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Manufacturing and Feasibility Test of Duck Egg Incubator Machine with Automatic System for Small Industrial Scale

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Abstract

This research aims to design and test the feasibility of an automatic system duck egg incubator, with 100% local ingredients (TKDN) and affordable for small duck egg hatching industries. Duck egg hatching continues to develop along with advances in technology and the increasing need for duck eggs and cut duck meat. The innovation of the automatic duck egg incubator machine is an effort to help the small duck egg hatching industry to increase production in a more efficient and ergonomic manner. In this research, the creation of an automatic duck egg incubator machine uses stages including problem identification, formulation and refinement of ideas, selection of design concepts, analysis and creation of working drawings, manufacture of tool prototypes, testing and refinement of tool prototypes, then feasibility tests for temperature stability and stability are carried out. humidity, and hatchability tests carried out at the small duck egg hatchery industry UD. Putra Jember, Puger, Jember. The result of this research is an automatic duck egg incubator with a capacity of 5000 eggs, with an LPG heating source. The feasibility test showed stable temperature and humidity fluctuations and produced a hatchability of 82%.

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1. Introduction

Duck meat is a livestock business that still exists today, and duck meat is a promising type of business because duck meat and eggs are widely consumed by the public, and duck meat is known to have a delicious taste. The duck business is in great demand from the public; it does not require much capital and is relatively easy to maintain. Duck marketing is primarily conducted through duck suppliers, restaurants, and online sales. Statistically, in BPS 2023, there is an increase in Manila duck/duck egg production by province (tons) in Indonesia; in 2021 it was 344.470,12 tons, while in 2023 it was 358.220,20 tons.

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Currently, many small industrial businesses are developing duck eggs and rearing ducks to produce eggs and meat ducks. Duck egg hatching was performed using a duck egg incubator made of wooden plywood. In line with current technological developments, duck egg incubator machines have also been developed on a larger scale and are controlled automatically. Each duck egg incubator has its own characteristics, which are influenced by the type of construction material, heating source, eggshell, and so on. Inappropriate or incorrect operation of an egg incubator will result in less than optimal results and even failure. In accordance with SNI standards, the incubation and/or hatching temperature was 38°C, humidity was 52 – 72%, hatcher humidity was 65 – 86%, and hatchability was > 70% of the fertile eggs. Research from SNI, 2009 shows that the temperature generated by the heating element in the egg hatching room can be measured and controlled by a temperature sensor and microcontroller system with a temperature range from 29.5°C to 47°C and an average scale factor of 10.05 mV/°C. The indoor temperature and measured voltage have a relatively linear relationship, that is R2 = 0.93 (Fadhila & Rachmat, 2014).

Arduino Uno-based automatic duck egg incubator. The temperature and humidity in the hatching box were 36 – 38°C and 50 – 60%, capacity 120 eggs, with a success rate of 62%. Sanjaya et al. (2018) explained that an Arduino microcontroller-based incubator system could automatically control the temperature, humidity, and turning of quail eggs. Internet of Things (IoT) systems can help farmers remotely monitor smart incubators. The quail egg smart incubator showed the best results for hatching the quail eggs. Approximately 87.55% of quail eggs hatched normally, 0.41% hatched with defects, 1.84% hatched dead, and 10.20% hatched (Sugara et al., 2023).

In research on the design of an incubator using Arduino, an egg incubator, as well as temperature and humidity using a DHT11 sensor, and the output was processed by Arduino Uno R3, the data results from 8 chicken eggs, six hatched, and two eggs failed, so the hatchability was 75% (Hartono et al., 2017). Results of research on the design of a hatching machine with an automatic hybrid power system, show that the hybrid-powered automatic egg incubator on the rack can shift automatically every 6 hours and has a battery life of up to 29.1 hours (Susetyo et al., 2020).

The heat efficiency analysis of egg incubators, capacity 100 eggs, incubation machine dimensions of length 600 mm, width 450 mm, and height 450 mm, capable of maintaining a temperature of 38°C – 41°C. The heat requirement for the incubator machine is 47.48 kcal/hour and the energy provided for the incubator machine is 72.6 watts, so the heat efficiency of the incubator machine is 76% (Fuazen et al., 2019). An automatic egg incubator was designed using an Arduino Uno microcontroller. In tests carried out using chicken eggs at the temperature set point of 37 – 38°C with humidity of 55 – 60%, results were obtained with a percentage of approximately 98% (Wirajaya et al., 2020).

