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Thermal and Humidity Control in LPG-Powered Poultry Incubators: Evaluating Environmental Stability and Hatchability Outcomes

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Abstract:
Stable thermal and humidity conditions are critical for achieving high hatchability in artificial poultry incubation. This study evaluates the performance of a Liquefied Petroleum Gas (LPG)-powered incubator, regulated by a PIC16F876A microcontroller, in maintaining optimal environmental parameters. Temperature and humidity were monitored continuously over a 21-day incubation cycle and correlated with hatchability outcomes. The system consistently maintained target values of 37.5 °C ± 0.5 °C and 45–55% relative humidity, despite external climatic fluctuations. A hatchability rate of 65% was achieved from 120 fertile eggs. Findings demonstrate that microcontroller-controlled LPG incubators can provide reliable, stable incubation environments in regions where electric power supply is inconsistent, supporting viable chick production and improved poultry productivity.

Key words: Thermal and Humidity Control, LPG-Powered Poultry Incubators, Hatchability, Environmental Stability

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I. Introduction

Poultry production is a major contributor to Nigeria's livestock sub-sector, providing a sustainable source of food, income, and employment for both rural and urban populations (Smith, 1990). Across the country's diverse ecological zones, poultry farmers engage in the production of meat, eggs, day-old chicks, and poultry manure, supporting household nutrition, agribusiness growth, and the broader national economy.

Artificial incubation has become an indispensable technology in modern poultry farming, enabling farmers to hatch eggs without the presence of a brooding hen. This method accelerates production cycles and improves planning by allowing for the simultaneous incubation of large batches of eggs. Unlike natural incubation, where the hen provides warmth through direct contact, artificial incubation creates a controlled environment in which temperature, humidity, and ventilation are maintained within precise limits to support embryonic development (University of Illinois, 1998).

The practice of artificial incubation dates back thousands of years. Historical accounts credit both the Chinese and the Egyptians with its early development—methods ranged from charcoal-fired heating systems in China to large brick incubators in Egypt, heated by open fires in the incubation rooms (Fuan, 1987). Over time, incubator designs have evolved to incorporate automated temperature control, forced-air ventilation, and mechanical egg turning (University of Illinois Extension Incubation and Embryology, 2014). Today, commercial incubators are typically powered by electricity, offering precise regulation of thermal and humidity conditions essential for successful hatching.

However, in tropical and sub-Saharan regions, such as Nigeria, unstable and inconsistent electricity supply remains a persistent challenge (Smith, 2014). Power outages cause fluctuations in incubator temperature and humidity, which can significantly reduce hatchability. Optimal incubation for chicken eggs generally requires a constant temperature between 37.0°C and 38.0°C, with relative humidity above 45% (Wilson, 1991). Even minor, prolonged deviations from these ranges can impair embryo development and reduce hatch rates (Tazawa et al., 1989; Meijerhof & van Beek, 1993). Overheating tends to accelerate embryonic metabolism, leading to early hatching and weak chicks, while low temperatures slow development and delay hatching (Vleck & Vleck, 1987). Humidity regulation is equally critical, influencing water loss, air cell development, and overall chick viability (Smith, 2014).

Given these constraints, alternative energy-powered incubation systems are gaining importance. Liquefied Petroleum Gas (LPG)-powered incubators, when equipped with automated environmental control systems, present a viable solution for off-grid or electricity-insecure regions. Such systems can sustain consistent incubation conditions through real-time monitoring and adjustment, mitigating the effects of ambient weather fluctuations (Agidi et al., 2014). This study investigates the thermal and humidity control performance of an LPG-powered poultry incubator regulated by a PIC16F876A microcontroller. The objective is to assess its ability to maintain optimal conditions and achieve satisfactory hatchability rates under variable environmental influences, thereby offering a reliable incubation alternative in regions with unstable electricity supply.

II. Literature Review

Incubating Conditions

Incubation is done by keeping the incubating environment within 36 0C to 37.5 0C at a relative humidity higher than 45%. Poor results are most commonly produced with improper control of temperature and/or humidity. Improper control means that the temperature or humidity is too high or too low for a sufficient length of time that it interferes with the normal growth and development of the embryo. Poor results also occur from improper ventilation, egg turning and sanitation of the machines or eggs. (Smith, 2014)

Smith (2014) obtained the best hatch by keeping the temperature at 37.78 0C. throughout the entire incubation period when using a forced-air incubator. Minor fluctuations (less than ½ degree) above or below 100 degrees are tolerated, but do not let the temperatures vary more than a total of 1 degree. Prolonged periods of high or low temperatures will alter hatching success. High temperatures are especially serious. A forced-air incubator that is too warm tends to produce early hatches. One that runs consistently cooler tends to produce late hatches. In both cases the total chicks hatched will be reduced.

