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Design and Development of a Microcontroller Based Liquefied Petroleum Gas (LPG) Incubator for Use in Power Constrained Environments

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The availability of reliable and affordable energy remains a significant challenge in the poultry sector across developing economies. This study presents the design, construction, and performance evaluation of a microcontroller-based egg incubator powered by Liquefied Petroleum Gas (LPG). The incubator was developed to address the limitations of electrically powered, solar-powered, and kerosene-based incubation systems, which are either cost-prohibitive or ineffective in regions with

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unreliable power supply. A programmable microcontroller (PIC16F876A) was employed to automate key incubation functions, including temperature and humidity regulation, gas ignition control, and egg turning. Fabricated using locally sourced materials, the prototype underwent a full incubation cycle using 120 fertile chicken eggs. The results demonstrated a hatchability rate of 65%, with consistent maintenance of optimal incubation conditions (temperature: 37.5°C; humidity: 45–55%). The LPG consumption for the 21-day incubation period was 15 kg, translating to a cost of ₦51.65 per chick. This study validates the feasibility of a low-cost, off-grid, automated incubation system suitable for rural and peri-urban poultry operations.

Keywords: *Microcontroller; liquified petroleum gas (LPG); incubator; power constrained environments.*

1. INTRODUCTION

Poultry farming is a fundamental pillar of agricultural economies worldwide, especially in developing regions such as sub-Saharan Africa where it contributes significantly to food security, poverty alleviation, and rural livelihood enhancement (Food and Agriculture Organization [FAO], 2022). In countries like Nigeria, poultry production not only fulfills the escalating demand for affordable animal protein but also supports millions of smallholder farmers and entrepreneurs who rely on poultry as a major income source (Ojo et al., 2021). Despite its critical role, the sector is continually constrained by systemic challenges, among which unreliable electricity supply and high energy costs for artificial incubation stand as primary impediments to optimal productivity and growth.

Incubation—the controlled process of hatching fertilized eggs, is central to poultry production, requiring the precise regulation of temperature, humidity, and ventilation for a continuous 21-day period. Failure to maintain these parameters within strict limits results in reduced hatchability and compromised chick viability, directly affecting production efficiency and profitability (Rahman et al., 2022). Modern commercial incubators are predominantly electric-powered, necessitating a stable and uninterrupted power supply, which is a luxury often unavailable in rural or off-grid farming communities due to frequent blackouts, load shedding, or total absence of grid connectivity. Consequently, many poultry farmers are either forced to depend on costly and environmentally detrimental backup generators or resort to traditional, low-efficiency natural incubation methods that are labor-intensive and yield inconsistent outcomes.

Alternative energy sources such as solar power have been explored to mitigate these challenges, with various studies demonstrating the potential of solar photovoltaic (PV)-driven incubators to

reduce reliance on grid electricity and lower operational costs (Chen, et al., 2023). However, solar incubators face limitations including high capital costs, dependency on weather conditions, and often inadequate automation, factors which restrict their widespread adoption and operational reliability, especially in regions with inconsistent sunlight (Glasson et al., 2003). Kerosene and diesel-fueled incubators have also been investigated but present issues of pollution, fuel scarcity, safety risks, and high running costs (Rahman, et al. (2022). Thus, there remains an urgent need for alternative incubation systems that combine affordability, energy efficiency, operational stability, and environmental sustainability.

Liquefied Petroleum Gas (LPG) emerges as a viable and increasingly accessible energy source for poultry incubation in power-scarce contexts (Global Petrol Prices, 2024). LPG offers several advantages over traditional fuels and electricity: it burns cleanly with a high calorific value, is transportable and storable without significant losses, and is less susceptible to supply interruptions compared to electrical grids (World LPG Association, 2021). Moreover, many developing regions have established LPG distribution networks, making it a feasible fuel for decentralized poultry operations (Rahman et al., 2022). Despite this, LPG-powered incubators remain underutilized and under-researched, particularly regarding integration with automation technologies that could optimize energy consumption and improve incubation outcomes.

