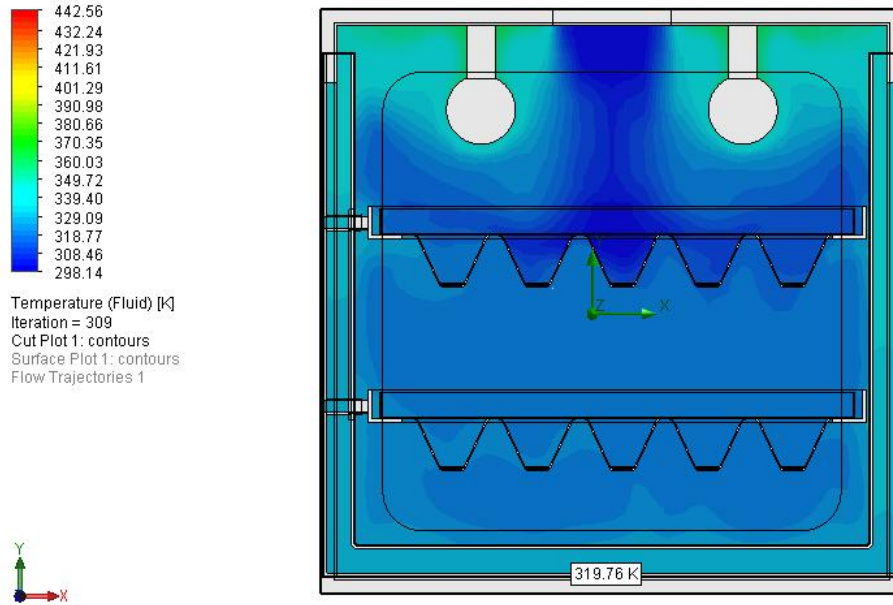


Figure 4.4 Contour plots showing Temperature distribution in the incubator

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°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 is shown in Figure 4.5.

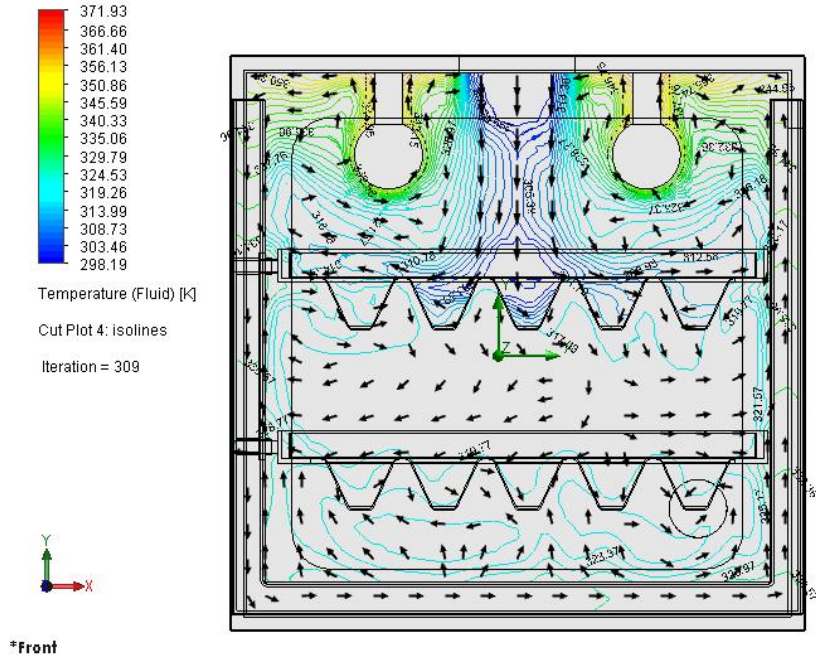


Figure 4.5 Contour plot of air velocity

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Total Temperature 1	[K]	303.098252 8	302.5949441	302.0907037	303.0982528
GG Av Velocity 1	[m/s]	0.00796761 3	0.007708312	0.007169849	0.008175266
GG Av Temperature (Fluid) 1	[K]	303.098252 7	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.

