Design and Fabrication of an Automatic Egg Incubator with Controls

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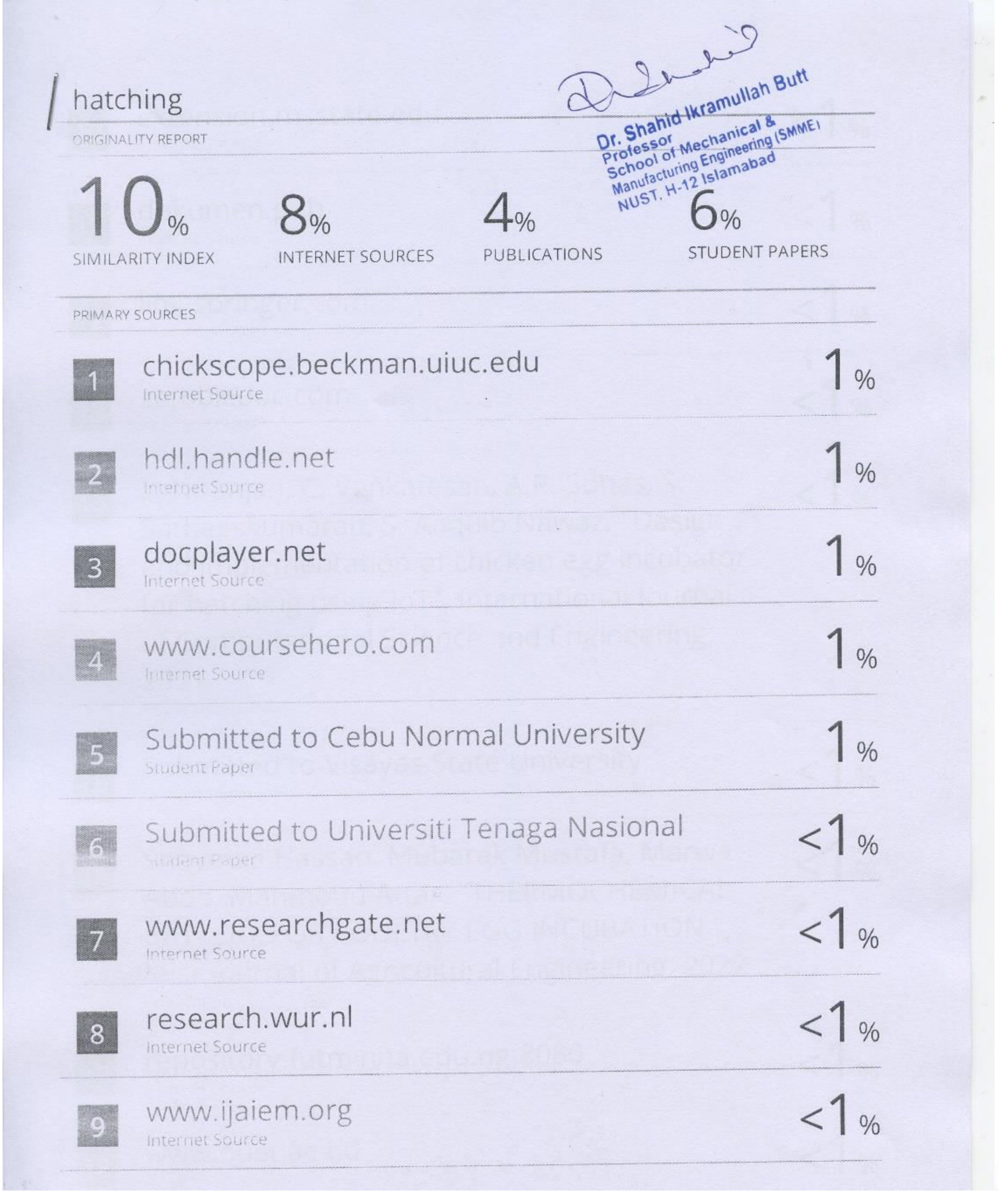

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Abstract

Poultry egg incubation is an essential step in meeting the growing demand for poultry meat. However, maintaining ideal incubation conditions can be challenging due to variations in environmental parameters, particularly in small-scale setups that struggle to regulate temperature effectively. Large-scale operations tend to use air conditioning to maintain consistent hatch rates, but this approach adds considerable costs.

The aim is to develop an economical and efficient incubator that adapts to variation in ambient temperature. TRIAC (Triode for Alternating Current) along with a temperature sensor outside the incubator is used to regulate the heat source with variation in ambient temperature. It is designed with two separate compartments, one for incubating eggs where temperature and humidity are maintained at 38 ºC and 60% respectively and the other for generating heat and moisture. This design minimizes hot and cold spots, monitored by deploying temperature sensors in each of the three layers holding 116 eggs. Two 4" fans are used to distribute heat and moisture generated through a PTC heater and an ultrasonic humidifier, respectively, while one 4" fan is used to dissipate heat and maintain optimum levels of CO_2 (4000 ppm) inside the incubator. The eggs are also rotated every 90 mins till the 18th day of incubation at 45 degrees to prevent the embryo from sticking to its shell and dying. Two incubation trials were conducted, and the hatch results obtained were 94.9% and 92.6%, respectively, indicating the effectiveness of the incubator in achieving consistent hatch efficiency.

The development of an economical incubator capable of adapting to variations in ambient temperature using locally sourced materials is crucial for poultry farms. The use of TRIAC, temperature sensors, and multiple fans ensures uniform heating and moisture distribution, resulting in consistent hatch efficiency. This study provides a potential solution to the challenges of maintaining ideal incubation conditions and improving hatch efficiency in poultry farms.

Keyword: *Egg Incubation, Hatch Rate, TRIAC (Triode for Alternating Current), Ambient Temperature*

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CHAPTER 1: INTRODUCTION

1.1 Background

The research is concerned with the development of an egg incubator that increases efficiency and prevents overheating during hot weather. The global demand for meat, particularly poultry meat, has been consistently rising over the past several decades, reaching 310 million tons in 2015 [1]. This trend is expected to continue, with poultry meat production predicted to reach 112 million tons by 2022 [2] leading to the need of increasing production capacity.

Hatcheries play a critical role in increasing production capacity, as they can hatch large numbers of eggs at a time, maximizing the efficiency of egg incubation. However, achieving high hatchability rates is dependent on maintaining optimal incubation conditions, including temperature, humidity, rotation of eggs, and air intake [3]. Poor control of these conditions can lead to poor hatchability rates, significant losses of time, money, and energy, as well as increased risk of spreading infections and diseases [4].

The first 24 hours after hatching are especially critical, as the health of the chick during this time can significantly impact its overall viability [5]. Ensuring optimal incubation conditions, particularly temperature and humidity, is crucial to maximizing the success rate of egg incubation and ensuring the healthy development of chicks [6]. The key component of this research is the use of TRIAC-controlled heating systems and temperature and humidity sensors to adjust the heating and ventilation systems accordingly, which can prevent overheating while maintaining the optimal conditions during the incubation process.

1.2 Problem Statement

The efficiency and effectiveness of incubators are essential for maximizing the success rate of egg incubation. However, traditional incubators often struggle to maintain consistent efficiencies, particularly in the face of fluctuations in ambient temperature. During summer, for example, incubators may overheat due to a decrease in heat requirements, leading to poor hatch rates. Hatcheries often resort to using air conditioning to maintain a constant external temperature, but this solution is costly and may not be practical for all users. Additionally, traditional incubators do not adequately regulate CO_2 levels, which is an important factor in maximizing fertility and hatch rates.

The goal is to design an incubator that can re-adjust itself to variations in ambient temperature and efficiently regulate CO_2 levels to optimize fertility and hatch rates. We aim to create an incubator that is both economical and efficient, capable of consistently producing high hatch rates without relying on air conditioning or other costly measures by addressing the issues of temperature fluctuations and CO_2 regulation, we hope to significantly improve the efficiency and effectiveness of incubators and ultimately increase the success rate of egg incubation.

1.3 Aim & Objectives:

The primary focus is to improve commercially available incubators in terms of production rate and energy efficiency. This will be achieved through the utilization of sophisticated control systems that employ ambient/environmental monitoring to determine the appropriate levels of heat source intensity, ventilation rate, and moisture adjustment.

The objectives are as follows:

- To **Design** an efficient incubator that can maintain optimal conditions for embryo development at varying temperature, humidity, and CO_2 concentrations, ensuring there are no cold spots in the incubator.

- To **Implement** an advanced control system that takes ambient conditions into account and adjusts the heat source, moisture rate, and ventilation as needed to maintain optimal incubation conditions.

- To **Fabricate** an economical incubator using locally sourced materials and provide a blueprint for manufacturers while ensuring it provides uniform temperature distribution.

- To **Monitor** the hatching of eggs in an optimal environment to evaluate the effectiveness of the incubator, including the uniformity of temperature throughout the incubator.

This will ensure that the design can provide optimal conditions for all the eggs, regardless of their position within the incubator. This will further improve the hatching rates and success rate of egg incubation.

CHAPTER 2: LITERATURE REVIEW

Incubation can be defined as handling fertilized eggs providing a healthy environment for the growth of embryo inside the egg until the egg hatches [7]. A healthy environment for the embryo to develop is where it receives proper warmth and is supplied with a fresh supply of air. The supply can be natural or artificial. The natural air supply is much like a bird sitting on the eggs it laid and is for a relatively smaller number of eggs. In an artificial incubator temperature, humidity and the supply of fresh air must be controlled along with the proper rotation of eggs so that the temperature of an egg is uniform throughout. The temperature for the first 18 days must be around 37.5 ºC to 39 ºC with a relative humidity of 60% [7]. In the later three days, the humidity increased up to 70% [8].

The storage temperature should be above 12.5 ºC at which embryonic development is arrested. The relative humidity should not be less than 80% to prevent dehydration of the eggs. If the storage temperature is too low (-2 ºC) the blastoderm may freeze [8]. The eggs selected should be of normal shape, a minimum of 56.7 g in weight, with good shell texture, and free from faults.

2.1 Care for Hatching Eggs

To properly care for eggs, it is important to keep the nest clean and dry. Collect the eggs early in the morning and frequently throughout the day to prevent temperature fluctuations. Eggs should not be washed unless necessary, and if they must be washed, use a damp cloth with water that is warmer than the egg to prevent bacteria from entering through the pores. Be sure the eggs are dry before storing and never store damp or wet eggs in a Styrofoam carton. Eggs should be stored at a temperature between 12.78-15.56 °C and humidity between 70-75%. Eggs should not be stored in temperatures above 23.8 °C or humidity below 40%, as these conditions can significantly decrease hatchability [9]. To maintain fertility, eggs should be turned and stored small end down at a 30–45-degree angle and should not be stored for more than 10-14 days [9]. Before setting eggs for incubation, they should be brought to room temperature and any cracked eggs should be removed.

2.2 Incubators

Types of incubators based on the flow of air.

- Still-air incubator
- Forced air incubator.

2.2.1 Still-Air Incubator

A still-air incubator consists of a box or container with the appropriate dimensions (30.50cm *30.5cm *40.5cm) [10]. There is a 0.95cm inlet at each end between the level of the eggs and the water pan, two outlets of 0.95cm in size are provided by pushing tape over half of the hole to restrict the rate of air flow. The heat source is provided using a light bulb and connected to the thermostat in series for the control of the temperature. Humidity is supplied from a part half the size on the floor area placed at the bottom of the incubator as shown in Figure 2.1, when the eggs have hatched the type placed over half of the hole is removed to increase the flow or air it common. Still-air incubators are used incubators with relatively less egg capacity compared to force air

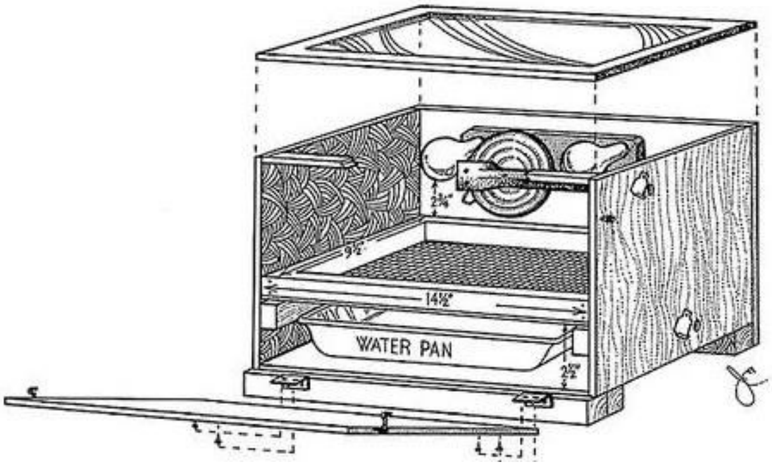


Figure 2.2: Exploded View of Still-Air Incubator [10].