In the design of an automatic egg incubator powered by a hybrid system based on a microcontroller, the overall hatching rate reached 81.3%, and the growth of egg cells until they became offspring was 88% (Supriadi et al., 2020).

The implementation and test results demonstrate that the transient response characteristics determine a more optimal temperature control method. PI-anti-windup control produces a fast transient response with a time constant value of 144.5 s, rise time of 226.5 s, peak time of 322.5 s, settling time of 280 s, and delay time of 98 s. Thus, these results show that the PI – anti-windup control algorithm is better than PI control (Yusuf & Saputra, 2020).

Fans are often used in egg-hatching incubators to absorb air from inside to outside the incubator, which affects the principle of heat transfer from the heat source. The results show that temperature fluctuations using fans are more stable (7.5°C) than those that do not use a fan, namely 7.7°C, the air humidity in the incubator that does not use a fan fluctuates by 29.9%, while that using a fan is 18.8%. Heat absorption by the air in the incubator that uses a fan is 1.67 watts, while those that do not use a 1.46 watt fan (Nasruddin & Arif, 2014)

The mortality rate for birds less than one week old or when they have just hatched accounts for 30% of the total population on the farm. One of the main causes of the high mortality rate is unstable environmental temperatures. The automatic temperature control simulator, which is equipped with PID control, aims to maintain the temperature with good power-usage efficiency. From the results of the tests carried out with a setpoint of 32°C, the error was 1.89% under no-load conditions and 2.5% under loaded conditions (Purnama et al., 2023).

The treatments for hatching machine temperature regulation patterns showed significant differences in embryo mortality and hatchability in local ducks (Anas sp.). Temperatures of 37.5°C (days 1-21), 39.5°C (days 22 - 24) for 3h per day, 37.5°C (days 25), and 37°C (days 26 - 28), are more effective and efficient in achieving optimal hatching (Sadiah 2015).

Embryos incubated at high eggshell temperatures (EST) and low O_2 concentrations had the highest mortality rate in the last week of incubation; high EST, compared to normal EST, reduced the low yolk-free body mass (YFBM), or reduced nutritional availability for hatching (Molenaar et al., 2011).

For daily incubation of eggs in the same incubator, higher hatching rates can be obtained using temperatures between 35.5°C and 36.5°C. Incubation temperature is inversely proportional to incubation time, and the absolute and relative weights of partridge chicks are not affected by incubation temperature (Nakage et al., 2003).

Incubation temperature and light are the two main factors that influence embryo development and post-hatching performance because chicken embryos are poikilothermic, and the metabolic development of the embryo depends on the incubation temperature, which affects the egg's nutrient

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use and embryo development. Incubation temperatures ranging between 37°C and 38°C (usually 37.5 – 37.8°C) optimize hatchability (Yalcin et al., 2022).

The traditional incubation scheme (program 1) was used as a control and was set for the incubation period (0-18 days) at a temperature of 37.5°C, and the recommended scheme incubation temperature (programs 2 and 3) was 37.5°C from 0-14 days and then increased to 39.5 or 40.7°C for 3 h daily until day 18 (days 15-17) for the first program and the second recommended scheme (programs 2 and 3). During the hatching period (days 19-21), the hatching temperature was 37°C for all the three programs. The relative humidity was 55% during the incubation period for all three programs and 65% during the hatching period. The recommended programs (2 and 3) resulted in a significant increase in embryo weight on day 18 of incubation and chick weight at release ($p \leq 0.05$), both of which produced chicks with higher body weights than those in program 1 (Elsayed, 2009). High fertility in duck eggs resulted from the Cihateup Alabio cross (average >75%) with a sex ratio of 4:16 (male: female) (Rukmiasih et al., 2016). Statistically, the use of hatching machines with different heat sources had no significant effect on any of the observed parameters. Hatching machines with different heat sources had no real effect on fertility, DHE, hatchability, hatching weight, and hatching time of Tolaki chicken eggs (Nafiu et al., 2015).