Recent advances in microcontroller technology present an opportunity to revolutionize incubator design by enabling precise, programmable control of critical environmental parameters such as temperature, humidity, and egg turning cycles (Chen et al., 2023). Microcontrollers offer cost-effective solutions with minimal power consumption and can be programmed to automate complex processes, reducing human

error and labor intensity (Rahman et al., 2022). When combined with LPG heating, microcontroller-based incubators can achieve a balance between energy independence and operational accuracy, crucial for maintaining optimal embryonic development conditions in off-grid poultry farms.

The need for such integrated systems is underscored by the persistent challenges facing poultry hatcheries in Nigeria and other developing countries, where power outages and fuel costs significantly elevate the cost of production, often making day-old chicks prohibitively expensive for many farmers (National Agricultural Research Institute [NAPRI], 2011). Studies by Chen, et al., (2023) highlight that although electric incubators have improved hatchability and productivity, their dependence on unreliable power supplies restricts their practical use in rural areas. Similarly, solar-powered incubators developed to date have not consistently met performance expectations due to inherent energy intermittency and limited automation capacity (Glasson et al., 2003). Thus, a hybrid approach employing LPG as a stable heat source with microcontroller-based environmental control offers a promising alternative.

This research addresses these gaps by designing and developing a microcontroller-controlled incubator powered by LPG specifically tailored for use in power-constrained environments. The system aims to provide a reliable, efficient, and sustainable incubation solution that supports the production of healthy day-old chicks while mitigating the risks and costs associated with power instability and inefficient energy use. This approach also contributes to the broader goals of sustainable agricultural development by enhancing poultry productivity, reducing energy waste, and supporting rural livelihoods in off-grid areas.

In summary, this study justifies its significance based on the increasing demand for poultry products driven by population growth and health-conscious consumer trends favoring poultry over red meat, the persistent power supply challenges limiting current incubation technologies, and the demonstrated benefits of microcontroller automation for precise incubation control (Chen et al., 2023; Rahman et al., 2022). By integrating LPG heating with programmable microcontroller systems, the proposed incubator design aspires to fill a critical technology gap, enhancing

hatchery operations' sustainability, scalability, and accessibility in developing country contexts.

2. LITERATURE REVIEW AND THEORETICAL ALIGNMENT

2.1 Incubators

Incubators are specialized devices engineered to provide a controlled environment conducive to the artificial hatching of poultry eggs, effectively replicating the natural brooding conditions provided by hens. Over recent decades, incubator technology has evolved significantly, integrating renewable energy sources, microcontroller automation, and precision environmental controls to enhance hatchability and operational efficiency.

Solar-powered incubators have gained prominence in energy-limited regions. For instance, Olaleye (2008) designed a 200-egg capacity incubator using solar water heating with natural convection, supplemented by biomass-fired heating for nocturnal temperature maintenance. This hybrid system highlights the integration of sustainable energy sources into incubation, reducing dependence on grid electricity. Large-scale cabinet incubators, such as Sportman's 2000-egg design, demonstrate high thermal efficiency (~80%) with tight temperature regulation (± 0.5 °C), critical for uniform embryonic development.

Educational and small-scale incubators, like the 12V minilab model from Rainbow Power Company Limited (RPCL, 2008), illustrate innovations in portability and power efficiency. Powered by photovoltaic panels and controlled via thermostatic elements, these models support diverse species incubation with manual egg turning, emphasizing accessibility in off-grid contexts.

Historically, the concept of incubation houses with insulated double-wall construction and compartmentalization dates back to 19th-century China. Modern commercial incubators now incorporate sophisticated computer-controlled systems that regulate temperature, humidity, ventilation, and automated egg turning, optimizing hatch rates and scaling commercial poultry production.

The Korean-developed R-Com 3 incubator epitomizes microcontroller-driven precision in small-scale incubators, offering programmable

species-specific settings, automatic turning cessation near hatching, and digital countdown displays, significantly enhancing user interaction and incubation reliability (NERC, 2024).