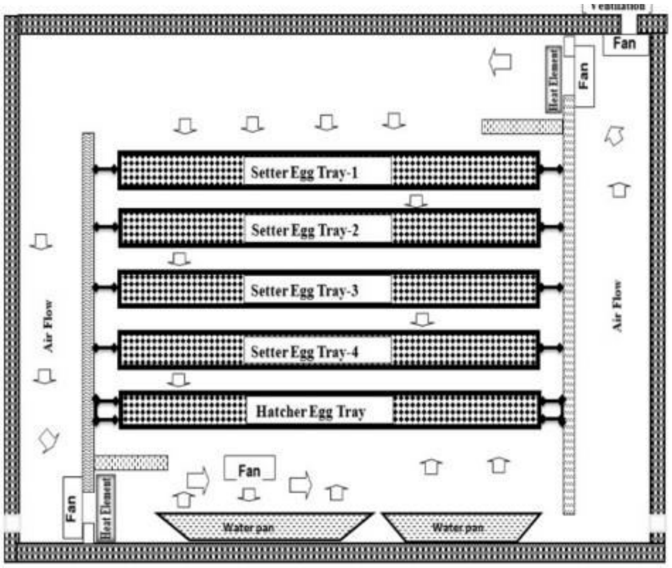


Figure 2.1: Forced Air Incubator [11]

incubators and they are not manufactured in the market as they are not feasible for business purposes.

2.2.2 Forced air incubator:

This type of incubator has fans that circulate the air in the incubator and around the eggs; the effect of forced air is to ensure air incubating temperature which varies from 37.56 °C to 38.00 °C and humidity which varies from 60 to 65% [11]. The only difference is the fans being installed in it as shown in Figure 2.2

2.3 Mechanics of Egg Incubator

From the bird's eye view, it seems that the eggs placed inside the chamber are completely isolated from the environment outside due to the isolation provided by the chamber itself, but this is not completely true. There exists an interaction of the environment with the inside as determined by the temperature, relative humidity, ventilation which governs the air quality, the rotation of eggs. These all contribute to the success of embryonic development. The eggs inside are not merely eggshells they are living beings and require the exchange of Carbon Dioxide CO_2, Oxygen O_2 and water [12]. The egg specifications/characteristics which include shape, size, eggshell thickness,

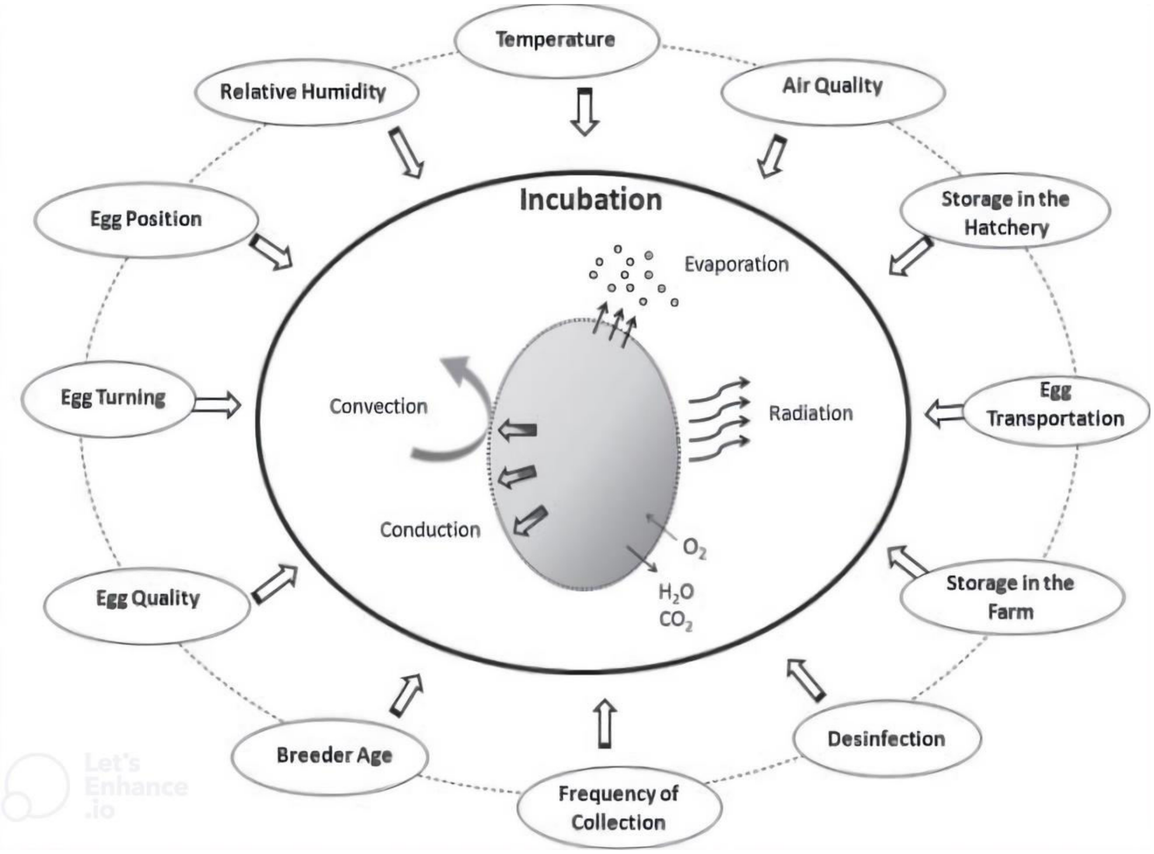


Figure 2.3: Physical Exchanges with Environment During Incubation [12].

and porosity contribute to the embryo metabolism rate and they cause deviations from the optimal set values of physical parameters as shown in Figure 2.3.

2.3.1 Conduction

Conduction is the process of heat transfer in which heat is transferred through physical contact from high temperature to low temperature. In the case of an incubator, conduction occurs from the embryo to the eggshell. The physique of an egg largely depends on the environment it is in as with the drop in temperature the egg tends to lose its weight [12]. The rate of transfer of heat inside the egg is greater than that of the eggshell and air. The factors that influence conduction are the eggs shell thickness and embryo metabolism.

2.3.2 Convection

Refers to the transfer of heat via convection currents. The hot air rising and the cooler air sinking at the bottom. Convection is determined by the air flow mechanism installed and the power of the heat source being used [12]. The better convection there is within the chamber the better the chances there are no cold spots either on the eggs or inside the chamber. However, the movements of air mustn’t be extreme, as the extreme movement of air will cause the loss of heat by eggshell which will be fatal in ovo-development. The settings must be optimal such that it enhances the internal conditions with uniform temperature across the chamber [12].

2.3.3 Radiation

The mode of heat transfer, i.e., radiation also complements our system because the heat generated from the bulb that is used is the only heat source transferring heat through radiation. With radiation, electromagnetic waves carry energy and will help the system in building its temperature [12].

2.4 Physical Conditions for Incubators

2.4.1 Temperature

The temperature inside the incubator plays the most crucial role in the development than any other physical factors involved. It encourages the growth of the embryo and ovo-development. The temperature that is to be maintained inside the incubator is 37.5 °C (ideal temperature) [9]. The temperature range that can be set is from 37 ºC to 39 °C. Above 40.5 ºC the embryo will stop developing and will die if preciously developed and will change its state from semisolid to liquid. Below 36 ºC the embryo does not die but stops growing initially till a certain period. The more time the embryo stays below this temperature the more time it will take to hatch added to its original incubation time and may also suffer from many diseases as its immunity drop quite a bit as it must fight against the cold temperature to survive [9]. The embryo will die if it is kept for too long below 36 ºC [9]. The lesser the temperature the lesser the chances of the embryo surviving. If the temperature drops below 16 ºC there will be no chance that the embryo will survive [8].

2.4.2 Relative Humidity of Air

Relative Humidity of Air deals with the transfer of water between the eggs and the environment in which it is placed. If the relative humidity is too low the pressure on the outside will drop or so it can be said that the concentration of water on the outside compared to that of the inside of the eggshell. So, it is important to maintain the right humidity in the surroundings of the egg. During the first 18 days of incubation, the relative humidity that is to be maintained is 40% to 50% and in the last 3 days, the relative humidity is increased from 65% to 70% [14] .

2.4.3 Rotation of Eggs

The rotation of eggs mainly deals with the adhesion of eggs yolk to the shell and encourages the diffusion of gases that takes place. The rotation/turning of eggs is the natural behavior of the birds and this practice is followed in artificial incubation as well. It is critically important during the first 7 days of incubations as the distance between the embryo and the shell is large compared to that of the latter days [15]. The rotation helps the embryonic cells to release CO_2 and inhale O_2 thoroughly when rotated efficiently. The eggs need to be rotated thrice a day at least during the first 18 days of incubation. After this time period, the embryo is fully developed and is adjusting its position to get the shell cracked and find its way out and is very much able to support its metabolism and respiratory requirements as the egg is filled by the embryo [15]. The egg rotation mechanism that will be followed in this setup is the motor gear mechanism in which the eggs will be rotated after each hour 45^{o} to either side and then it will return to their mean position after each other the quarter oscillation will take place as shown in Figure 2.4.

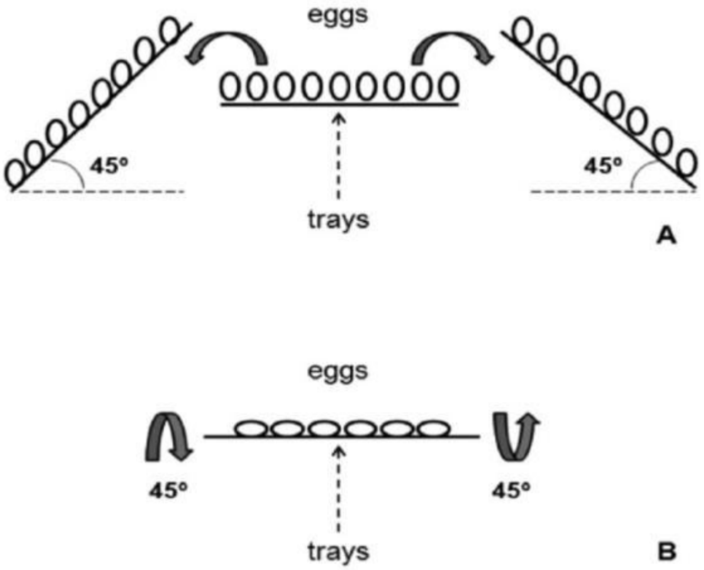


Figure 2.4: Egg Rotation Mechanism [12]

2.5 The Stages of Development of an Embryo

2.5.1 Before Egg is Laid

Soon after the releasing of the ovum from the hen's ovary funnel or infundibulum pick them up. The male sperm found in the funnel as soon as the egg is picked by it [16]. The sperms then contact the germinal disc but only one gets successful in uniting with the germ. Thus, the process of fertilization occurs before the egg is even laid.

2.5.2 Storage

The fertilized eggs must spend a day in the warmth of the hen's body i.e., 42 ºC [16]. Certain developments occur in an embryo during this process. The cell divides into two after the fertilization in a germinal disc. The cell then further divides into four, eight sixteen and more until white spots are visible on the upper surface of the yolk. The temperature falls to 80 ºC as the egg is laid by the hen in the open [16]. The embryo will not be dead if the egg is being cooled at a lower temperature but if the temperature of the storage exceeds 26.67 ºC embryos will start to develop and will get weak as the temperature is very less to that of an incubator and will eventually die [16].

2.5.3 Placed in Incubator

Once the eggs are placed in the incubator many processes such as excretion, respiration, nutrition and protection still go on inside the egg until the chick hatch. There are membranes known as extraembryonic membranes outside the embryo which are responsible for carrying out all these processes. The membranes include chorion, allantois, amnion, and yolk sac [17]. The tissue which is growing on the yolk's surface is called the yolk sac. For the digestion n and absorption of yolk, a special tissue yolk sac lines the wall of the egg. The amnion is a sac that is transparent filled with a colorless fluid [17]. The amnion and amniotic fluid as shown in Figure 2.5 protects the embryo inside the egg from mechanical shocks and allows it to move. Allantois are responsible for the respiration as it carries blood vessels for colorless oxygen and removing carbon dioxide from the system. It stops functioning as soon as the chick punctures it and starts breathing on its own [17].

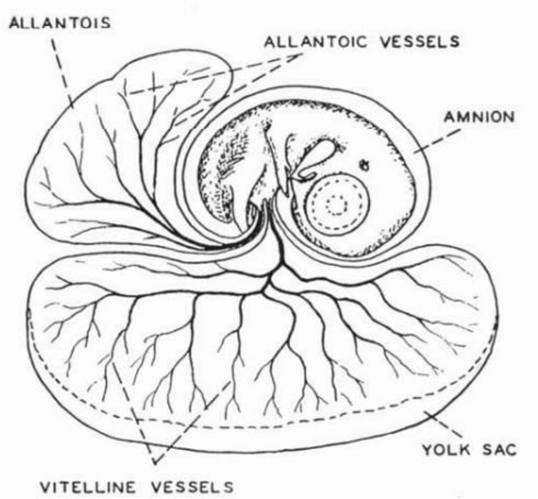


Figure 2.5: Embryo Inside an Egg During Incubation [17].