This study aimed to design and test the feasibility of an automatic duck egg incubator system with a 100% Domestic Component Level that is affordable for small duck egg hatching industries. It works automatically to control temperature and humidity because it is equipped with a sensor, LPG heater, exhaust fan, and water pump to be more efficient, ergonomic, affordable, and easier to maintain.

2. Materials and Methods

This study was conducted from May to October 2023. Tool making was carried out at the Jember State Polytechnic Workshop, whereas the feasibility test was carried out at UD. Putra Jember, Puger, Jember. The research materials consisted of galvalum, ST 32 hollow iron, cork, fertile duck eggs, LPG, water, and a hatching tank.

The equipment used was workshop equipment, data logging of calibrated temperature and humidity measurements, and a timer.

2.1 Methods

The design method is based on a structural design approach and a functional design approach in several stages (Ryder Richardson et al., 2005):

2.1.1 Identify the Problem, Design Requirements, and Design Criteria

To analyze the problems that arise during duck egg hatching activities, information is needed to find solutions in the form of designs.

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Figure 1. Conventional duck egg incubator.

Figure 1 shows a conventional duck egg incubator with dimensions of 1200 mm × 1000 mm × 1500 mm and a capacity of 700 eggs. The heater uses 6 dop lamps of 60 W, and humidity was regulated by manually spraying water 2 times per day. Some problems with conventional duck egg incubators include the following.

1. It is not space-efficient because a capacity of 700 eggs requires an area of 1.2 square meters.
2. Costs are less efficient because heaters with hubcap lamps require electricity and maintenance to replace hubcap lamps.
3. Less ergonomic because the process of controlling temperature and humidity, spraying water, and turning eggs was performed manually.

Based on observations and problems with conventional duck egg incubators, the design requirements and criteria for the automatic duck egg incubator system that will be designed can be determined as follows:

1. An egg rack that can accommodate 5000 duck eggs with a size of 800 × 1400 × 1600 mm is portable.

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2. Actuator on the egg rack to move and turn the eggs automatically
3. Incubation chamber measuring 1200 × 2400 × 2600 mm, with space for incubating duck eggs from day 1 to day 25.
4. Hatching room measuring (1200 × 2400 × 2600) mm, space for hatching duck eggs on the 26 to 28 day.
5. Temperature and humidity sensor units were placed in incubation and hatching rooms.
6. Exhaust fan unit for uniform temperature distribution
7. The water pump unit was connected to a sprayer in the incubation and hatching room.
8. LPG gas unit as a heating source and equipped with an automatic fire starter
9. Electrical panel unit and LCD displaying temperature and humidity

2.2 Prototypes, Analysis of Structural and Functional Design

2.2.1 Prototypes

A prototype of the automatic duck egg incubator system is shown in Figure 2, and a flowchart for creating a duck egg incubator with an automatic system is shown in Figure 3.