Smith (2014) also maintained a still-air incubator at 38.89 0C. to compensate for the temperature layering within the incubator. Proper temperature readings were obtained by elevating the bulb of the thermometer to the same height as the top of the eggs when the eggs are laying horizontal. When the eggs are positioned vertically, the thermometer bulb was elevated to a point about 6 mm to 12.7 mm below the top of the egg. This was dove to prevent incorrect readings. (Smith, 2014)

Humidity is carefully controlled to prevent unnecessary loss of egg moisture. The relative humidity in the incubator between setting and three days prior to hatching should remain at 58-60% or 28.89 - 30 0C., wet-bulb. When hatching, the humidity is increased to 65% relative humidity or more. An excellent method to determine correct humidity is to candle the eggs at various stages of incubation. The normal size of the air cell after 7, 14, and 18 days of incubation for a chicken egg is shown. Necessary humidity adjustments can be made as a result of the candling inspection. The egg's weight must decrease by 12% during incubation if good hatches are expected (University of Illinois, 1998). Stages in the decrease of the egg`s weight is as shown in Appendix B, plate 4.12B

Frequently there is confusion as to how the measurement of humidity is expressed. Most persons in the incubator industry refer to the level of humidity in terms of degrees celcius, (wet-bulb) rather than percent relative humidity. The two terms are inter-convertible and actual humidity depends upon the temperature (0C) as measured with a dry-bulb thermometer. Conversion of the two humidity measurements can be made using the following table:

Table 2.1: Common incubation values for temperatures and humidity

Wet-Bulb Values For Four (dry-bulb) Incubation Temperatures				
Relative Humidity(%)	37.22 ^{0}C	37.7 ^{0}C	38.3 ^{0}C	38.8 ^{0}C
45	26.94	27.39	27.89	28.33
50	28.06	28.50	29.00	29.44
55	29.17	29.61	30.11	30.56
60	30.28	30.72	31.22	31.67
65	31.11	31.67	32.22	32.78
70	32.06	32.61	33.17	33.72

Source: (Smith, 2014)

Level of humidity do not usually go high in properly ventilated still-air incubators. Increased ventilation during the last few days of incubation and hatching may necessitate the addition of another pan of water or a wet sponge. Humidity is maintained by increasing the exposed water surface area.

Ventilation is very important during the incubation process. While the embryo is developing, oxygen enters the egg through the shell and carbon dioxide escapes in the same manner. As the chicks hatch, they require an increased supply of fresh oxygen. As embryos grow, the air vent openings are gradually opened to satisfy increased embryonic oxygen demand. Care must be taken to maintain humidity during the hatching period. Unobstructed ventilation holes, both above and below the eggs, are essential for proper air exchange (University of Illinois, 1998).

What must be done if the power goes off during incubation? A proper response depends on several factors, some of which include the temperature of the room in which the incubator is located, the number of eggs in the machine, and whether the eggs are in the early or late stage of incubation (University of Illinois, 1998).

The two most important considerations in this situation are to (i) keep the eggs from overheating and (ii) be sure they have an adequate oxygen supply. The longer the eggs incubate and the greater the number of eggs in the incubator, the greater the chance that you will experience overheating and suffocation of the embryos.

Eggs must be turned at least 4-6 times daily during the incubation period. Do not turn eggs during the last three days before hatching. The embryos are moving into hatching position and need no turning. Keep the incubator closed during hatching to maintain proper temperature and humidity. The air vents should be almost fully open during the latter stages of hatching (University of Illinois, 1998).

The eggs are initially set in the incubator with the large end up or horizontally with the large end slightly elevated. This enables the embryo to remain oriented in a proper position for hatching. Never set eggs with the small end upward.

In a still-air incubator, where the eggs are turned by hand, it may be helpful to place an "X" on one side of each egg and an "O" on the other side, using a pencil. This serves as an aide to determine whether all eggs are turned. When turning, be sure your hands are free of all greasy or dusty substances. Eggs soiled with oils suffer from reduced hatchability. Extra precautions should be taken when turning eggs during the first week of incubation. The developing embryos have delicate blood vessels that rupture easily when severely jarred or shaken, thus killing the embryo. The following table lists incubation requirements for species of fowl. (University of Illinois, 1998)

Table 2.2: Incubation requirements for species of fowl

Species	Incub. Period (days)	Temp. (F.)[1]	Humidity (F.)[2]	Do not turn after	Humidity Last 3 days[2]	Open vent more
Chicken	21	100	85-87	18th day	90	18th day

(University of Illinois, 1998)

Thermal stability is closely tied to embryo metabolism and developmental outcomes (Meijerhof & van Beek, 1993). Embryos are sensitive to deviations in temperature beyond ±0.5°C, especially after Day 10 of incubation (Tazawa et al., 1989). Humidity influences water loss and gas exchange, with critical ranges necessary to prevent shell desiccation or drowning of embryos (Smith, 2014). Recent studies (Agidi et al., 2014; Vleck & Vleck, 1987) have highlighted the need for real-time environmental control in alternative energy-powered incubators, such as those using LPG.

Optimum incubation temperature

Optimum incubation temperature is normally defined as that required to achieve maximum hatchability. Most poultry species have an optimum incubation temperature of 37 to 38^{0}C and small deviations from this optimum can have a major impact on hatching success and embryo development (Wilson, 1991). The vast majority of poultry hatching eggs are artificially incubated in incubators that must be designed to accurately control the temperature inside the machine to ensure that the temperature of the developing embryo does not deviate from this optimum.

The temperature experienced by the developing embryo is dependent on three factors: (i) the incubator temperature, (ii) the ability of heat to pass between the incubator and the embryo, and (iii) the metabolic heat production of the embryo itself.