The stages of embryonic development are listed in Figure 2.6 and Fig 2.7 below and Table 2.1 shows the timeline of ovo-development. These developments cannot be seen with the naked eye but by breaking the egg and observing the development. Candling can also be used to determine the growth of an embryo from the outside. It is advised not to touch or rotate eggs after the 18th day, as the embryo settles and takes its position from where it will puncture the egg and will be independent [16]. If the eggs are rotated, the embryo will then again take its time to adjust to a position it seems suitable. If it punctures the egg from the bottom side, the eggs will have to be rotated so it has an adequate supply of oxygen or else it will die [16].

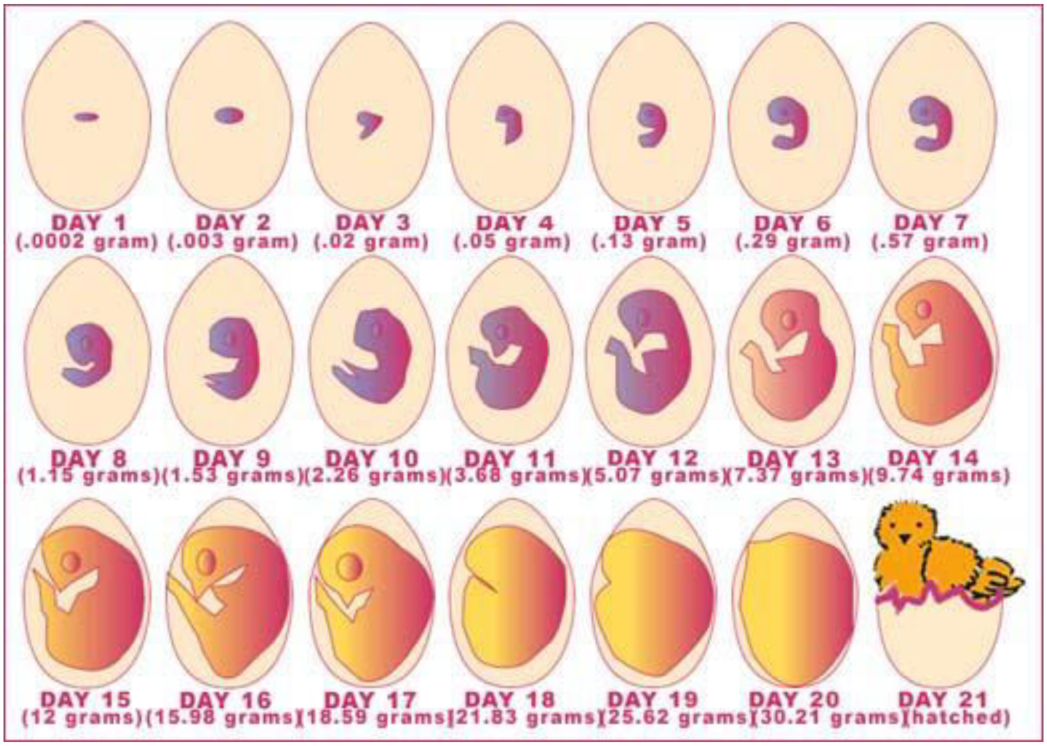


Figure 2.6: Development of Embryo Inside an Egg in a 21-day Incubation Cycle [16].

Table 2-1: Incubation Timeline [18].

BEFORE EGG LAYING

Fertilization

Division and growth of living cells

Segregation of cells into groups of special function

BETWEEN LAYING AND INCUBATION

No growth; stage of inactive embryonic life

DURING INCUBATION

FIRST DAY:

FIFTH DAY:

Beginning of formation of reproductive organs and differentiation of sex

SIXTH DAY:

Beginning of formation of beak and egg tooth

EIGHTH DAY:

Beginning of formation of feathers

TENTH DAY:

Beginning of hardening of beak

THIRTEENTH DAY:

Appearance of scales and claws

16 hours - First sign of resemblance to a chick embryo

18 hours - Appearance of alimentary tract

20 hours - Appearance of vertebral column

21 hours - Beginning of formation of nervous system.

22 hours - Beginning of formation of head.

23 hours - Appearance of blood islands - vitelline circulation

24 hours - Beginning of formation of eye.

SECOND DAY:

23 hours - Beginning of formation of heart.

35 hours - Beginning of formation of ear.

42 hours - Heart begins to beat.

THIRD DAY:

50 hours - Beginning of formation of amnion.

60 hours - Beginning of formation of nose.

62 hours - Beginning of formation of legs.

64 hours - Beginning of formation of wings.

70 hours - Beginning of formation of allantois.

FOURTH DAY:

Beginning of formation of tongue

FOURTEENTH DAY:

Embryo turns its head toward the blunt end of egg.

SIXTEENTH DAY:

Scales, claws, and beak becoming firm and horny.

SEVENTEENTH DAY:

Beak turns toward air cell.

NINETEENTH DAY:

Yolk sac begins to enter body cavity.

TWENTIETH DAY:

Yolk sac completely drawn into body cavity; embryo occupies practically all the space within the egg except the air cell.

TWENTY-FIRST DAY:

Hatching of chick

2.5.4 Taking Care of Hatched Chick

The chick is very tied once it frees itself from the shell and must not be disturbed. It takes about 6 hours to completely dry. No food or water is provided to the chick during its first day and it will remain in the incubator for the given day. Once 24 hours are completed, the hatched chicks will be shifted to the brooder where they will have a fresh supply of food and water and a healthy environment where they can spend their next 7 days before they are released in the open [16].

2.6 Candling of Eggs

Egg candling is the process through which the development of an embryo can be seen. This is a simple process that requires a significantly dark room and a bright flash. As the shell is opaque and lets the light pass through it helps to visualize the embryo inside. The fascinating movement of the chick within its heart beating and its limbs moving. It can be deduced through this method whether the embryo is alive or dead and can also predict the exact age or phase of development with the aid of Figure 2.7. It is suggested to not move or touch the eggs after the 18th day of incubation as the embryo is placing itself to hatch and moving it from its place can seriously hurt it.

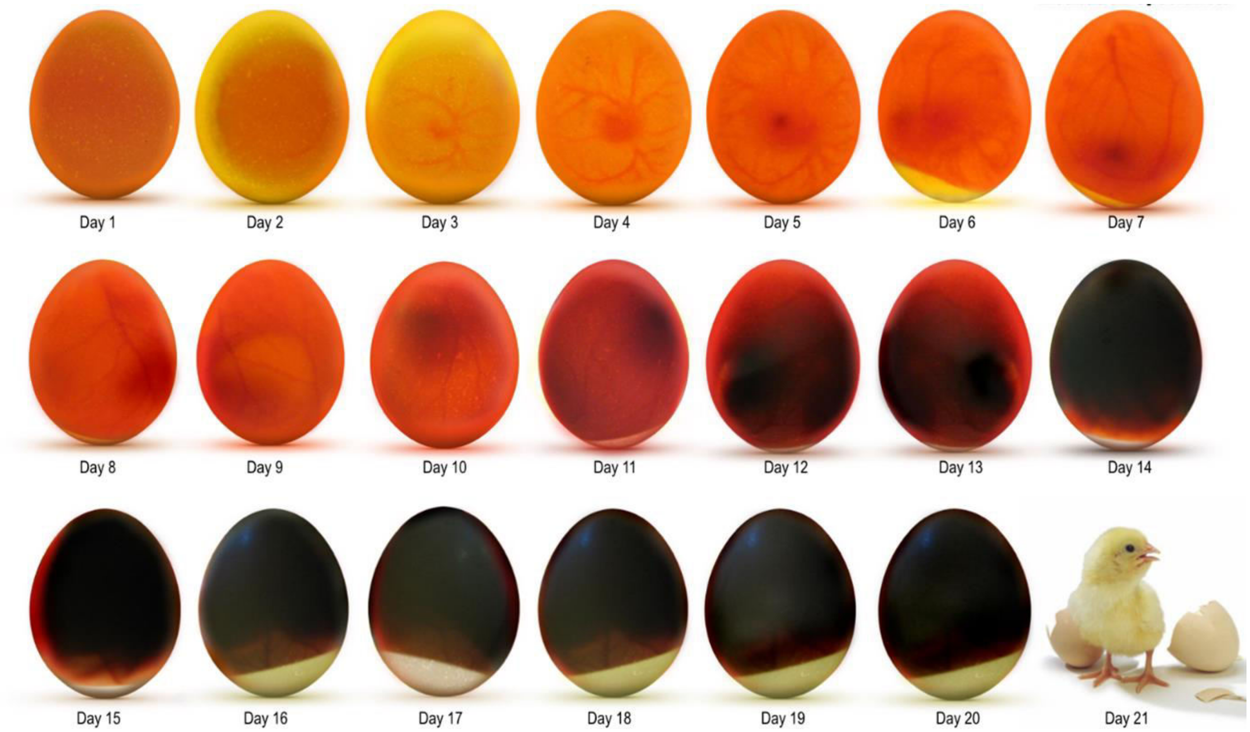


Figure 2.7: Candling Results for Incubated During Egg Incubation [17].

2.7 Parts of an Egg Incubator

The first process required is the construction of the main chamber where the eggs will be kept for 21 days. Chamber is the most vital part of the incubator as it will contain all the eggs and accessories that are to be installed. The selection of material is very important for its development to maintain the required parameters such as temperature, humidity, and ventilation. The design of the chamber should be simple so it can be easily cleaned to avoid death in shell chicks and respiratory diseases in chicks as soon as they hatch. The walls of the chamber will have three layers. The inside of the chamber is made of stainless steel with glass wool padding and the exterior is made of rigid PVC sheets. Stainless- steel sheets will help keep the temperature difference as minimal as possible between the farthest end being a good conductor while on the other hand glass wool padding will minimize the heat dissipation on the outside. On the outside plywood sheets will be used to provide it with an attractive look. PVC being an insulator will also aid glass wool sheets in decreasing rate of heat dissipation.

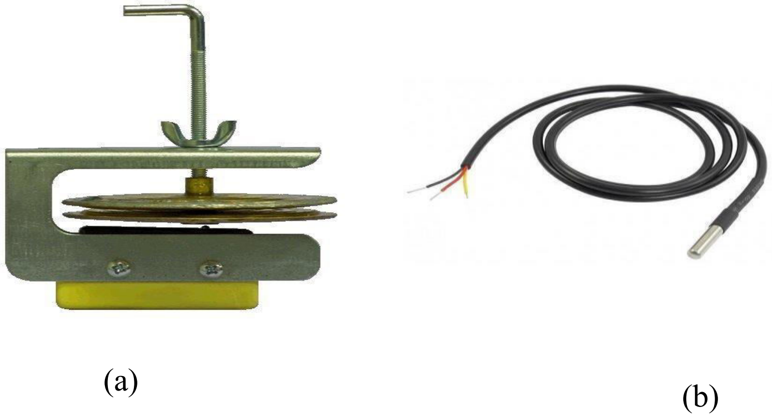
2.7.1 Sensors

There are two types of sensors that are available in the market which can be classified into two types i.e., mechanical sensors and electronic sensors.

2.7.1.1 Thermostat

To control the temperature inside the chamber using either a wafer thermostat or electronic thermostat. The Wafer thermostat Figure 2.8(a) expands and contracts with the variation in temperature inside the chamber. At the required temperature, the wafer expands and gets in contact with the metal tip completing the circuit and shutting off the electric heat source.

An electronic thermostat (DS18B20) shown in Figure 2.8(b) is more sensitive and easier to use but it senses the temperature of a point inside a chamber while a wafer thermostat takes into consideration the temperature of the whole chamber.



(a)

(b)

Figure 2.8: (a) Silicon-Wafer Thermostat (b) DS18B20 Electronic Thermostat

2.7.1.2 Hygrometer

A hygrometer is built inside the thermostat module to govern the humidity within the chamber. A digital hygrometer is illustrated in Figure 2.9. The range for relative humidity is flexible in comparison with the temperature. The boundary condition for relative humidity is 45% to 70%. As soon as the relative humidity reaches 70% the power to the heat source is cut off.

Figure 2.9: Hygrometer DHT-21

2.7.1.3 Ultrasonic Humidifier

Humidity fire is used to create moisture inside the chamber. It is placed inside the water container at the bottom of the chamber. Humidity fire heats up and converts water into vapors. As soon as the water dries inside the water container the sensors turn it off automatically, so no damage is sustained by it. Figure 2.10 shows an ultrasonic humidifier.

Figure 2.10: Ultrasonic Humidifier

2.7.1.4 Rotating Mechanism

This is the part that differentiates automatic incubators from semi-automatic incubators. It becomes an impossible task to rotate hundreds of eggs thrice a day. It will not only drop the temperature as the door is opened to rotate eggs and will surely take a lot of effort. Rotating eggs 3 times daily is only the minimum requirement. For the incubator to be more productive the eggs rotate every hour at 45^0 to the right and the left. To do that install a dc motor to rotate the stacked trays. A timer module will be used alongside it to limit the rotation and rotation interval. Refer to Figure 2.4 to visualize the rotating mechanisms.