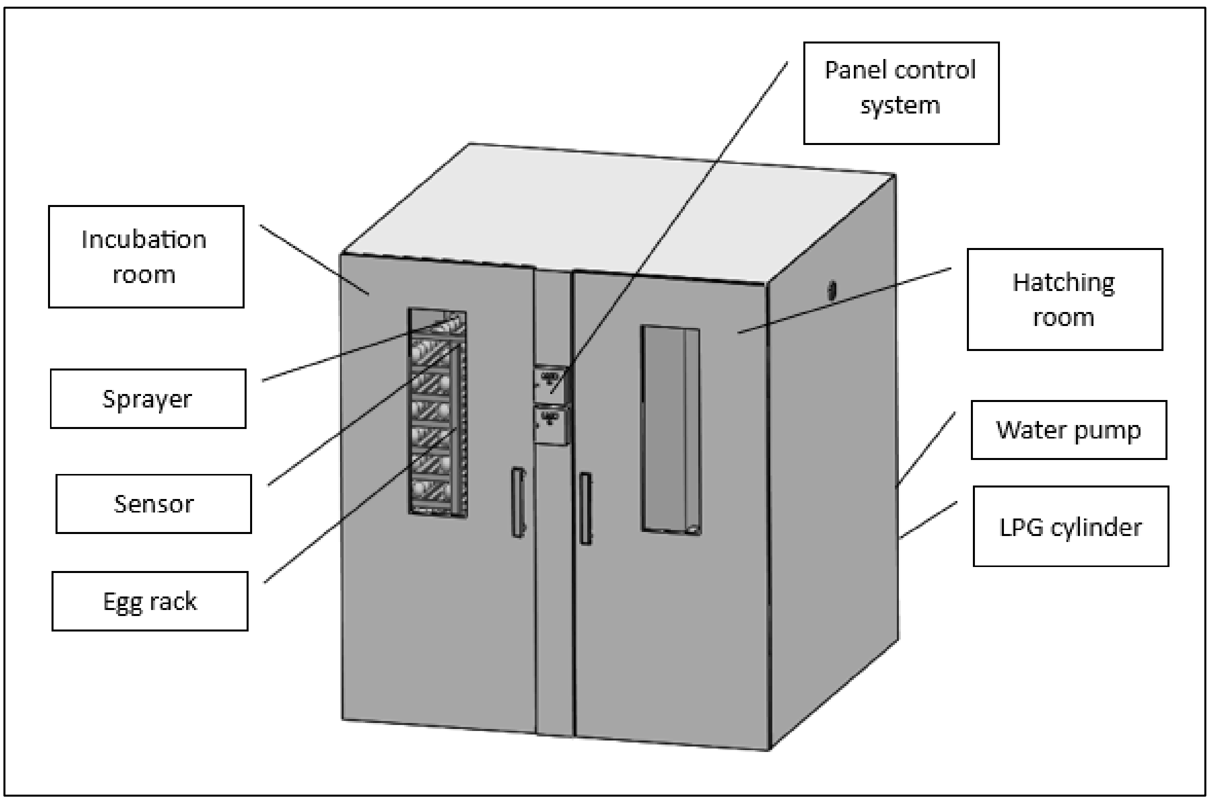

Figure 2. Prototype of automatic system duck egg incubator

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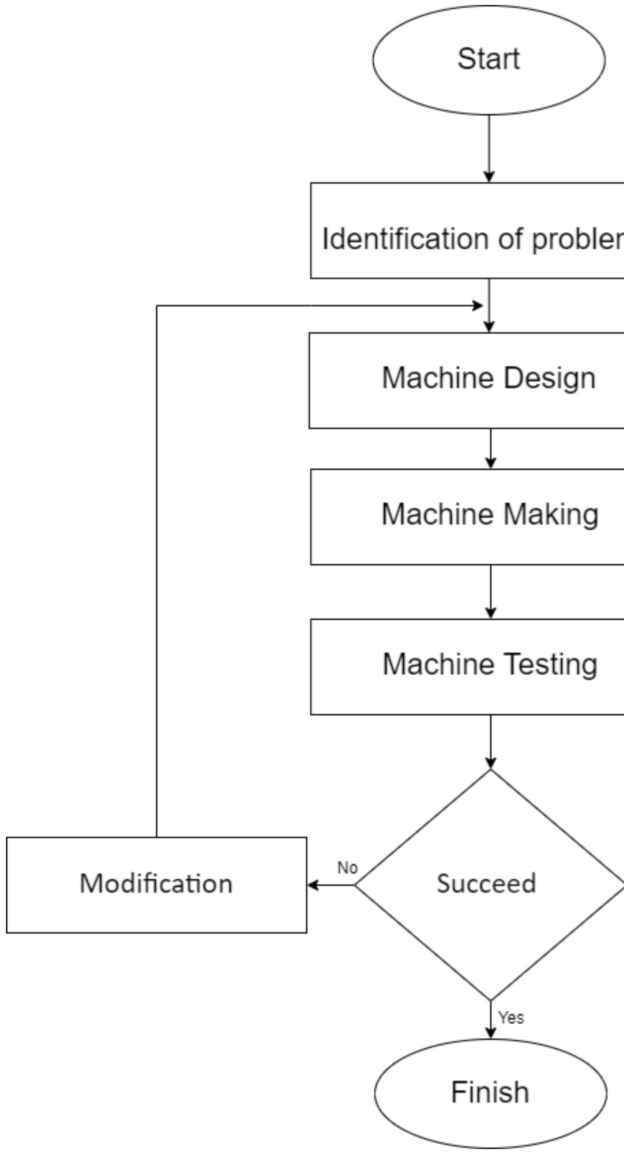

Figure 3. Flow chart for making a duck egg incubator with an automatic system.