III. Methodology

Design Framework

The LPG-powered poultry incubator was constructed using medium-density fibreboard (MDF) due to its low thermal conductivity, ease of fabrication, and structural stability. The unit was designed as a two-chamber system: the upper chamber served as the incubation compartment, while the lower chamber housed the heating and humidity control mechanisms. The incubator was configured to accommodate up to 180 chicken eggs arranged in a trolley-based tray system, enabling efficient egg turning and easy access for loading and unloading.

The heating system consisted of a Liquefied Petroleum Gas (LPG) burner connected to a gas cylinder, with combustion heat transferred through a heat barrier and distributed via a fan-assisted airflow system. Humidity was maintained using a water-filled trough fitted with a humidifier, while air circulation was ensured through strategically positioned ventilation inlets and outlets.

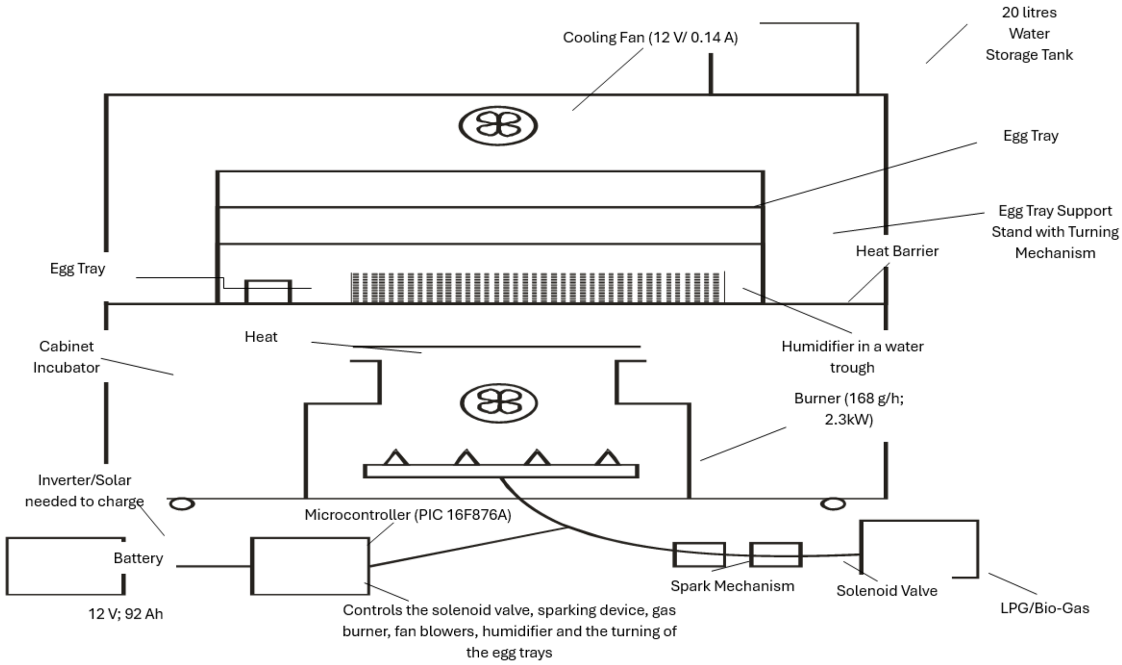


Figure 3.1: Schematic Diagram of the Incubaton

Design Considerations

The design process was guided by the following operational and environmental requirements:

i. Egg capacity: Target capacity of 180 chicken eggs to suit small-to-medium-scale poultry operations.
ii. Optimal incubation temperature: 37.5°C ± 0.5°C, in accordance with established hatchability standards (Wilson, 1991; Smith, 2014).
iii. Relative humidity: Maintained between 45–55% during incubation to support adequate moisture loss and air cell development.
iv. Reliability: Continuous operation despite ambient temperature fluctuations, supported by an automated microcontroller-based control system.
v. Energy source: LPG heating to overcome the limitations of unreliable grid electricity in rural and peri-urban environments.

Control System Configuration

The environmental parameters of the incubator were regulated using a PIC16F876A microcontroller programmed in Mikrobasic. The control system integrated multiple functional modules:

i. Temperature regulation: A DHT11 digital sensor monitored chamber temperature, activating the solenoid valve to initiate LPG ignition when readings fell below 36°C. The burner was automatically shut off once the temperature reached 37.5°C.
ii. Humidity control: Relative humidity was monitored using the same sensor, with the humidifier activated whenever readings dropped below 45% and deactivated at 55%.
iii. Egg turning mechanism: A motor-sprocket assembly automatically rotated egg trays at two-hour intervals to prevent embryonic adhesion and ensure uniform heat exposure.

iv. Gas flow and ignition: The solenoid valve controlled LPG flow, while an integrated sparking device ensured safe and timely ignition.
v. Air circulation: Fan blowers provided forced-draft ventilation to maintain uniform temperature and humidity distribution within the incubation chamber.

Fabrication and Assembly

The incubator design was modelled using SolidWorks to generate 2D engineering drawings and 3D visualisations. These models were used to guide the fabrication process, which utilised cutting machines, welding tools, screwdrivers, and electric drills. The MDF panels were cut to specification, joined, and insulated to minimise thermal loss. The heat source, humidifier, fans, and turning mechanism were securely installed to ensure durability and safe operation.