2.7.1.5 Ventilation Fans

Ventilation is a very important aspect that needs to be watched and examined carefully in this project. A hole is needed to be drilled with a fan installed that will provide fresh air in the chamber while on the other hand smalls fans will be needed to circulate that fresh air inside the chamber and to maintain a constant temperature with the aid of convection.

2.8 Troubleshooting

The troubleshooting techniques are as follows determined based on the condition of the embryo, shell thickness, dead in shell conditions etc. These conditions aid in identifications of the parameters or problems faced in the system as shown in Table 2.2.

Table 2-2: Troubleshooting Failures in Egg Incubation [18].

Symptoms	Possible Causes	Solving Methods
Eggs with no structure developed inside i.e., without any embryonic development (i.e., infertile)	Eggs put in storage for very long or incorrectly	Store eggs at around 10 ºC to 15.56 ºC and keep the relative humidity to 0.60. Put eggs in an incubator within seven days of laying.
Circular patterns made of blood	Storage not proper	Follow preferred egg storage and gathering practices.
	Temperatures of incubator not proper	Test thermometer accuracy and other functions of the

		incubator. Follow preferred temperature settings.
	Breeder nutrition not proper	Give breeders a diet that has nutritive levels that are balanced.
Several embryos dying during the initial stages	Temperatures of the incubator (generally very high)	Set temperatures within the prescribed range.
	Eggs are not turned properly	Ensure turning three times every day.
	Airing not proper	Make ventilation system better, inside the room also. Prevent drafts. Provide oxygen if altitudes are higher.
Eggs pipping and dying unhatched	Moisture not sufficient	Raise ventilation rate in incubator and room, however, prevent drafts.
	Ventilation not proper	Raise ventilation rate in incubator and room, however, prevent drafts.
	Eggs setting causing mispositioned embryos	Set eggs with a pointy end down. Ensure turning of eggs but not within 3 days of hatching.
Premature hatching (bloody navels may be visible)	High temperatures inside the incubator	Keep temperatures within the right range. Check machine for proper function. Prevent any surge in electricity.
	Improper egg storage	Keep the temperature around 10 ºC to 15.56 ºC and the relative humidity to 0.60.

		Ensure the rotation of eggs three times every day.
Belated hatching or non-uniform	Low temperatures inside an incubator	Keep temperatures within the right range.
	Too hot and/or cold zones in the incubator because of incorrect design	Change the incubator design.
	Eggs being too old and/or not stored properly	Collect eggs more often, cool off at once. Ensure proper storage of eggs. Avoid storing for more than seven days
Embryos sticking (embryos may be smeared with egg contents)	Humidity too high	Keep humidity within the recommended range.
	Low temperatures in an incubator	Keep temperature settings according to the recommendation.
	Poor/insufficient ventilation	Improve ventilation rate in incubator and room, while avoiding any drafts.
Embryos sticking to the shell	Too low humidity (especially during hatching)	Raise humidity inside the machine.
	Ventilation rate too high	Lower ventilation rate while maintaining air exchange (although minimal) to avoid choking of an embryo.
Disabled and abnormally formed chicks	Temperatures not proper (usually too high)	Keep the temperature within the range.
	Humidity too low	Raise incubation humidity.

	The setting of eggs being improper; position or turning during incubation not proper	Place eggs with the pointy end facing down. Rotate eggs three times a day, however, do not rotate within three days after laying.
	Slicky trays	Use trays that have wire floors or put crinoline on the surface.
	Nutrition of breeders not being proper	Give a balanced diet to breeders.
Weak, abnormal chicks or chicks diminished in size	High temperatures inside the incubator, especially during hatching.	Keep incubation temperatures within the prescribed range
	Humidity not being sufficient	Set humidity as prescribed for species being incubated.
	Ventilation being poor	Raise the rate of ventilation, while avoiding drafts.
	Too much fumigation in hatcher frame	Reduce the effects of fumigation and fumigate properly
Large chicks having a soft mushy body; chicks dying on trays; giving off a stinky smell	Average temperature too small. Improper ventilation.	Keep incubation temperatures within the range. Raise the rate of ventilation inside the machine and room, while avoiding drafts.

CHAPTER 3: EXPERIMENTAL DESIGN AND MODELLING

3.1 Material Selection for Incubator Chamber

Following are the materials and/or components that were used for making the egg incubator.

3.1.1 Wooden Bars

Timber (wooden) bars are commonly used in the construction of incubators because wood is a readily available, renewable resource that is relatively inexpensive compared to other building materials. In addition to being inexpensive, wood is also easy to work with and can be cut, drilled, and shaped to fit a wide variety of applications. It is also a good thermal insulator , which means that it can help to maintain a consistent temperature within the incubator. To make the structure of incubator wooden bars (timber) of 2" * 2" are used.

3.1.2 Stainless-Steel Sheets:

There were numerous options available for making the inside of chamber which include stainless steel sheets (SS 304) and aluminum sheets (Al 6061). Though Aluminum has much better thermal conductivity compared to stainless-steel but stainless steel was preferred due to the following reasons.

- Durability and corrosion resistance: Stainless steel is more durable and resistant to corrosion than aluminum, which is important for the longevity of the incubator and for preventing the growth of bacteria and other harmful microorganisms.
- Consistency: Stainless steel has a higher thermal mass, meaning that it can store and release heat more slowly than aluminum. This can result in a more consistent temperature within the incubator, which is important for the health and well-being of the organisms being incubated.
- Sterilization: Stainless steel is more resistant to high heat and chemicals, making it easier to sterilize and preventing cross-contamination.
- Safety: Stainless steel is considered safer as it doesn't have potential risk of flammability as aluminum.

Gauge 22 was selected majorly because of weight and cost point of view. Gauge 22 will serve the purpose of durability and consistency in temperature. The load of eggs will primarily be on the wooden structure. Using thicker gauges will increase the weight, affecting the mobility of the incubator and will also increase the cost. The sheet will be good enough to support the weight of light and 4-inch fans which can be screwed on it.

3.1.3 Glass Wool Padding

Glass wool is a common insulation material that is often used in a variety of applications, including incubator padding. 2" thick glass wool is a commonly thickness used as it provides a good balance of insulation and ease of installation.

Using glass wool as a padding in an incubator has several benefits such as:

- Thermal insulation: Glass wool is an effective insulation material, it can help to maintain a consistent temperature within the incubator, which is important for the health and well-being of the organisms being incubated.
- Low cost: Glass wool is relatively inexpensive compared to other insulation materials, making it a cost-effective option for incubator padding.
- Lightweight: Glass wool is lightweight, which makes it easy to handle and install in tight spaces.
- Non-flammable: Glass wool is a non-flammable insulation material, which makes it safer to use in an incubator
- Sound insulation: Glass wool can provide sound insulation by reducing the transmission of sound waves.

Glass wool is preferred over Styrofoam or expanded polystyrene due to the following reasons.

- Environmental Impact: EPS is a form of plastic, and it is not biodegradable which means it takes a long time to decompose in the environment and it's not considered an environmentally friendly material.
- Offgassing: Styrofoam may emit volatile organic compounds (VOCs) which can affect air quality and potentially harm human health.
- Difficult to recycle: Styrofoam is not easy to recycle and most of it ends up in landfills.

3.1.4 PVC Exterior

The materials available for making the exterior are PVC and press board/chip board. PVC is preferred due to following reasons

- Weather resistant: PVC is more resistant to moisture and humidity than pressed board, which makes it a better option for use in outdoor or high-humidity environments.
- Durability: PVC is more durable than pressed board, it can withstand a variety of weather conditions and impacts without showing signs of wear and tear.
- Easy to clean: PVC is easier to clean and maintain than pressed board, it can be wiped down with a damp cloth to remove dirt and grime.
- UV resistant: PVC is more resistant to UV radiation than pressed board, it will not discolor or degrade over time.
- Non-flammable: PVC is non-flammable while pressed board can easily catch fire, which makes it safer to use in an incubator.
- Lightweight: PVC is generally lighter than pressed board, this can be an advantage when the incubator needs to be moved often.

3.2 Design of Main Chamber

The design of the main chamber as shown in Figure 2b is mainly dependent on the size of the egg trays. Standard PVC chicken egg tray of 88 eggs is used with dimensions 14.17" * 19.69" with thickness of 1.18" weighing 600g as shown in Figure 3.2(b) and Figure 3.1. The tray-frame to hold and rotate egg trays is constructed using L-shaped angle-iron and rectangular iron bars that are nut bolted and free to rotate. The frame has three levels, each containing two trays. The distance between each level is 8" for easy placement and monitoring of eggs. The top and bottom tray frame are welded by metallic pipes and further welded to bearings with a diameter of 2". This assembly allows for clockwise and counterclockwise rotation of eggs.

The main chamber is designed to be compact with two trays on each level and sufficient space for the motor assembly on the left side. The height of the chamber allows for the rotation of eggs at a 45-degree angle in both directions. The dimensions of the main chamber (internal) are 38.5" * 26.5" * 32" (W*D*H).

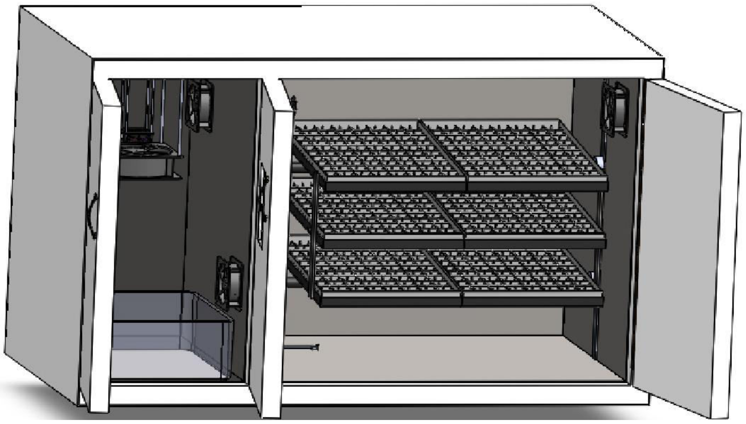


Figure 3.1: 3D Model of the Incubator

3.3 Design for Heating Chamber

The heating chamber, separated from the main chamber, consists of a PTC heater and a 10" fan for temperature control, along with a water container and ultrasonic humidifier for maintaining proper humidity levels. Two 4" fans distribute heat and moisture evenly as depicted in Figure 3.2a and Figure 3.1. The internal dimensions of the heating chamber are 16" * 26.5" * 32" (W*D*H), providing optimal conditions for embryo development and hatch rate.

Figure 3.2: (a) Heating Chamber (b) Main Chamber for Incubating Eggs

3.4 Egg Holding and Rotating Mechanism

3.4.1 Egg Trays

Egg trays are used for holding eggs during the incubation process. They are specially designed to hold and support the eggs during incubation, typically in a vertical position. Egg trays come in a variety of sizes and designs, depending on the type of egg and the incubation equipment being used.

The number of eggs that can be held in an egg tray depends on the size and design of the tray. A standard egg tray hold 88 chicken eggs. These trays are made of plastic and have slots or cups that are designed to hold and support the eggs in a stable position.

The use of egg trays are important as it allows the eggs to be stored and incubated in a safe and stable environment. This can help to prevent the eggs from being damaged or broken during incubation and increasing the hatchability rate. The trays also make it easy to move and handle the eggs during the incubation process. The size of egg tray is 14.17" * 19.69"with thickness of 1.18" weighing around 600g shown in Figure 3.3. It is readily available in market and for these standard dimensions variable slot sizes are also available to accommodate quail and duck eggs.

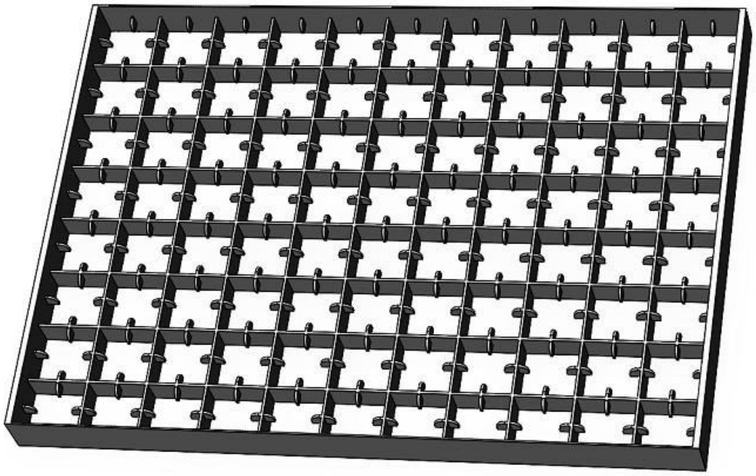


Figure 3.3: 3D Model for Egg Tray

3.4.2 Frame for Egg Tray

Egg trays in an incubator are typically held in place and made to rotate using a tray-frame that is constructed using L-shaped iron bars. The iron bars used have a size of 0.5" * 0.5" * 0.1" and are connected to a gear motor which allows the trays to rotate. This allows for even incubation and helps to prevent the eggs from sticking to one side. The tray frame has a three level design with each level containing two tray holders of size 20" * 14.3", which provide a secure and stable base for the egg trays to sit on. The tray-frame is constructed using L-shaped angle-iron, which is a strong and durable metal that can bear the weight of all the trays and eggs during operation as shown in Figure 3.4.