2.3 Analysis of Structural and Functional Design

A prototype design for an automatic duck egg incubator machine was adapted to its function, namely, incubating and hatching duck eggs. Temperature, humidity, and egg turning are controlled automatically so that the component design, material selection, and strength are adjusted to the function. The results of the structural and functional design analyses are as follows.

Table 1. Structural and functional design

No.	Selected components	Structural design	Functional design
1	Portable egg rack	Size 800 x 1000 x 1600 mm. The main frame is made of ST32 hollow iron measuring 40 x 40 mm	Lays 5000 duck eggs, easy to put in and take out of the incubation room
2	Egg rack drive source actuator	Single phase AC motor, 60 W	Move the shelf up and down, maximum 30 degrees
3	Incubation room	Size 1200 x 2400 x 2600 mm, galvalum material coated with cork	A place for incubating duck eggs
4	Hatching room	Size 1200 x 2400 x 2600 mm, galvalum material coated with cork	Place for hatching duck eggs
5.	Temperature and humidity sensor	Sensor DHT-22	Sensors for measuring temperature and humidity. The unit of temperature is degrees Celsius (^{o}C) and the unit of humidity is percent (%)
6	Control unit	Microcontroler arduino uno	The Arduino Uno microcontroller functions to control the LPG lighter, water pump and exhaust fan
7	Water pump	Single phase AC motor, 120 W	To pump water from the tub to the sprayer
8	Heating Source	LPG, blender, automatic lighter	To heat the incubation room and hatching room

2.4 Model Evaluation

In the temperature and humidity control process, the temperature and humidity inputs are regulated according to the temperature and humidity controller. If the temperature and humidity are not suitable, it will be managed by an Arduino to turn on or turn off the LPG, exhaust fan, and water pump. A diagram of the control unit is shown in Figure 4.

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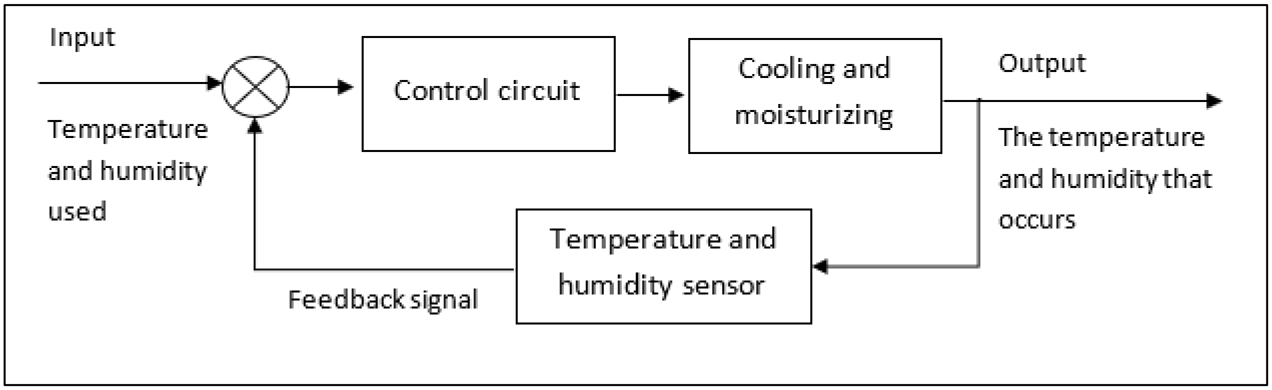

Figure 4. Diagram of the temperature and humidity control unit

2.5 Framework Strength Analysis

Analysis of the strength of the frame for egg racks using hollow iron squares ST 32, dimensions 40 x 40 x 1.6 mm with material allowable stress σ = 620.44 N/mm2

The weight of the egg and frame is 516 N; therefore, the amount of tensile stress that occurs in the four vertical column frames is:

$$F = \frac{516}{4} = 129 \text{ N} \quad (1)$$

Maximum span 1000 mm, then Mmax = 129 x 500 = 64500 Nmm.

The moment of inertia was.