A 12V, 92Ah DC battery served as the primary power supply for the microcontroller and auxiliary components, with provision for recharging via solar panels or an inverter system. The LPG burner, rated at 168 g/h (2.3 kW), was mounted in the lower chamber, with a heat radiator and barrier to distribute warmth evenly to the incubation chamber. Wiring and control circuits were laid out to ensure safe operation and ease of maintenance.

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.

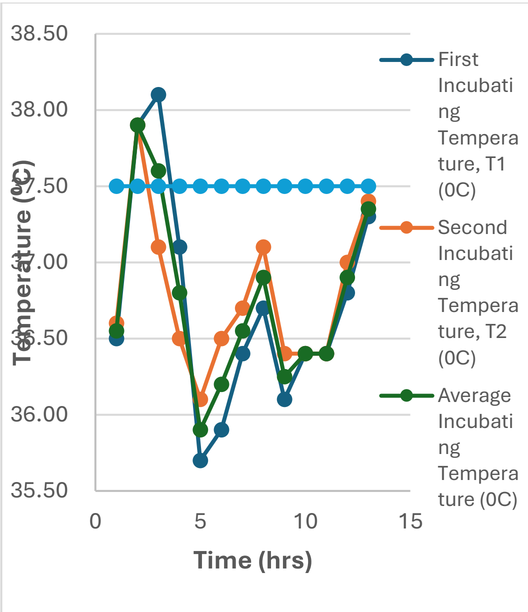
The prototype incubator was designed to maintain a temperature of 37.5°C and 45–55% humidity, controlled by a programmed microcontroller. Temperature and humidity data were collected using integrated sensors (DHT11) at hourly intervals. Fertile eggs (n = 120) from NAPRI were incubated for 21 days, and hatchability was recorded. Performance trends were visualized via time-series plots.

IV. Results and Discussion

The performance of the LPG-powered incubator was evaluated over a 21-day incubation period using 120 fertile eggs. Temperature and humidity readings were recorded at hourly intervals via the integrated DHT11 sensor, and key data points were analysed alongside hatchability outcomes.

Thermal and Humidity Trends

Figures 1 and 2 present temperature and humidity readings recorded on Days 4 and 5. During these days, the system maintained temperatures within the optimal range for incubation (37.0–37.8°C) and humidity levels above the minimum threshold of 45%. Variations in humidity, though observed, remained within acceptable limits for embryonic development (Smith, 2014).