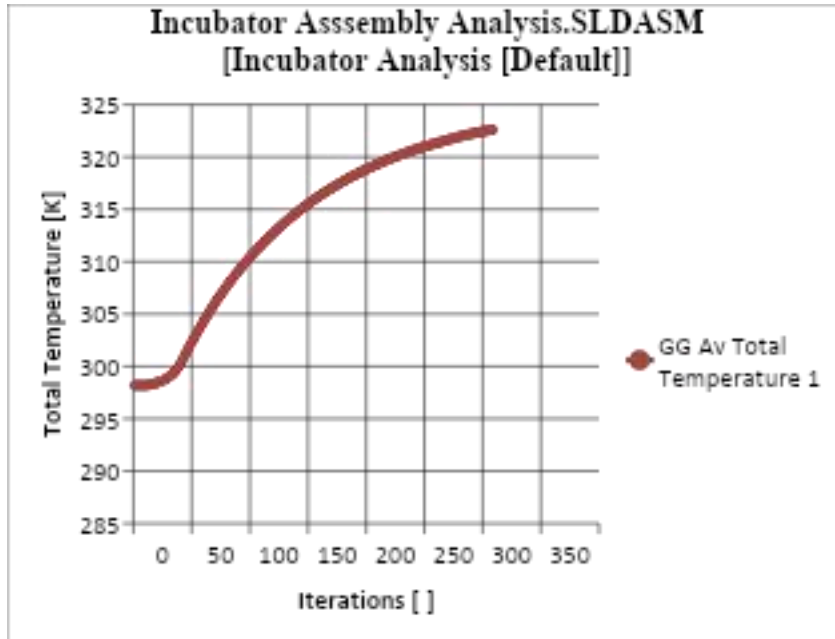


Figure 4.6 Heat flow pattern in the incubator

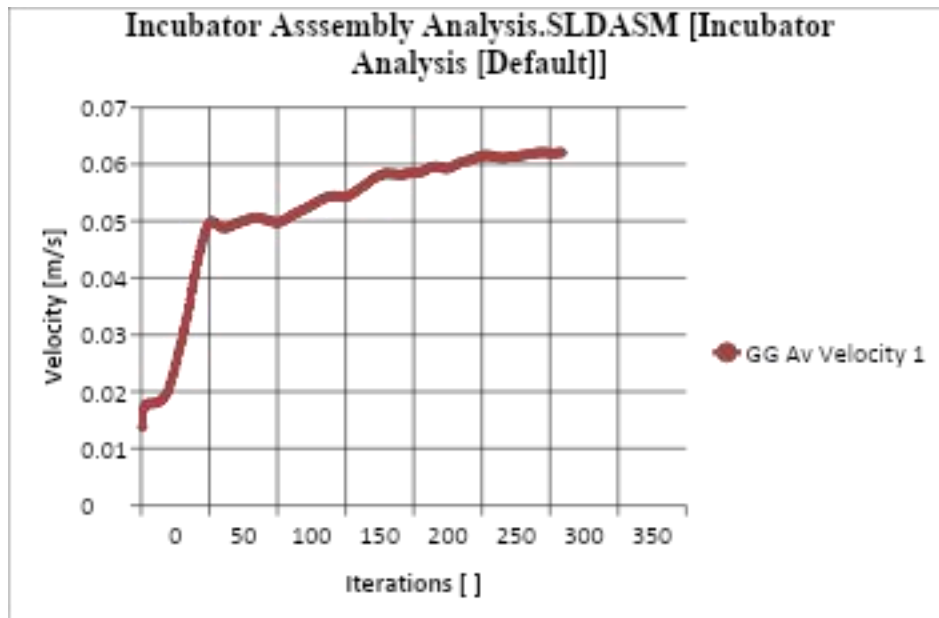


Figure 4.7 air flow pattern inside the incubator

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 humidities 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 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

CONCLUSION 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°C throughout the incubation period with the aid of the temperature control system and the energy source employed. It was found that the incubator system is capable of incubating 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 contribute to the overall incubation process of eggs using a solar drying device.
- ii. Solar incubator devices 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.

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