I = (b4 - h4)/12 = (404 - 324)/12 = 125952 mm^4

Center of gravity distance

Y = b/2 = 40/2 = 20

The tensile stress in the frame is:

Σ = (Mmax x Y)/I = (64500 x 20)/125952 = 10,24 N/mm^2

The stress that occurred was still smaller than the allowable stress.

2.6 Hatching Machine Testing

The test methods for automatic system duck egg incubators include the following:

1. Structural and functional tests
2. Test temperature and humidity distribution
3. Test the resulting hatchability

3. Result and Discussion

The designed and manufactured duck egg incubator system is shown in Figure 5.

Figure 5. Prototype of an automatic duck egg incubator

The duck egg incubator with an automatic system had the following specifications:

1. Dimensions (L x W x H): 2400 x 2400 x 2600 mm
2. Sensors: Sensor DHT-22
3. Egg capacity: 5000 eggs
4. Exhaust fan: 125 watts
5. Actuator: Motor AC 1 phase, 60 watts
6. Heat source: LPG stove
7. Water pump: Motor AC 1 phase, 125 watts
8. Material: iron, galvalum, isolator
9. Actual weight: 280 kg

3.1 Machine Performance Testing

The structural test results showed that all components were strong and sturdy, whereas the functional tests showed that all components functioned well. In the preliminary engine testing, all components functioned well. Temperature and humidity control in the incubation and hatching rooms could be adjusted as desired.

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In testing the suitability of the tool using treatments, among others, treatments of the LPG opening percentage included LPG opening 50% and LPG opening 75%. Temperature and humidity control treatments included temperature settings of 36°C and 60% humidity, and temperature settings of 38°C and 75% humidity, and each treatment was repeated three times. The observation parameters included temperature and humidity measurements at six measurement points, which were measured at certain time intervals.

The results of the temperature measurement data show that the amount of ignition influences the speed of increase at room temperature, as shown in Figure 6, Table 2, Table 3, Figure 7, and Table 4.