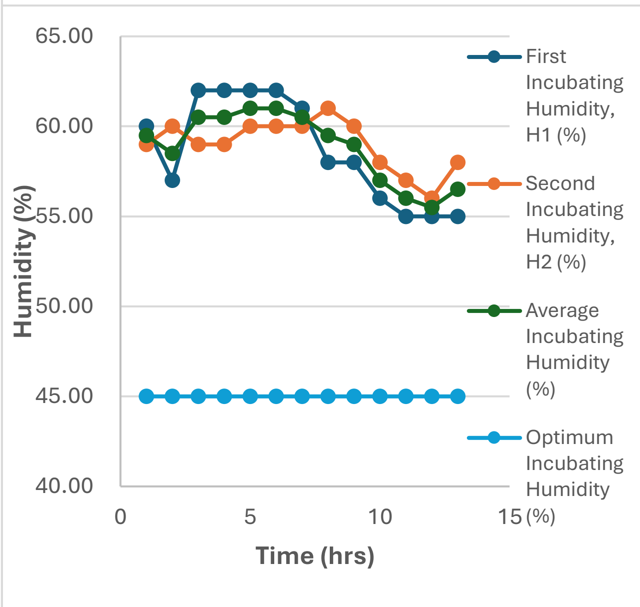


Figure 1: Temperature and Humidity Readings for Day 4

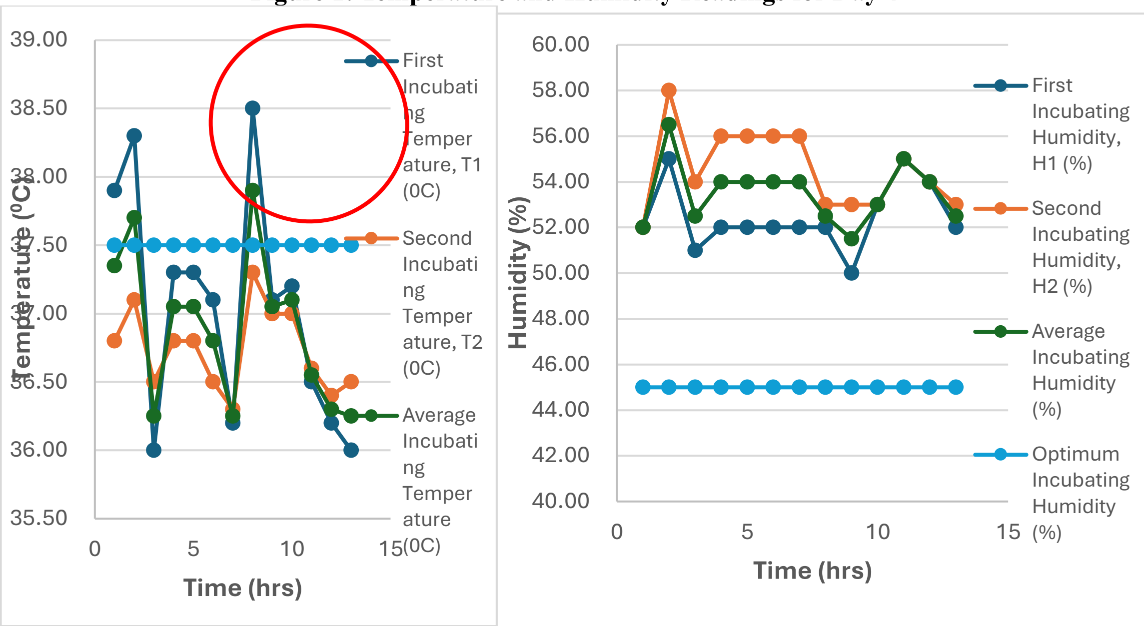


Figure 2: Temperature and Humidity Readings for Day 5

On Day 7 (Figure 3), an elevated humidity level corresponded with a temporary reduction in internal temperature. The control system responded by activating the heating mechanism, gradually restoring thermal conditions to target values. This demonstrated the responsiveness of the automated regulation system in correcting environmental imbalances.
Day 8 data (Figure 4) revealed a sudden temperature drop attributed to frequent door openings for demonstration purposes. The incubator successfully recovered to the set point, confirming the robustness of the feedback control mechanism even under disruptive conditions.