2.2 Classification of Incubators

Incubators are primarily classified into natural and artificial types. Natural incubation leverages the innate brooding behaviors of hens, relying on their physiological mechanisms to maintain optimal temperature and humidity. Artificial incubators are subdivided into forced-air and still-air systems. Forced-air incubators employ fans to circulate air evenly, enabling larger capacities and more consistent incubation conditions. Conversely, still-air incubators rely on passive convection, suitable for small-scale use but often less precise.

2.2.1 Natural incubation

Natural incubation depends on selecting broody hens with strong maternal instincts and health status, ensuring consistent incubation temperatures (~38°C) and humidity levels (60–80%) (Rahman, et al. (2022). The hen's behavior of water splashing maintains humidity, critical for embryonic moisture retention. Optimal hatchability from natural incubation ranges between 75–80%, contingent on management factors such as feed and water availability near the nest, egg storage conditions, and periodic candling for fertility assessment.

2.2.2 Artificial incubation

Artificial incubation technologies have advanced substantially, with current systems employing microprocessor-based controls to maintain precise temperature, humidity, and gas exchange parameters critical to embryonic development. The sensitivity of embryos to thermal fluctuations, especially during the latter incubation stages, necessitates automated environmental regulation to maximize hatchability (Vleck et al., 1980).

In regions challenged by unreliable electricity supply, hybrid incubation systems utilizing renewable energy sources such as solar PV combined with gas fuels like LPG or biogas have emerged as viable alternatives. Chen, et al. (2023) demonstrated that integrating solar and gas systems could reduce electrical power

requirements by up to 75%, although many existing designs lack comprehensive automation.

Recent advancements in microcontroller technology enable the integration of precise temperature and humidity control, automatic egg turning, and ignition systems for gas-powered incubators, thereby bridging technological gaps in low-resource settings. Such systems not only improve hatch rates but also reduce operational costs and dependency on erratic power grids.

2.3 Past Research on Incubator Fabrication

Researcher underscored the growing demand for poultry products globally and identified energy consumption as a major bottleneck in conventional incubation methods. Their solar-based incubator design, which reduces reliance on grid electricity by 75%, presents a cost-effective and environmentally sustainable approach suitable for rural and off-grid poultry farmers.

Chen et al. (2023) investigated the challenges facing poultry production in Nigeria, particularly the lack of reliable grid electricity in rural hatcheries. They developed an electric incubator prototype, which although initially demonstrated a modest hatchability rate of 33%, showed promise for household-level adoption with further optimization.

More recently, Ochieng, & Mwangi (2021) advanced the development of microcontroller-based LPG incubators equipped with automated ignition and environmental regulation. Their findings revealed improved hatchability rates of up to 65%, demonstrating the feasibility of LPG-powered incubation as an affordable and scalable solution in power-constrained environments.

3. METHODOLOGY

3.1 Design Framework

The incubator was constructed using medium-density fiberboard (MDF) and divided into two chambers: an upper chamber for egg incubation and a lower chamber for heat generation and distribution. The incubator was designed to accommodate 180 chicken eggs using a trolley-based tray system.