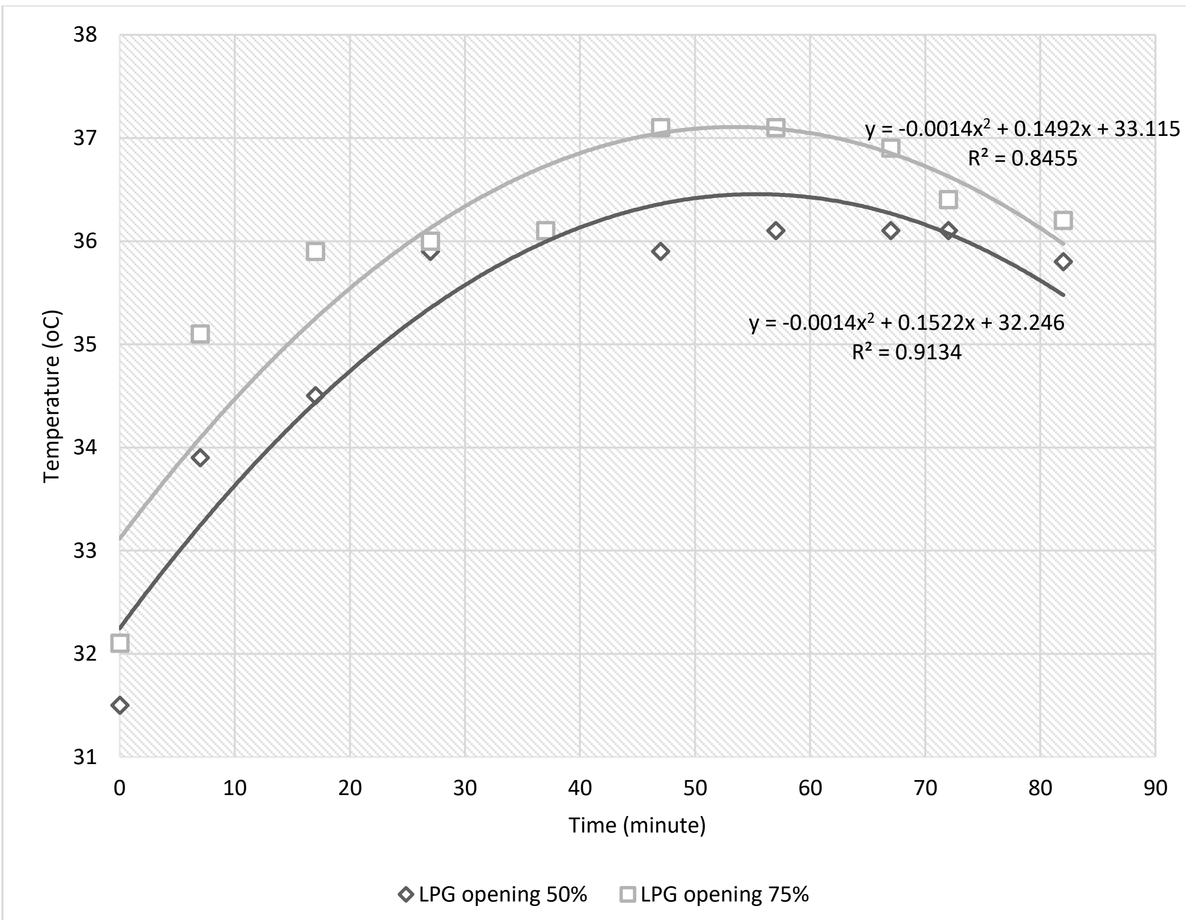

Figure 6. Graphic of temperature data at a temperature setting of 36°C in the incubation room (R_1)

Table 2. Temperature data for a certain period and the influence of the amount of LPG ignition on setting a temperature of 36°C and humidity of 60% in the incubation room (R1).

Observation period (minute)	Temperature (°C)		Humidity (%)	
	LPG opening 50%	LPG opening 75%	LPG opening 50%	LPG opening 75%
0	31.5	32.1	78	78
7	33.9	35.1	71	71
17	34.5	35.9	64	64
27	35.9	36	64	64
37	36.1	36.1	66	65
47	35.9	37.1	66	64
57	36.1	37.1	65	65
67	36.1	36.9	64	63
72	36.1	36.4	63	63
82	35.8	36.2	64	64

Table 3. Temperature data for a certain time period and the influence of the amount of LPG ignition when setting a temperature of 38°C and humidity of 75% in the hatching room (R_2)

Observation period (minute)	Temperature (°C)		Humidity (%)	
	LPG opening 50%	LPG opening 75%	LPG opening 50%	LPG opening 75%
0	31.5	31.5	79	79
7	33.9	33.9	74	74
17	34.6	35	74	74
27	35.8	36	73	73
37	36.1	37.8	74	75
47	36.4	38.1	75	76
57	37.1	39.1	72	71
67	38	37	73	72
72	38.5	37.6	73	72
82	38	38.2	75	74

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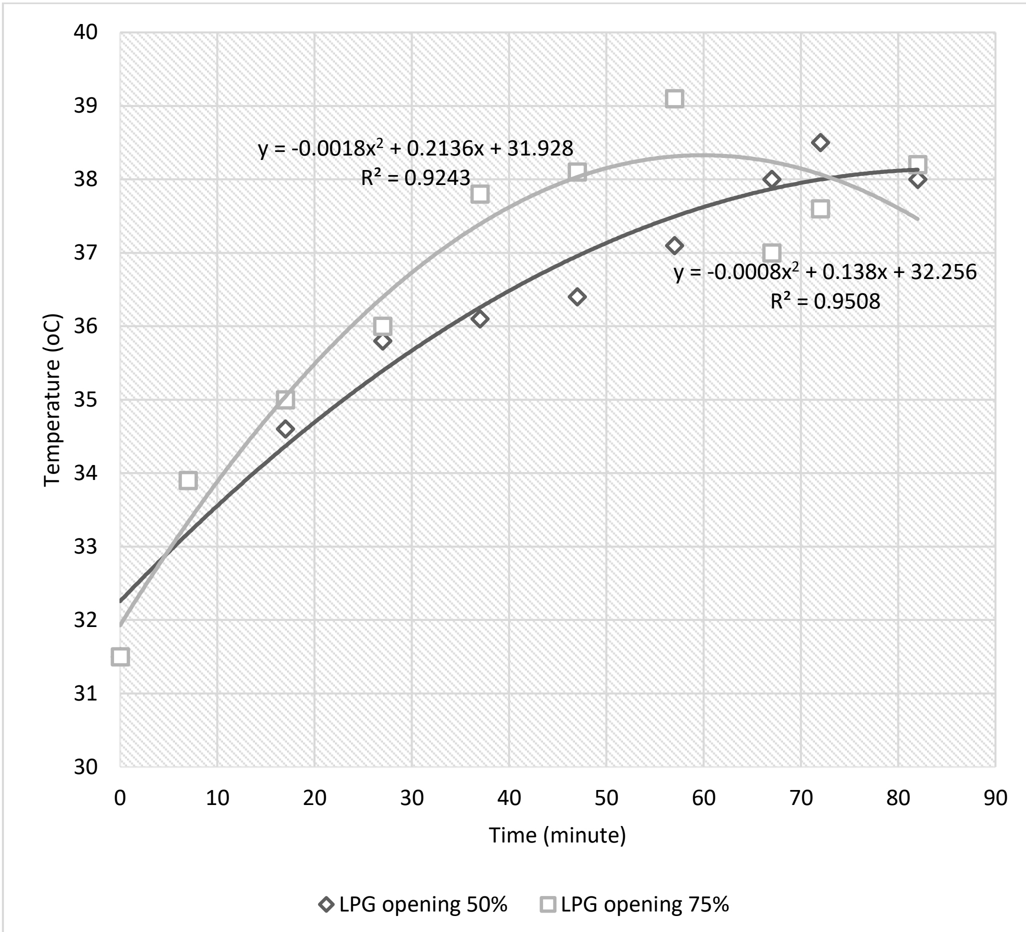