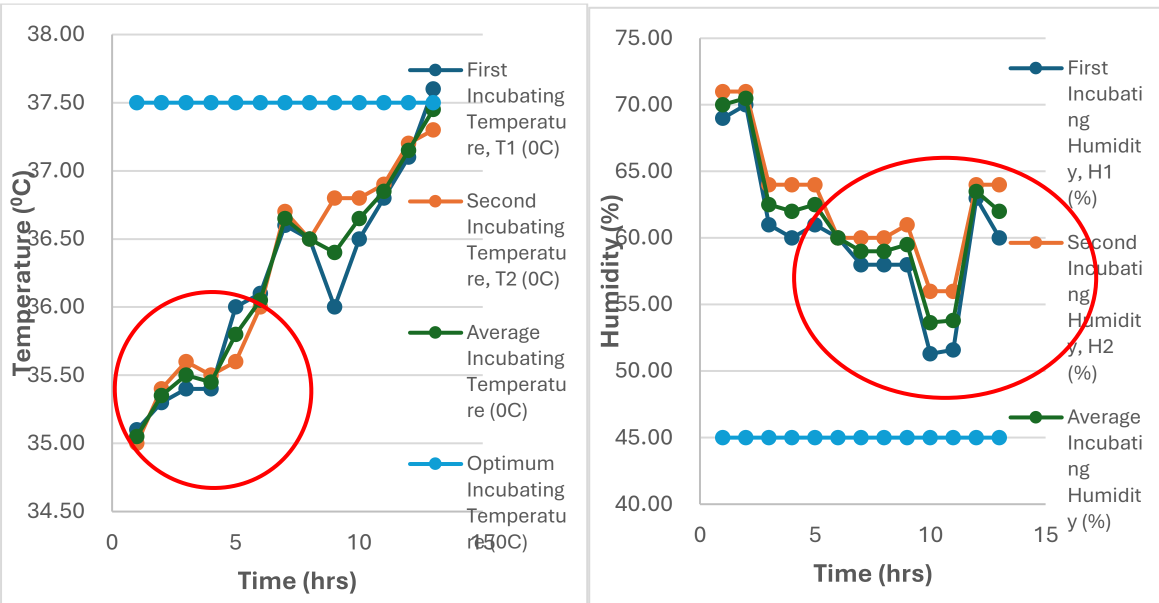


Figure 3: Temperature and Humidity Readings for Day 7

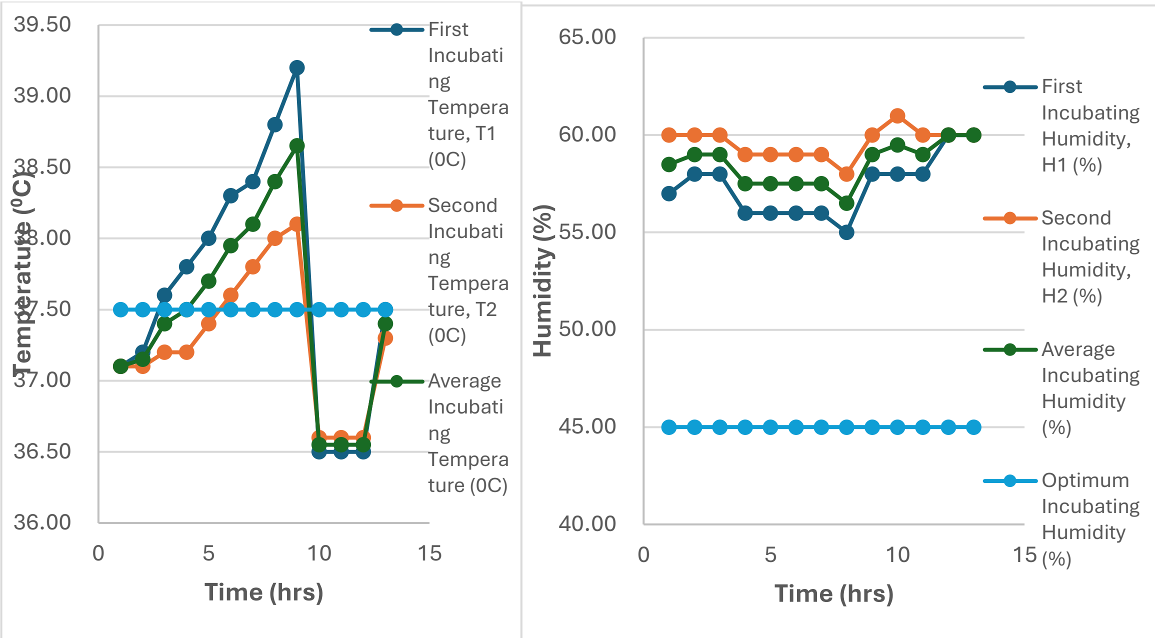


Figure 4.Temperature and Humidity Readings for Day 8

Impact of External Environmental Variations

Between Days 11 and 17, significant fluctuations in temperature and humidity were recorded (Figures 5–8). These variations coincided with external weather events, including heavy rainfall followed by periods of intense afternoon heat. Such conditions elevated internal temperatures while reducing humidity levels. This was of concern, as higher-than-optimal temperatures can accelerate embryonic metabolism and potentially impair chick viability (Tazawa & Nakagawa, 1985; Meijerhof & van Beek, 1993). Nonetheless, the system maintained parameters within the tolerance thresholds, aided by its forced-air circulation and automated humidity control.(Tazawa and Nakagawa, 1985)