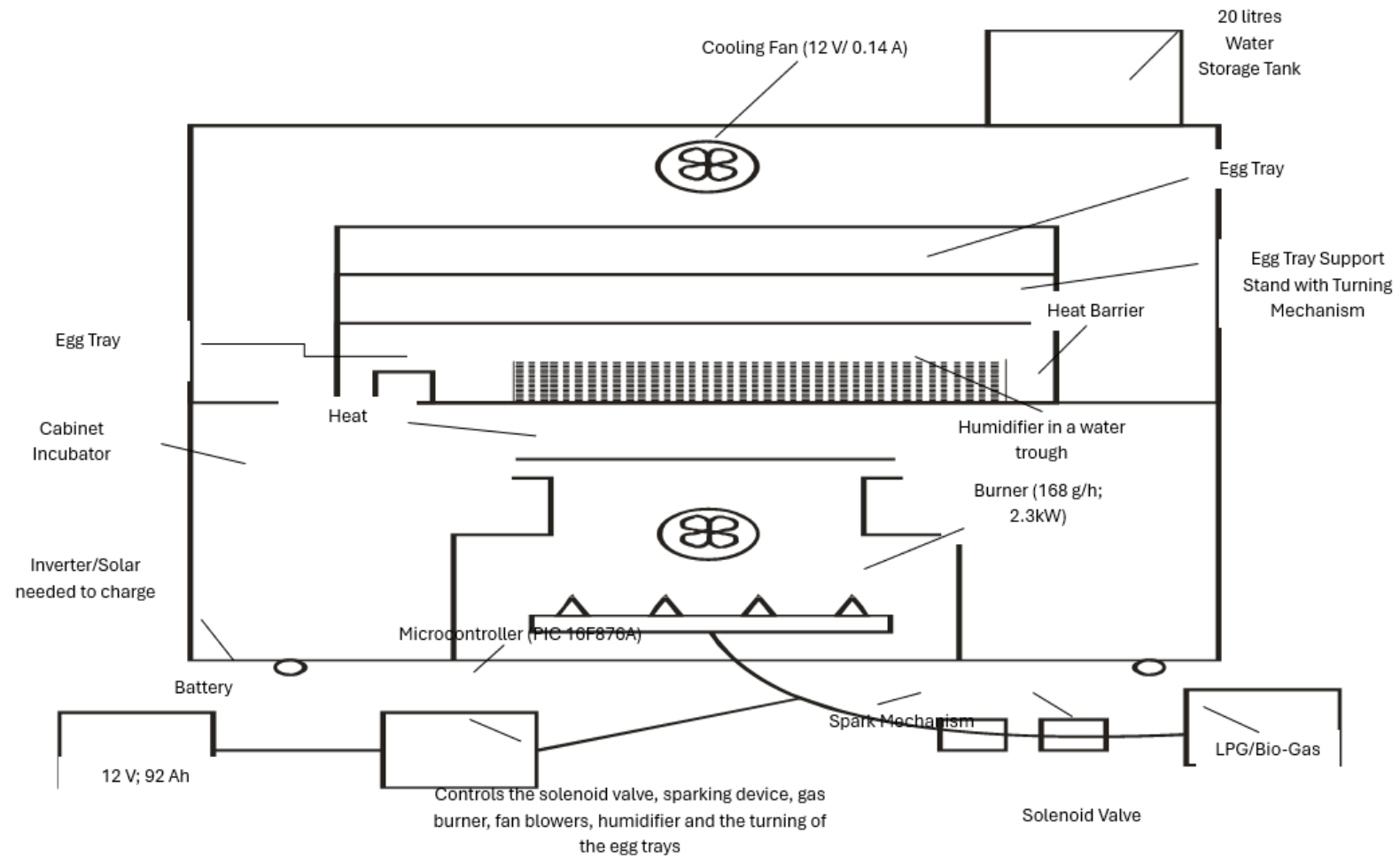


Fig. 1. Schematic diagram of the Incubator

3.2 Design Considerations

The design considerations that were used in the fabrication of the incubator are:

1. Number of eggs to be hatched which in this case is 180 eggs.
2. Optimum incubation temperature of 37.5 °C
3. Humidity within the incubator of average of 45%
4. Reliability of the incubator.

3.3 Control System Configuration

A PIC16F876A microcontroller, programmed using Mikrobasic language, served as the core control unit. It managed:

- Automatic sparking and gas inflow when temperature dropped below 36°C.
- Deactivation of the gas burner at 37.5°C using a temperature sensor (DHT11).
- Humidity control using a humidifier triggered between 45–55% relative humidity.
- Automated egg turning at two-hour intervals using a motor-sprocket system.