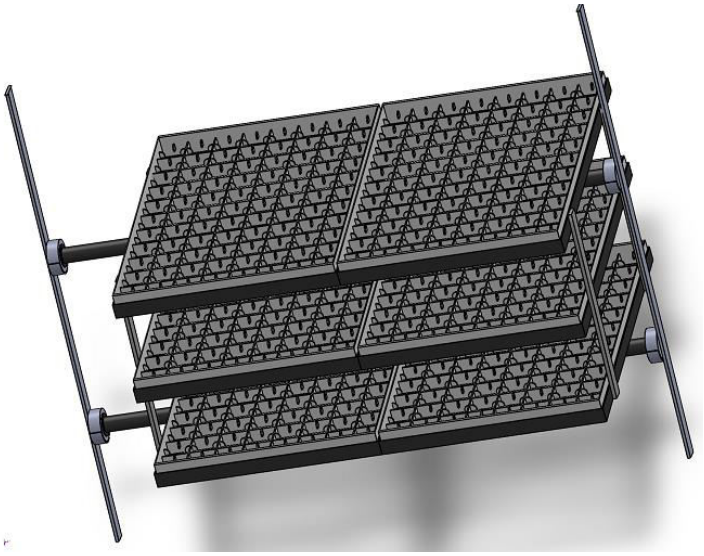


Figure 3.4: 3D Model for Egg Tray Assembly

These frames are connected by rectangular iron bars 1" * 0.1" in cross sections. The distance between the trays is kept 8" so it is easy to place the eggs in the trays and it will also help in easy monitoring of the eggs. These irons bars are nut bolted to the frame so they are free to rotate. Top and bottom trays welded by metallic pipes which is further welded to bearing 2" in diameter (external). This assemble enables the eggs to rotate clockwise and counter-clockwise. The bearing assembly is represented in Figure 3.5.

Figure 3.5:Bearing Assembly

3.5 Selection of Heat Source

To determine the exact power of the heat source required for an incubator, it is necessary to calculate the amount of energy required to raise the temperature inside the incubator, as well as the heat losses. This can be done by performing a heat load calculation, which considers factors such as the volume of the incubator, the desired temperature range, the insulation properties of the incubator, and the ambient temperature. By calculating the heat load and factoring in the heat losses, it is possible to determine the exact power of the heat source needed to maintain the desired temperature within the incubator. This will ensure that the incubator is able to maintain a consistent temperature and that the heat source is energy efficient.

3.5.1 Heat Energy Required to Maintain Temperature

It is important to calculate the amount of heat required to raise the temperature of Incubator with everything inside it to the required temperature for further analysis of selection of heat source. Heat required can be calculated using equation 3.1.

$$Q = m\, c\, \Delta T \tag{3.1}$$

The required heat energy Q is calculated by computing the product of mass (m), specific heat capacity (c) and the difference in required and ambient temperature (ΔT). The parameter ΔT is a variable quantity in each case due to which the values for heat energy are presented in graphical form.

3.5.1.1 Heat Required to Raise Air Temperature

Volume of air inside the incubator = $(16" * 26.5" * 32") + (38.5" * 26.5" * 32") = 46216\ in^3 = 0.75734455\ m^3$

Density of air at 38^0C = 1.137 kg/m^3
Mass of air in incubator = mass x volume = $0.75734455 * 1.137 = 0.861101\ kg$
Cp of air in incubator = 1.007 J/kg K
Heat required to raise the temperature of air represented in Figure 3.6 can be computed using Eq 3.1.

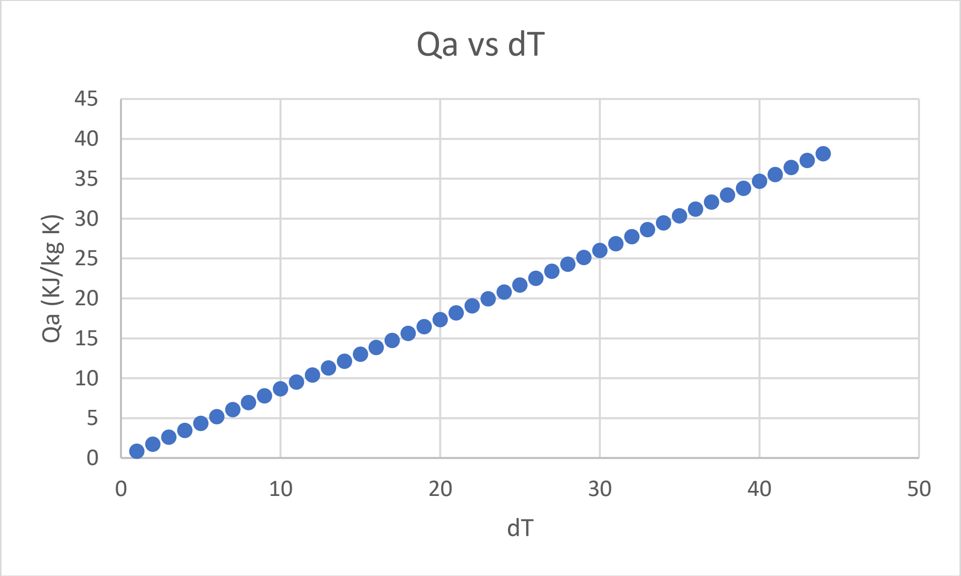


Figure 3.6: Energy Required to Raise Air Temperature to 38 ^{0}C with Difference in Temperature

3.5.1.2 Heat required to raise the temperature of Stainless-Steel Sheets (SS 304)

Area covered by stainless steels = $2(38.5 * 26.5) + 2(38.5 * 32) + 2(26.5 * 32) + 2(16 * 26.5) + 2(16 * 32) + 2(26.5 * 32) = 9768.5\ in^2 = 6.30224546\ m^2$

The thickness of the sheet is 20 gauge = 0.9 mm = 0.0009 m
Volume = 6.30224546 * 0.0009 = 0.00567202091m^3
Density of SS 304 = 7930 kg/m^3
Mass = 0. 0.00567202091 x 7930 = 44.9791258163 kg
Specific Heat = 0.5 KJ/ kg K
Heat required to raise the temperature of SS 304 Q_s is represented in Figure 3.7 calculated using Eq 3.1.

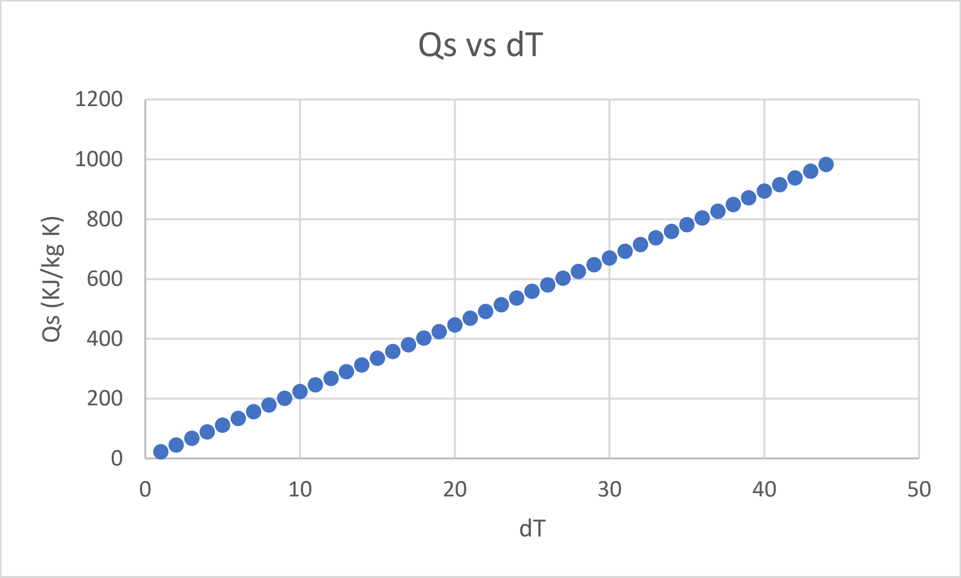


Figure 3.7: Energy Required to Raise Temperature of Stainless Steel to 38 ^{0}C with Difference in Temperature

3.5.1.3 Heat is required to raise the temperature of eggs.

Average mass of eggs = 60 g = 0.06 kg
No of eggs = 528
Total mass of eggs = 0.06 * 528 = 31.68 kg
Specific Heat of eggs = 3.182 KJ/kg K
Heat required to raise temperature for egg Q_e is presented in Figure 3.8 calculated using Eq 3.1.

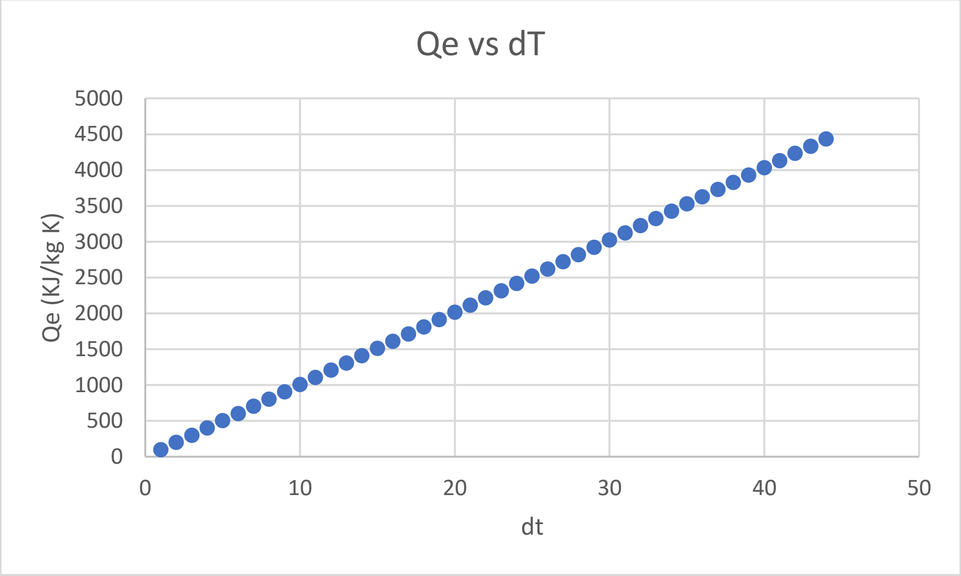


Figure 3.8: Heat Required to Raise Egg Temperature to 38 ^{0}C with Difference in Temperature

3.5.1.4 Heat required to raise temperature of egg trays.

Mass of egg trays = 600 g =0.6 kg
No of egg trays = 6
Total mass = 3.6 kg
Specific Heat of PVC = 0.84 KJ/kg K
Heat required to raise temperature of egg trays Q_{et} is shown in Figure 3.9 computed using Eq 3.1.

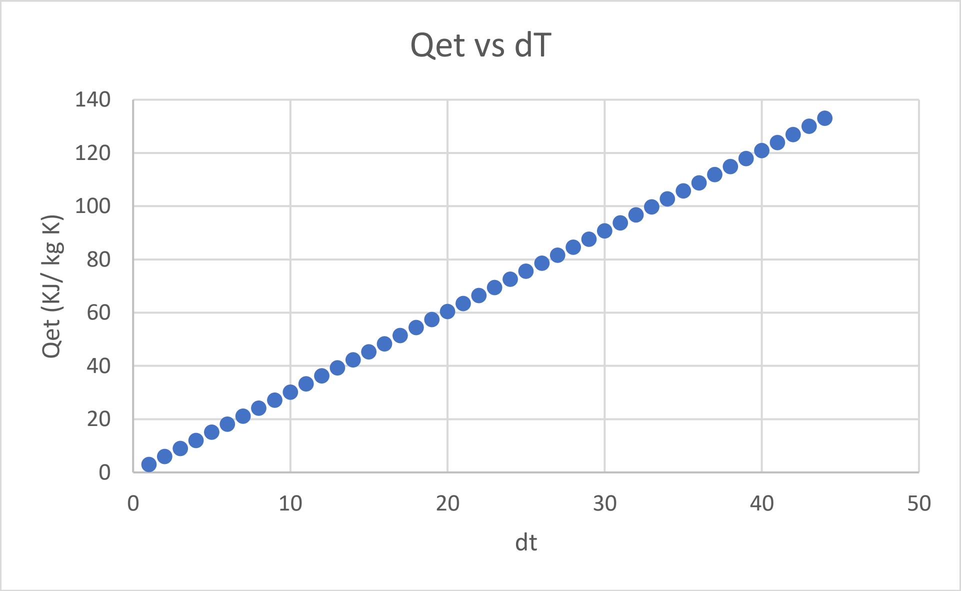


Figure 3.9: Heat Required to Raise Temperature of Egg Trays with Change in Temperature

3.5.1.5 Heat is required to raise the temperature of egg turning equipment.

Egg turning equipment includes a frame for egg trays, supporting bars and shaft for rotating.