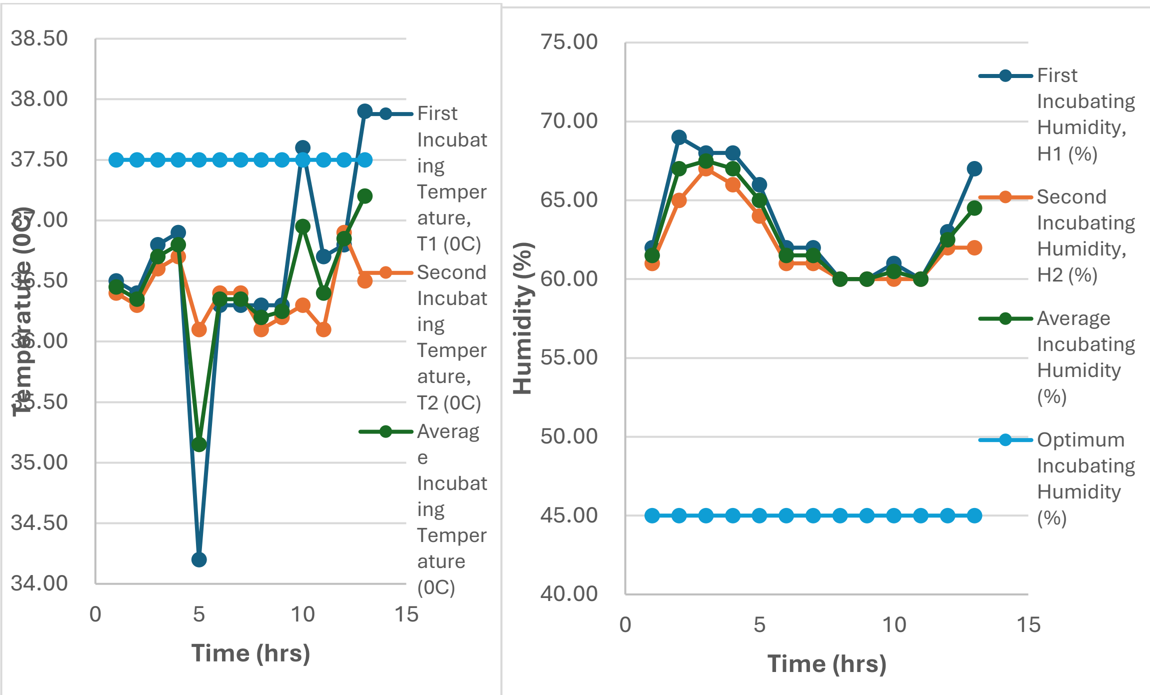


Figure 5: Temperature and Humidity Readings for Day 18

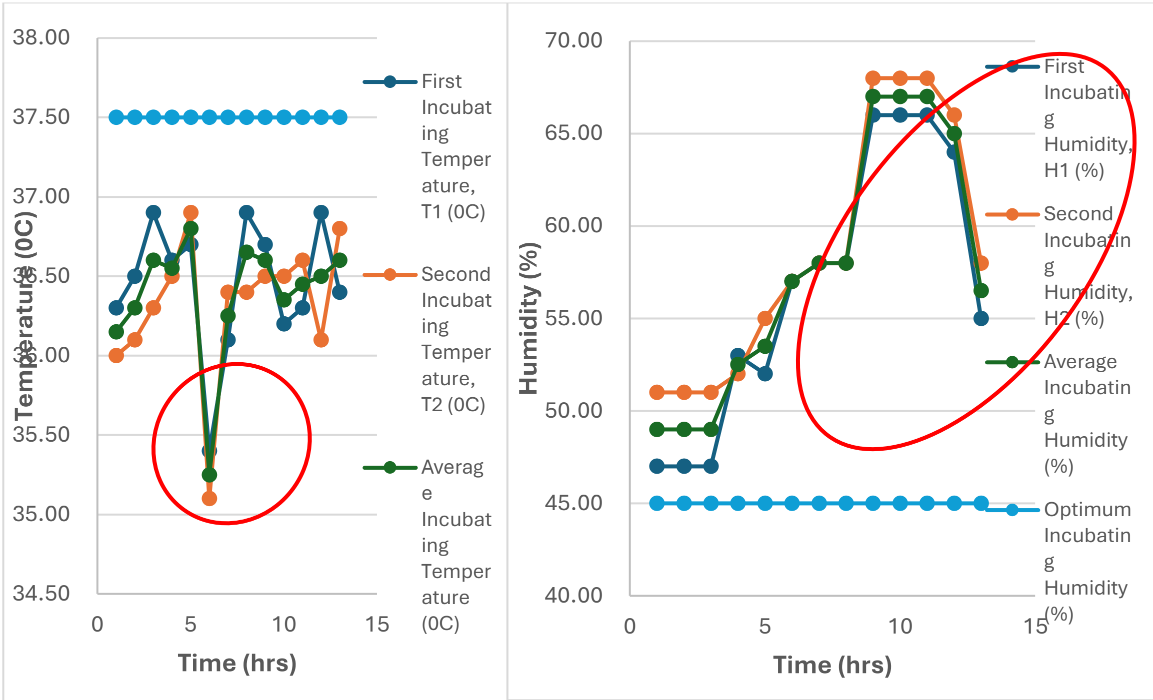


Figure 6: Temperature and Humidity Readings for Day 19

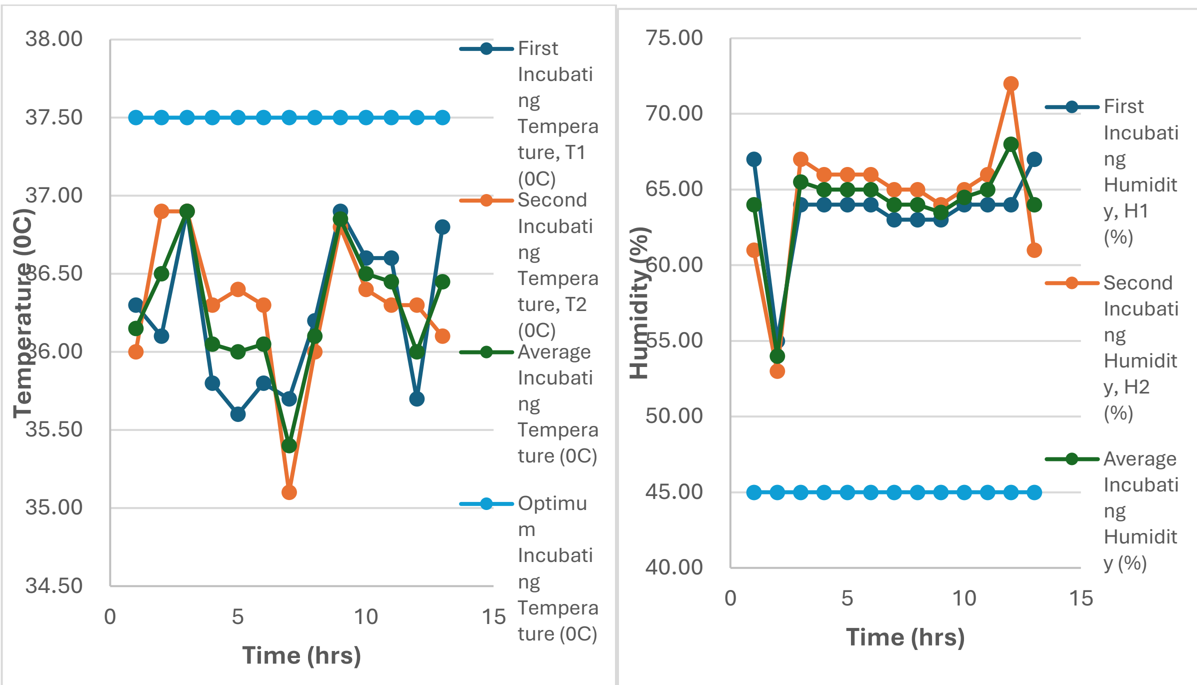


Figure 7: Temperature and Humidity Readings for Day 20

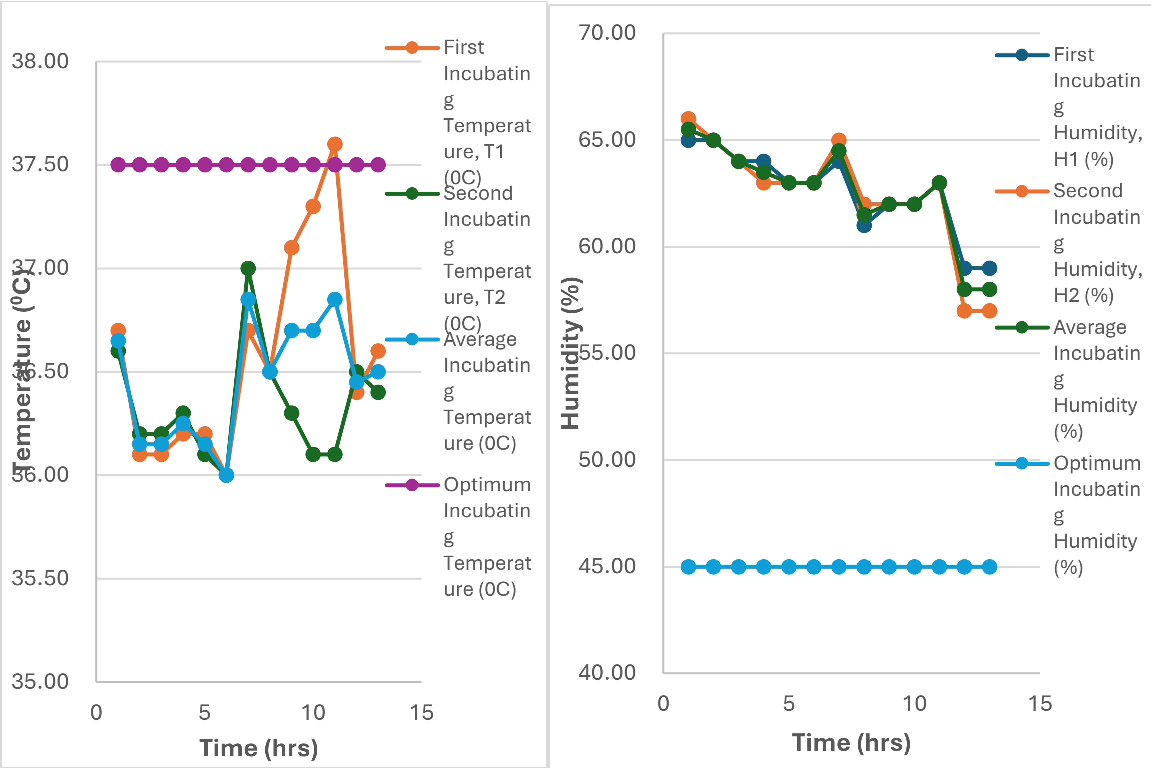


Figure 8: Temperature and Humidity Readings for Day 21

Final Hatching Phase

From Day 18 onwards, when eggs were transferred to the hatcher, recorded temperatures were slightly below the upper limit for incubation. This reduction was expected, as developing embryos generate substantial metabolic heat in the final days before hatching (Vleck & Vleck, 1987). During this stage, cooling was more critical than heating to avoid overheating. Humidity was also carefully managed, with controlled increases during the final three days to facilitate successful hatching.

Performance Summary

Throughout the incubation cycle, average daily temperatures remained within 37.1–37.8°C, while humidity consistently fell between 45–55%, apart from short-term deviations caused by human interaction or abrupt ambient changes. These fluctuations were rapidly corrected by the automated control system. The hatchability rate achieved was 65%, confirming that environmental conditions were adequate for sustaining embryonic development.

The results affirm that LPG-powered incubators equipped with microcontroller-based regulation can match the environmental stability of electric-powered units (Romijn & Lokhorst, 1960; Agidi et al., 2014). This makes them particularly suitable for rural and peri-urban poultry producers in regions with unreliable electricity supply.

V. Conclusion and Recommendations

Conclusion