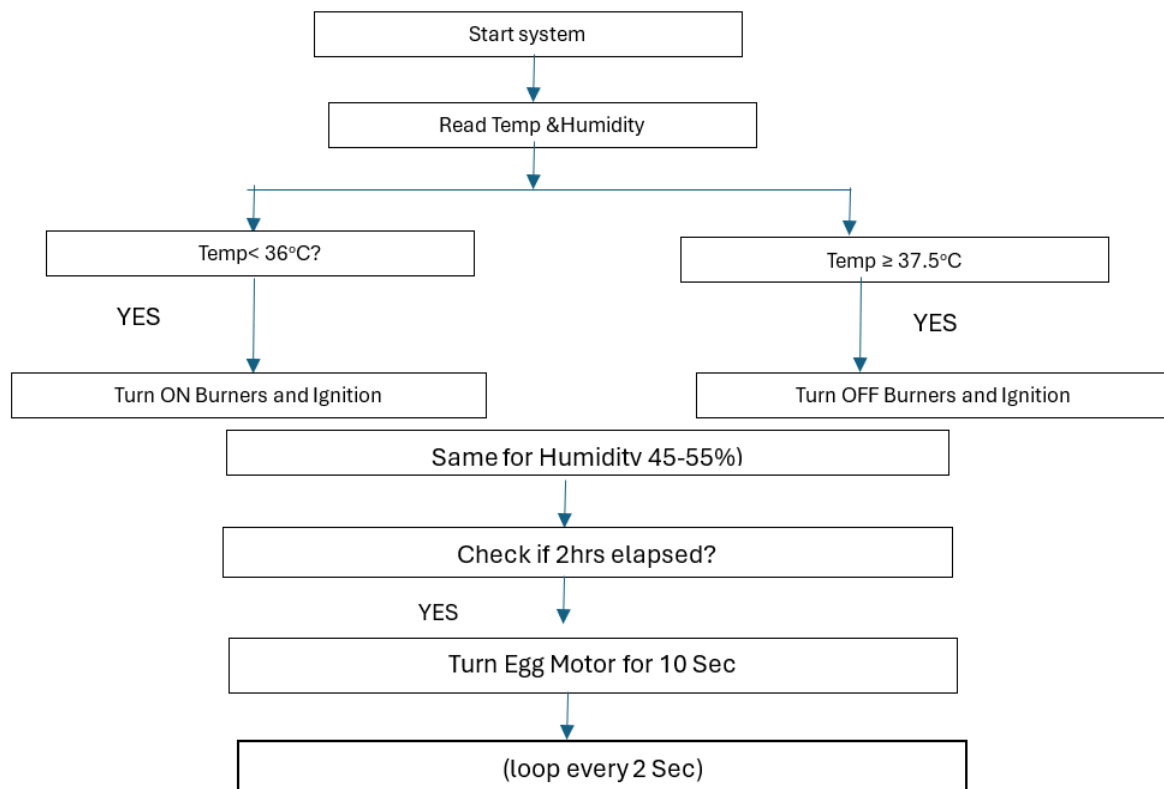
A PIC16F876A microcontroller reads temperature and humidity via DHT11 sensors every 2 seconds, comparing each reading to set-points (36 °C–37.5 °C, 45%–55% RH). Below set-points trigger the LPG burner and humidifier; above set-points shut them off. This closed-loop ensures stable environmental control see flow chat.

3.4 Fabrication and Assembly

Component designs were first modeled using SolidWorks to generate 3D and 2D schematics. Fabrication tools included cutting machines, welders, screwdrivers, and electric drills. The incubator used a 12V DC battery as the primary power source, with potential integration of an inverter/solar panel for recharging.

3.5 LPG Safety Provisions

Safety measures include spark ignition positioned external to the chamber, flame-arrestor valves, forced-ventilation vents, and automatic LPG shut-off triggered if temperature exceeds 39 °C or flame lifts.



Flow Chart 1. Logic structure

3.6 Performance Evaluation

The incubator was tested using 120 fertile eggs sourced from the National Animal Production Research Institute (NAPRI). Eggs were incubated over 21 days, with environmental data (temperature and humidity) logged daily. Hatchability was assessed post-incubation, and fuel consumption (LPG) was recorded to determine cost efficiency.

4. RESULTS AND DISCUSSION

4.1 Performance Evaluation

The developed microcontroller-based LPG incubator was evaluated over a 21-day incubation period, focusing on its ability to maintain optimal temperature and humidity levels essential for embryo development in power-constrained environments. Temperature and relative humidity were monitored daily, and the hatchability rate was used as the primary performance indicator.