Figure 7. Graphic of temperature data at a temperature setting of 38°C in the hatching room (R_2)

3.2 Hatchability Test

Based on the data in Table 2, it can be seen that when using medium heat and setting a temperature of 36°C, the room temperature reached according to the setting temperature was 37 min, whereas when using a fairly large fire, the room temperature was reached according to the setting temperature of 27 min. Many mistakes occur in small industries when setting a large ignition on LPG because they want to quickly reach a room temperature that matches the setting temperature, even though sensor readings take time, resulting in heat accumulation and greater temperature fluctuations, which cause frequent overheating. This causes hatchability to be less than optimal, and even causes many failures. As can be seen in the data from minutes 37 to 82, the room temperature tends to be higher, although the air humidity slightly decreases owing to evaporation. Figure 6 also shows that the use of a rather large fire has a smaller R2 value or data fluctuations are greater. Room humidity data were obtained in accordance with the required range.

Tabel 4. Results of duck egg hatchability using an automatic system duck egg incubator at a temperature of 36°C, humidity 70% on days 1 - 20, and a temperature of 38°C, humidity 80% on days 21-28 to use LPG gas valve openings of 50%

Observation	Initial number of eggs	Number of eggs hatched	Hatchability (%)
1	5,000	4,098	81,96
2	5,000	4,100	82
3	5,000	4,102	82,04

The data in Table 3 also show the same trend: when using a medium fire and setting a temperature of 38°C, the room temperature is reached according to the setting temperature of 67 min, while when using a fairly large fire, the room temperature is reached according to the setting temperature of 47 min, and the temperature trend tends to fluctuate more. This can also be observed in Figure 7, which shows that the use of a relatively large fire has a smaller R2 value. Room humidity data were obtained in accordance with the required range.

Table 4 shows that the duck egg incubator with an automatic system produces a hatchability of 82% to use LPG gas valve openings of 50%, This automatic system duck egg incubator has better performance than similar automatic system egg incubators, the incubator (Hartono et al., 2017) produces a hatchability of 75%, the hatching machine (Sugara et al., 2023) has a hatchability of 65%.

4. Conclusion

The automatic duck egg incubator machine that has been made has a strong construction, functions well, and has a capacity of 5000 eggs. Temperature and humidity can be adjusted according to the requirements because it is equipped with sensors, an LPG heating source, an exhaust fan, a water pump, and a sprayer. Feasibility testing showed that this incubator produced 82% hatchability. Duck egg incubators with automatic systems are more efficient because temperature and humidity controls are achieved with sensors. This machine contained domestic ingredients 100%. When using an LPG heating source, it is recommended to use an LPG opening of 50%, so that there are no excessively large temperature fluctuations that can reduce the success of hatching or even.

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