Mass = 12.06 kg
Specific heat of mild steel = 0.42 KJ/ kg K
Heat required to raise temperature of egg turning equipment Q_{te} is shown in Figure 3.10 using Eq 3.1 to compute.

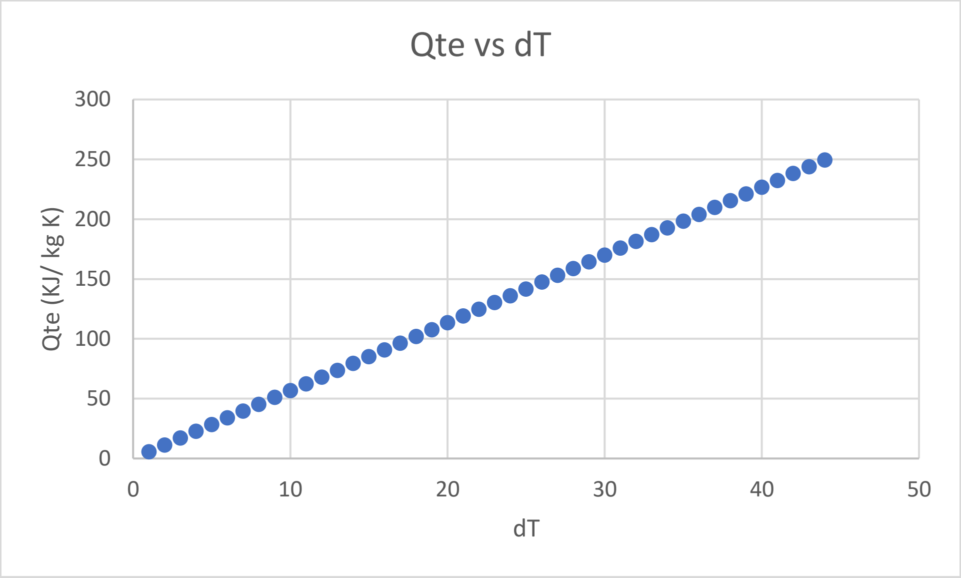


Figure 3.10: Heat Required to Raise Temperature of Turning Equipment with Change in Temperature

3.5.1.6 Heat is required to raise the temperature of water.

Volume of water container = 162.84 in^3 = 0.002668469502 m^3
Density of water = 1000 kg/m^3
Mass = 0.002668469502 * 1000= 2.67 kg
Specific heat for water = 4.187 KJ/ kg K
Heat is required to raise the temperature of water shown in Figure 3.11 computed by Eq 3.1.

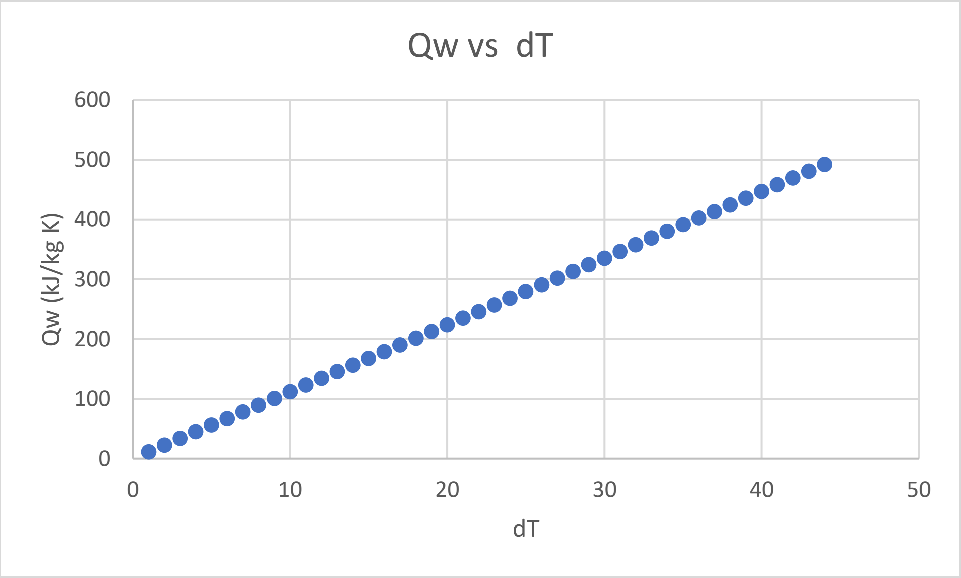


Figure 3.11: Heat Required to Raise Temperature of Water with Change in Temperature

Sum of heat required (Figure 3.12) = Q_t = heat required to raise the temperature of (air + eggs + egg trays + turning equipment + water)

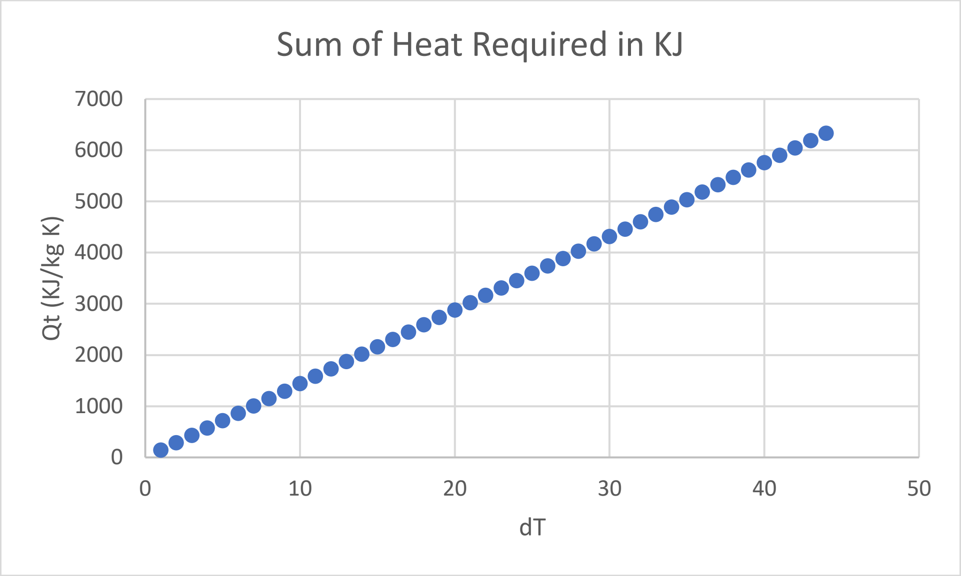


Figure 3.12: Sum of Required Heat Energy

3.5.2 Heat Loss from the Walls of Incubator

In order to properly design and operate an incubator, it is important to accurately determine the total heat required to maintain the desired temperature within the incubator. One of the key factors that must be considered in this calculation is the heat loss from the walls of the incubator.

To calculate the total heat required by the incubator, it is necessary to perform a heat loss calculation. This can be done by using Eq 3.2.

$$Q = U * A * (Ti - To) \tag{3.2}$$

U = overall heat transfer coefficient
A = the total area of the walls
Ti = inside temperature of the incubator
To = outside temperature

The methodology to find the value of overall heat transfer coefficient is to know the values of thermal conductivity and thickness of material layer in walls using Eq 3.3.

$$U = \frac{1}{R} = \frac{x}{k} \tag{3.3}$$

In the equation, R represents the thermal resistance of a material, x is the thickness of the material, and k is the thermal conductivity of the material. The values of x and k for the materials used can be found in Table 3.1.

The wall structure of incubator is shown in Figure 3.13. The structure shows that glass wool is sandwiched by the timber structure, with stainless steel and Rigid PVC sheet on either side. Thermal resistances representing the composite wall are as shown in Figure 3.14.

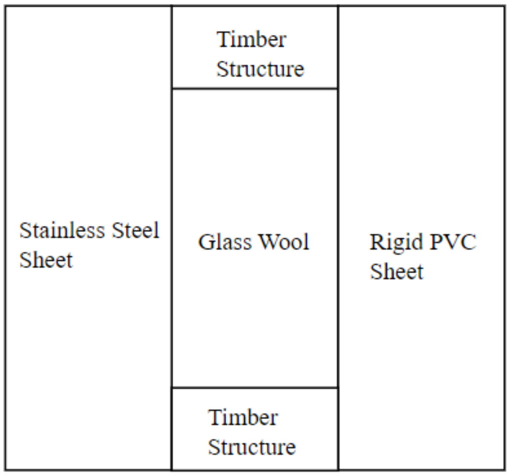


Figure 3.13: Wall Structure of Incubator

Table 3-1: Thermal Conductivity and Thickness of Materials used in Incubator.

Sr No	Material	K (Thermal Conductivity W/m K)	X (thickness m)
1	Stainless Steel (SS 304)	16.2	0.0009
2	Timber (Softwood)	0.1154	0.0508
3	Glass Wool Padding	0.023	0.0508
4	Rigid PVC	0.17	0.003

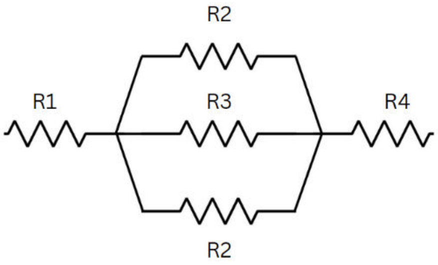


Figure 3.14: Wall Structure in Terms of Thermal Resistances

Solving for these thermal resistances shown in Figure 3.14.

$$R = \left(\frac{0.0009}{16.2} + \frac{1}{\left(\frac{0.0508}{0.023} + \frac{0.0508}{0.1154} + \frac{0.0508}{0.1154}\right)} + \frac{0.003}{0.17} \right) = 0.34142 \ \frac{m^2K}{W}$$

$$U = \frac{1}{R} = 2.93 \ \frac{W}{m^2K}$$

The area of the walls through which heat will be dissipated = 2(60.5 x 30.5) +2(60.5 x 36) + 2(30.5 x 36) =10242.5 in^2 = 6.6080513 m^2

The heat loss through the walls of incubator Q_{walls} using Eq 3.4.

$$Q_{walls} = U\ A\ dT \tag{3.4}$$

Similarly, it is important to calculate the heat loss through glass that is placed on the front door for the ease of monitoring eggs. The size of the glass window is 8" * 6" and the thickness is 3 mm with thermal conductivity of 0.8. Heat loss through the glass window Q_{glass} is computed using Eq 3.5.

$$Q_{glass} = \frac{(k\ A\ dt)}{x} \tag{3.5}$$

In order to ensure the safety of the system, a 10% margin of error is applied to the total heat loss values. This safety limit is considered as a precautionary measure, and it is applied to account for any potential errors or uncertainties in the calculations.

The overall heat loss through the walls (Figure 3.15) = 1.1 (heat loss through wall + heat loss through glass window)

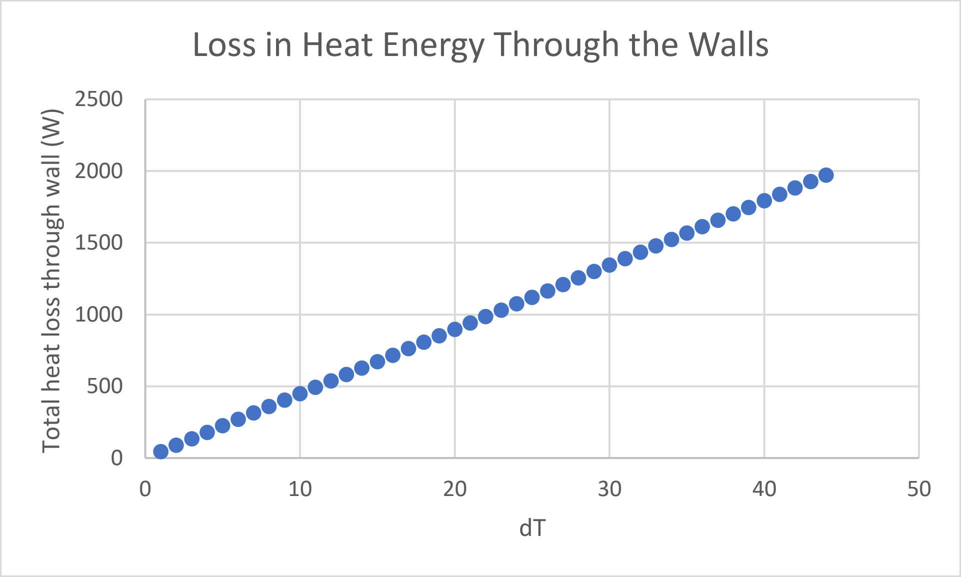


Figure 3.15: Heat Energy Lost through the Walls of Incubator

It is important to select a heat source for an incubator that is capable of compensating for heat loss. This can be determined by observing the heat loss and ensuring that the heat source is greater than it. The remaining heat can then be utilized to maintain the desired temperature within the incubator. The requirement of heat source may vary with the change in ambient temperature, it's essential to consider the range of temperature in which the incubator is intended to operate while selecting the heat source. Furthermore, a graph can be used to illustrate the relationship between heat loss and ambient temperature.