This study evaluated the performance of a Liquefied Petroleum Gas (LPG)-powered poultry incubator equipped with a PIC16F876A microcontroller for automated regulation of temperature, humidity, and egg turning. Over a 21-day incubation period, the system consistently maintained environmental parameters within optimal thresholds, temperature between 37.1°C and 37.8°C, and relative humidity between 45–55%, despite external climatic fluctuations.

A hatchability rate of 65% was achieved from 120 fertile eggs, indicating that the incubator provided stable conditions conducive to embryonic development. The system's feedback control effectively responded to environmental disturbances, including door openings, atmospheric changes, and variable humidity levels. These results confirm that microcontroller-regulated LPG-powered incubators can serve as reliable alternatives to electric-powered units, particularly in regions with unstable or unavailable electricity supply

Recommendations

1. Enhanced Insulation – Incorporating external thermal insulation materials could further minimise the impact of ambient temperature variations and improve energy efficiency.
2. Real-time Monitoring and Alerts – Integrating data logging with wireless alert systems (e.g., SMS or mobile app notifications) would enhance quality control by enabling prompt corrective action when parameters deviate from set thresholds.
3. Longitudinal Performance Evaluation – Conducting multi-season and multi-location trials would help assess the system's adaptability to varying climatic conditions and inform design refinements.
4. Comparative Hatchability Studies – Benchmarking against electric-powered incubators under identical operating conditions would provide deeper insight into performance parity or potential advantages of LPG-powered systems.
5. Capacity Scaling – Exploring scalable designs for higher-capacity units could expand the technology's utility for medium- and large-scale poultry enterprises.

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