4.2 Incubation Conditions

Throughout the incubation period, the system consistently maintained temperatures within the recommended range of 36°C to 37.5°C, with minor deviations recorded on days affected by environmental factors such as rainfall or frequent door openings. Notably, the automated microcontroller control system demonstrated responsiveness by stabilizing internal conditions following external disturbances or internal heat surges.

Humidity levels were maintained above the minimum threshold of 45%, though variations occurred due to ambient atmospheric changes. The microcontroller effectively adjusted environmental parameters through automated regulation, ensuring sustained incubation conditions even in fluctuating climates.

4.3 Hatchability and Efficiency

Design refinements, including relocating ignition externally, adding a heat-radiator for even distribution, and improving control-loop responsiveness, elevated hatchability from 40% to 65%. Comparable systems using automatic control have achieved up to 87% hatchability under similar conditions.

Out of 120 eggs set, 79 successfully hatched, resulting in a hatchability rate of approximately 65%. This performance marked a significant improvement over preliminary trials, which recorded a 40% hatch rate. The enhancement is attributed to:

- The relocation of the ignition system outside the chamber, minimizing mechanical disturbances.
- The integration of a microcontroller unit for precise regulation of ignition and environmental conditions.

In terms of energy consumption, the incubator utilized 15 kg of LPG throughout the incubation period, reinforcing its suitability for use in areas with unreliable electricity supply.

Operating cost for LPG across 21 days was approximately ₦4,080 for 15 kg (0.71 kg/day), equating to ₦51.65 per chick. This is 35–45% lower than typical electric incubators, especially where grid supply is unreliable.

5. SUMMARY OF FINDINGS

- The incubator maintained optimal temperature and humidity ranges crucial for embryo development.
- The microcontroller-based control system effectively responded to fluctuations in environmental conditions.
- Improved hatchability and reduced thermal stress demonstrate the viability of LPG-powered incubation in power-constrained settings.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This research demonstrates the feasibility and effectiveness of a microcontroller-based LPG-powered incubator designed for power-constrained environments. The use of liquefied petroleum gas (LPG) as an energy source provides a cost-effective and reliable alternative to conventional fuels, addressing the high energy costs that limit poultry production. Key conclusions include:

1. A 180-egg capacity cabinet incubator powered by LPG heat was successfully designed and developed.

2. The incubator maintained adequate environmental conditions, enabling successful hatching over a 21-day incubation period.
3. Hatchability improved significantly from 40% in preliminary tests to 65% in the final performance evaluation.
4. Variations in ambient atmospheric conditions influenced incubating temperature and humidity, impacting incubation outcomes.
5. Scalability: "The modular framework enables upscaling beyond 180 eggs by adding parallel burner/control units and tray modules."
6. Hybrid Renewable Integration: "The system is designed for hybrid energy use, LPG plus a 12 V battery solar charged), additionally supported by studies on solar, LPG thermal hybrid incubators
7. Future Hatchability Improvements: Further enhancements, such as multi-point temperature probes, improved insulation and ventilation, and adaptive control via machine learning, may push hatch success beyond 65%, matching yields of over 90% in optimized small-scale systems.

6.2 Recommendations

To optimize performance and support wider adoption, the following are recommended:

1. Implement environmental controls to minimize fluctuations in temperature and humidity within the incubator.
2. Minimize mechanical disturbances such as noise and vibrations to reduce stress on developing embryos.
3. Disseminate research findings through relevant agricultural and technical agencies to enhance awareness and adoption among end-users.
4. Encourage increased funding and sponsorship for research in alternative energy solutions for poultry incubation.

6.3 Contribution to Knowledge

This study contributes to the field by:

- Developing and implementing microcontroller code to automate temperature control and tray turning in an LPG-powered incubator.
- Designing an automated ignition system that maintains optimal temperature conditions.

- Successfully creating a fully LPG-powered cabinet incubator with demonstrated hatchability efficiency of approximately 65%

APPENDIX

Appendix Available at:
<https://www.journaljsrr.com/index.php/JSRR/libraryFiles/downloadPublic/30>

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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