A graph can reveal that when the temperature difference is 9 ºC, the heat source of 400 W is inadequate as the heat loss exceeds it. To compensate for this, a heat source of 800 W can be used. With this heat source, 400 W will be dissipated through walls and the remaining 400 W will be utilized to heat the incubator. However, even with the use of 800 W heat source, it's only sufficient to maintain a temperature difference of 20 ºC.

Theoretically, it's important to note that if the incubator is not at risk of overheating, selecting a heat source with higher power will only decrease the time required to reach the set temperature within the incubator.

A heat source of 1500 W is selected to test the incubator as it covers a wide range of temperature and is suitable up to ambient temperature of 7 ºC. The heat loss through the wall at that point is 1388 W/s and the remaining 112 W is used to build up temperature. The time required to achieve the set temperature can be calculated using the following Eq 3.6.

$$Time\ required\ = \frac{(energy\ required\ to\ raise\ temperature\ to\ set\ point\ in\ J)}{(power\ of\ \ heat\ source\ in\ W -\ \ heat\ loss\ through\ walls\ in\ W)}$$

$$= \frac{4464853.528}{1500 - 1388.733717}\ =\ 28572.08504\ s\ =\ 7.9\ hrs$$

3.6 Optimization of Heat Source Using TRIAC (Triode for Alternating Current)

It's crucial to optimize the heat source in order to achieve optimal results. At high ambient temperatures, the heat loss through the walls is relatively high. In such cases, the use of relays alone may result in excessive energy being induced into the incubator. To mitigate this, the output heat must be controlled in relation to the ambient temperature. This approach will ensure that the desired temperature is maintained within the incubator while minimizing energy consumption.

For this experiment, a 1500 W PTC (Positive temperature coefficient) heater is used. In these heater resistance increases with an increase in temperature of heater, and from safety point of view when it reaches 50 ºC (found through experimentation) it will turn off completely. To somewhat minimize these effects a fan of 10 inch is placed in front of it, to distribute heat in the main chamber. Though with the increase in temperature of whole incubator, the heater will itself automatically regulate itself to less power. Even then the TRIAC is used, to have complete control over the power of heater so the incubator doesn’t overheat.

When utilizing a 1500 W heat source within an incubator, it is expected that 1500 W/s of energy will be induced into the system. However, when relying solely on relays to regulate the heat source, it can result in a scenario where the energy has been excessively induced into the incubator, leading to overheating, particularly when ambient temperatures are elevated. This is because as ambient temperatures increase, the temperature differential between the interior and exterior of the incubator decreases, leading to a reduced rate of heat loss through the walls. As a result, the heat energy that has been induced into the incubator may not dissipate as rapidly, causing the incubator to overheat. To mitigate this, it is essential to implement a system that controls the output heat in relation to ambient temperatures, thus ensuring that the desired temperature is maintained within the incubator while minimizing energy consumption.

The optimization of the heat source in an incubator is crucial for maintaining the desired temperature within the system. One method of achieving this is using a TRIAC, which enables the precise control of the alternating current (AC) power delivered to the heater. The system can be designed such that the incubator is initially operated at full power until the temperature reaches 37.8 degrees Celsius. Subsequently, the power of the heat source is modulated in a controlled manner to reach the set temperature of 38 °C over a period of 6 minutes. This approach not only prevents overheating but also ensures that the temperature within the incubator is reached in a timely and efficient manner. Additionally, the power of the heater is adjusted based on the ambient temperature, this ensures that the temperature within the incubator is maintained at the desired set point even when the ambient temperature fluctuates. Once the set temperature is reached, the heat source is turned off and the temperature is continuously monitored to ensure that it remains within the desired range.

The heat required to raise the temperature from 37.8 ºC to 38 ºC can be calculated by utilizing the equations, by subtracting the result of the calculation with the temperature of 37.8 ºC from the result with the temperature of 38 ºC, resulting in a total heat energy of 29 KJ.

The time required to reach from 37.8 ºC to 38 ºC is set to be 6 minutes as the values obtained from the equations are in KJ and the time parameter must be fixed to convert it into Watts.

$$Power\ required\ = \frac{(29 * 10^3)}{6(60)} = \ 80.5\ W$$

The power of the heater at 37.8 ºC will be regulated and will be (Figure 3.16) = heat loss through the walls + 80.5 W.

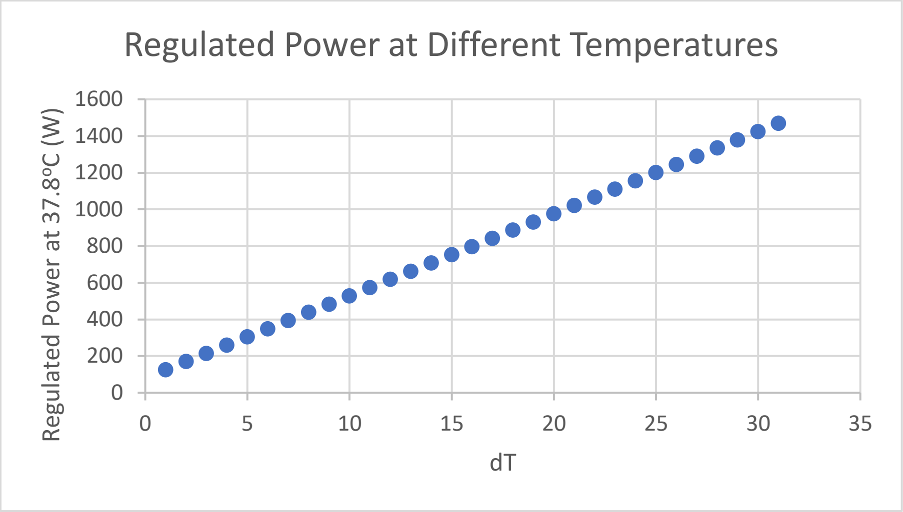


Figure 3.16: Power Regulated at 37.8 ^{0}C with Temperature Difference

3.6.1 Components and Programming of a TRIAC

A TRIAC, or thyristor for alternating current, is a semiconductor device that allows for the control of current in an AC circuit as shown in Figure 3.17. It works by conducting current in only one direction and can be triggered to turn on and off at specific points in the AC waveform [19].

The trigger point, also known as the firing angle, is the point in the AC waveform at which the TRIAC is turned on, allowing current to flow through the load. The trigger point is controlled by applying a small current to the gate of the TRIAC [19]. This current can be provided by a device such as an optocoupler, which uses an LED and a phototransistor to provide electrical isolation between the control circuit and the AC load.

The firing angle is the amount of time that the TRIAC is conducting current during each half-cycle of the AC waveform. By controlling the firing angle, the amount of power delivered to the load can be controlled [19]. A shorter firing angle will result in less power being delivered to the load, while a longer firing angle will result in more power being delivered.

The components of a TRIAC module are as follows [19]:

- Optocoupler: an electronic component that uses a light-emitting diode (LED) and a phototransistor to provide electrical isolation between two circuits. In this module, it is used to isolate the control circuit from the AC load.

- Zero crossing sensor: a device that detects the zero-crossing point of the AC waveform. This information can be used to trigger the TRIAC at the appropriate time to control the AC load.
- TRIAC: a three-terminal semiconductor device that allows for the control of current in an AC circuit. It serves as the main switch to control the flow of current to the AC load.
- Passive components such as resistors, capacitors, and diodes: these components are used for protection and noise reduction in the circuit.
- A full wave bridge rectifier is used to convert the AC voltage into a DC voltage that is used to trigger the TRIAC. This ensures a more consistent and stable DC voltage and improves overall performance of the circuit by reducing ripple voltage.
- Connector: a device that connects the module to the AC load and the Arduino board.

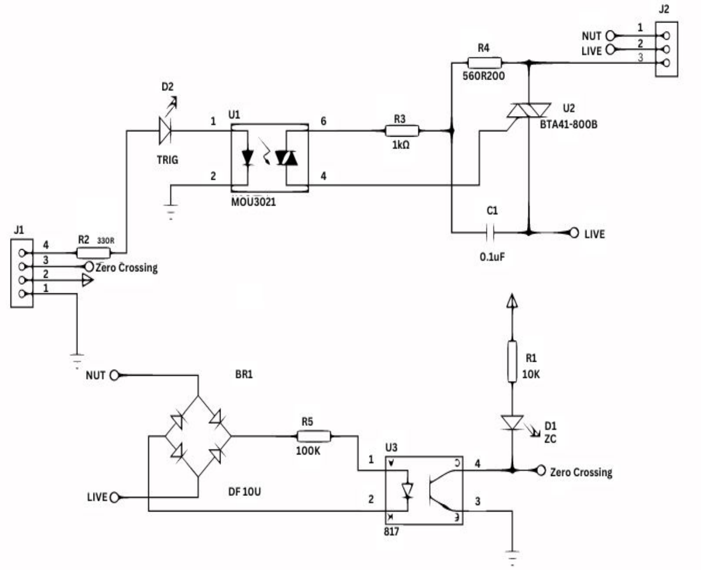


Figure 3.17: Schematic of TRIAC Module

When programming the control of power delivered to a load using a TRIAC, it's important to translate the desired power level into a delay in microseconds between the zero crossing of the AC current and the trigger point of the TRIAC. This delay can be programmed into the control system and adjusted dynamically to regulate the power delivered to the load. The TRIAC module detects the zero crossings of the AC current, and the delay can be set in microseconds to control the overall power delivered to the load.

Now, the heater of 1500 W at 220 V consumes 6.82 amperes of current and has a resistance of 32.27 ohms. The power regulated at 37.8ºC can be converted to the required voltage at that point. Using Eq 3.6 and the results shown in Figure 3.18.

$$(Vrms)req = \left(\frac{P}{R}\right)^{\frac{1}{2}}$$

3.6

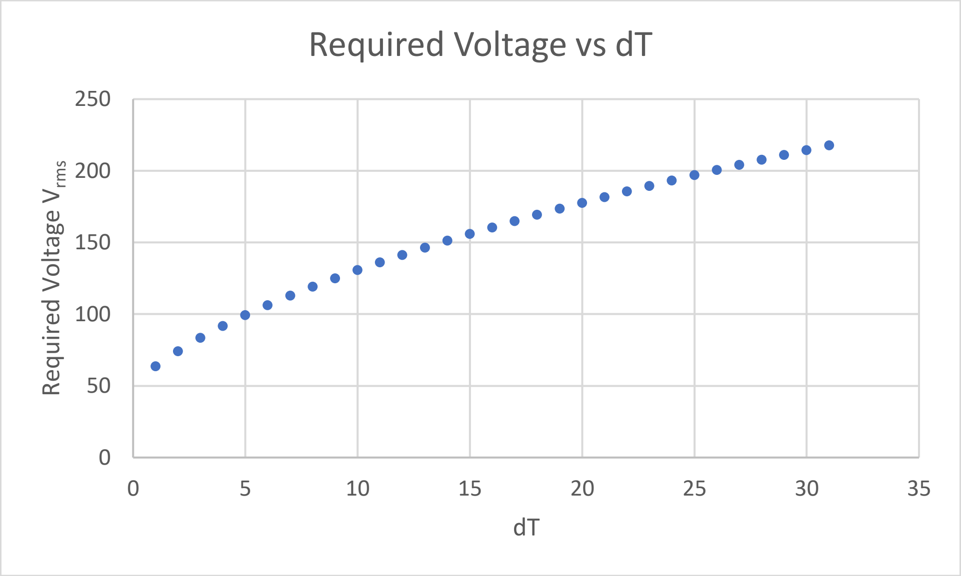


Figure 3.18: Required Voltage to Step Down Power with Temperature Difference

It is important to know the relation between firing angle and firing delay. One complete sine wave corresponds to 360 degrees which is 2π radians. The frequency of AC current in Pakistan in 50 Hz which means that a sine wave is completed in 20 ms and there is a zero crossing after every 10 ms.

So, the firing angle can be calculated using Eq 3.7 and the results are shown in Figure 3.19.

$$\alpha = \omega t$$

$$\alpha = 100\pi\, t$$

3.7

α = firing angle (rad)

ω = angular velocity (rad/s)

f= frequency of AC current = 50 Hz

t = time (s)

$$V_{rms} = Vs * \left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin(\alpha)}{2}\right)\right]^{1/2}$$

3.8

Vrms = Required voltage

Vs = Supplied voltage = 220 V

Transcendental Eq 3.8 is used to calculate the firing angle in a circuit [20]. Direct calculation of the firing angle for the Vrms is not possible. An approach is used where a spreadsheet is prepared, where time is varied from 1 microsecond to 10,000 microseconds. Using this data, the firing angle is calculated. This firing angle value is then used to calculate the required voltage (Vrms). The spreadsheet relates the firing angle, time and Vrms. By referencing this spreadsheet, an approximate value of delay time and angle can be found Vrms.

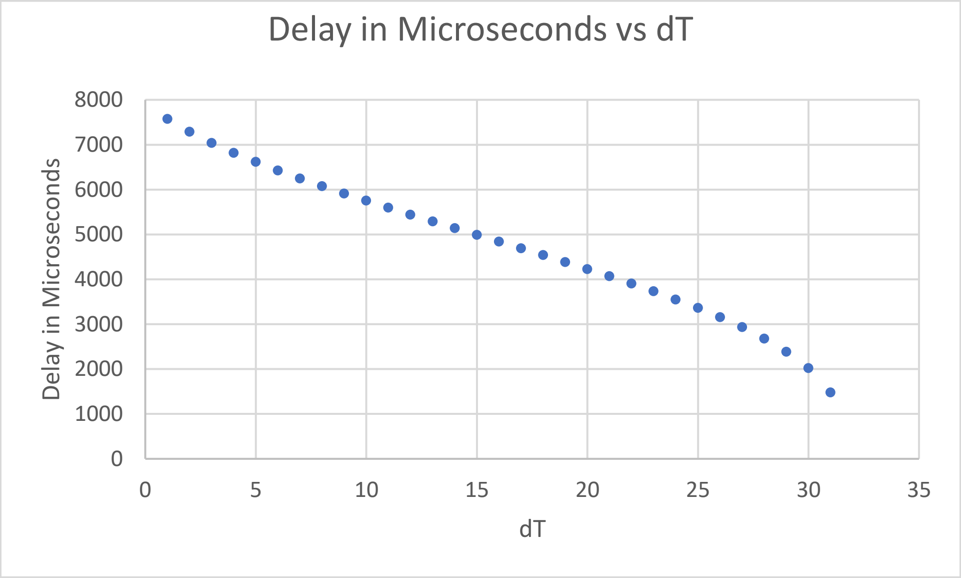


Figure 3.19: Required Voltage Translated in Terms of Required Voltage

Figure 3.19 relates the delay time after zero crossing required to regulate power once the temperature inside the incubator reaches 37.8 ºC in correspondence with the ambient temperature.

3.7 Ventilation Requirements for Egg Incubation in Relation to Heat and CO_2 Production.

To calculate ventilation rates for egg incubation, it is important to first understand the concept of respiratory coefficient and its specific value for eggs. The respiratory coefficient (R.Q) is a measure of the amount of CO_2 produced by an organism compared to the amount of oxygen consumed [21]. It is commonly used to determine the metabolic rate of an organism and is typically expressed as a ratio of amount of CO_2 produced to Amount of O_2 consumed.

The respiratory coefficient for eggs varies depending on the species, but it is typically around 0.7. This means that for every 1 liter of oxygen consumed, the egg will produce 0.7 liters of CO_2. By knowing the respiratory coefficient for eggs, one can calculate the amount of CO_2 produced and thus determine the appropriate ventilation rate needed to maintain a healthy incubation environment [21].

To create a protected environment for the optimal development of embryos, the concentration of CO_2 beneath a hen is generally at a level of 4000 ppm or higher to prevent air flow around the eggs [21]. To replicate this effect, the ventilation rate inside the incubator is adjusted so the CO_2 levels inside the incubator are maintained at 4000 ppm and average CO_2 concentration in the air is around 400 ppm. Energy produced per l of CO_2 can be calculated using Eq 3.9 which can be further used in Eq 3.10 to calculate ventilation rate [25].

Size of machine in terms of eggs = 528

CO_2 inside the incubator = C1 = 4000 ppm

CO_2 outside the incubator = C2 = 400 ppm

R.Q = 0.7

$$\frac{Energy\ produced\ in\ \frac{kJ}{hr}}{production\ of\ CO_2\ in\ \frac{l}{hr}} = \frac{16.2}{R.Q} + 5 \tag{3.9}$$

$$= 28.1 \frac{kJ}{l} = 28100 \ \frac{kJ}{m^3}$$

$$Ventillation\ rate\ in \frac{m^3}{hr} = \frac{\left(No\ of\ eggs * Heat\ Produced\ in \frac{kJ}{hr}\right) * \ 10^6}{Energy\ produced\ in\ kJ\ per\ m^3\ of\ CO_2 * (C_2 - C_1 in\ ppm)} \tag{3.10}$$

Table 3.2 shows production of heat by egg per day as the incubation goes on and through the formula of ventilation rate, for each day rate of ventilation is calculated.

Table 3-2: Heat Production and Ventilation Rate during Incubation [22].

Day	**HP (W/egg)**	**Ventilation (m^3/hr)**
1	0.0001	0
2	0.0009	0
3	0.0023	0
4	0.0037	0
5	0.0055	0
6	0.0081	0
7	0.0111	0
8	0.0158	0
9	0.0223	0
10	0.0309	1
11	0.0448	1
12	0.0646	1
13	0.0881	2
14	0.1131	2
15	0.1312	2
16	0.1406	3
17	0.1433	3
18	0.1501	3
average	*0.0543*	*1*
19	0.1600	3
20	0.2500	5
21	0.3500	7
average	0.2533	5

For ventilation purposes a 4" fan is used in the incubator with airflow of 143 m^3/hr. To fulfill the requirement the system can be instructed to turn on the fan for 25 seconds after every hour for the first 18 days and for 2 minutes and 5 seconds after every hour in the last 3 days of incubation.

3.8 Humidity

The ideal humidity level in an incubator for eggs is around 60% [23]. This level of humidity is considered optimal because it provides the right amount of moisture for the development of the embryos without causing any negative effects.

If the humidity level in the incubator is too low, the eggs may become dehydrated and the embryos might stick to the shell, which can negatively impact the growth and development of the embryos. Additionally, low humidity can also cause the eggs to lose heat more rapidly, which can affect the hatch rate. On the other hand, if the humidity level in the incubator is too high, the eggs may become too moist making it hard for the embryos to crack shell and hatch [24].

Lowest relative humidity in Pakistan is Observed in the month of October around 28.6% and the lowest average temperature in October is 18.8ºC with water content 3.5 g/m^3.

Moisture loss by eggs per day in terms of weight = 0.6% per day [23]

Moisture loss by eggs per hour in terms of weight = 0.025 % per hour

No of eggs = 528

Weight of eggs = 60g

Moisture content in air at 38ºC and 60% relative humidity = 28.0 g/m^3 (Mollier Diagram)

Average air flow for 18 days = 1 m^3/hr

Average air flow for last 3 days = 5 m^3/hr

Δm = difference in moisture inside and outside the incubator = 28-3.5 =24.5 g/m^3

$$\text{Air flow m}^3/\text{hr} = \frac{(NO\ of\ eggs\ x\ Weight\ x\ \text{Moisture loss by egg per hour})+\text{water spray })}{Moisture\ in\ Atmosphere - Moisture\ inside\ Incubator} \quad 3.11$$

This Eq 3.11 can be re-arranged into Eq 3.12 to find the amount of water to be sprayed in (g/hr) which can be further converted in l/h by dividing it by density of water which is 1000 g/l [23].

$$water\ spray = (air\ flow * \Delta\text{m}) - (No\ of\ eggs * Weight\text{Moisture loss by egg per hour}) \quad 3.12$$

Amount of water spray for first 18 days = 0.01658 l/hr

Amount of water spray for last 3 days = 0.11392 l/hr

So, to get the required humidity, the ultrasonic humidifier must have the capability of producing 0.113912 liters of mist in one hour. The humidifier even though is operated by a relay using input values from a humidity sensor, in dry weather due to limited capability of humidifier achieving a relative humidity of 60% becomes a hideous task .

CHAPTER 4: ANALYSIS

4.1 Testing Main Chamber for Cold Spots.

Testing an incubator for cold spots is important because it ensures that the incubator is providing consistent and uniform heating throughout its interior. In an incubator, the temperature should be maintained at a constant level to ensure that samples or organisms being cultured are growing under optimal conditions.

Cold spots in an incubator can lead to temperature fluctuations and uneven growth of the samples, which can compromise the quality hatching. Testing an incubator for cold spots can help identify any areas of the incubator that may not be heating properly. This helps to ensure that the experimental results obtained from the incubator are reliable and reproducible.

To test the incubator, it is divided into equal parts consisting of 27 cells as shown in Figure 4.1. The cells are arranged in a grid format, with 3 rows and 3 columns in each of the 3 layers. This allows for a total of 9 cells per layer and 27 cells in total.

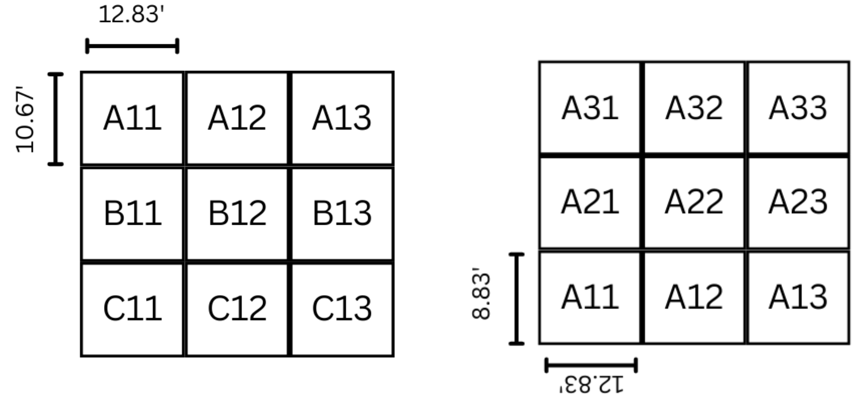
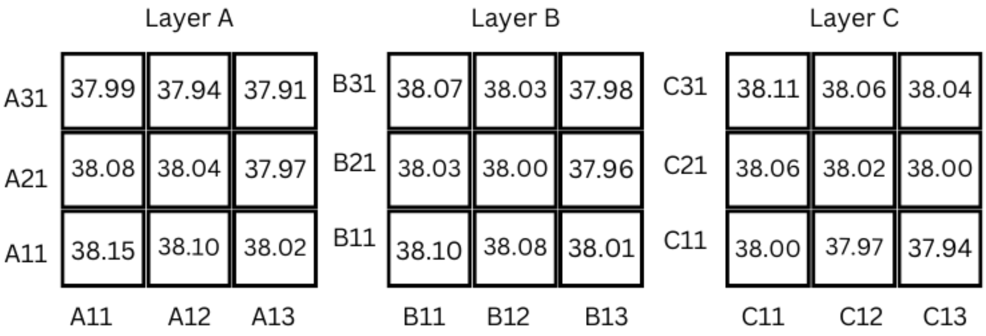


Figure 4.1: Division of Incubator in Cells

The temperature sensor based on which relays operate is placed in the exact center of the incubating center in cell B22 along with humidifier while to measure the temperature of each cell accurately five DS18B20 censors were use at each end and one at the center of cell. The readings of these sensors were recorded once the temperature of the main sensor placed at B22 had reached

38 ºC with humidity maintained at 60%. To find the exact temperature of each cell, the average value was calculated in ºC, and the results are mentioned below in Figure 4.2.



Layer A

	A11	A12	A13
A31	37.99	37.94	37.91
A21	38.08	38.04	37.97
A11	38.15	38.10	38.02

Layer B

	B11	B12	B13
B31	38.07	38.03	37.98
B21	38.03	38.00	37.96
B11	38.10	38.08	38.01

Layer C

	C11	C12	C13
C31	38.11	38.06	38.04
C21	38.06	38.02	38.00
C11	38.00	37.97	37.94

Figure 4.2: Temperature Zones in Incubator

The lowest temperature recorder inside the incubator was 37.8 ºC and the highest temperature was 39.23 ºC.

4.2 Experimentation (Hatch 1)

In the first hatch 350 eggs were kept inside the incubator where the external/ambient temperature was 17 ºC in the room in which the incubator was placed. It approximately took 97 mins to reach the temperature of 38 ºC. The eggs placed inside the incubator had an average weight of 55 grams and the eggs were frequently candled after 4 days of incubation. In the first three days, there is no significant development of embryos within the eggs which can be seen under the flashlight beneath the egg in the dark environment. 4th day of incubation is when red lines (blood vessels) are visible in the yolk. The timeline of this experiment is shown in Table 4.1.

Table 4-1: Results for Hatch 1

Days	Date (Hatch 1)	Min Temp ºC	Max Temp ºC	Min R.H	Max R.H	Non-Viable Eggs	Date (Hatch 2)	Non-Viable Eggs

		(H.S = ON)	(H.S= OFF)					
1	Jan 15	37.8	38.0	55%	60%	No Candling	Feb 10	No Candling
2	Jan 16	37.8	38.0	55%	60%	No Candling	Feb 11	No Candling
3	Jan 17	37.8	38.0	55%	60%	No Candling	Feb 12	No Candling
4	Jan 18	37.8	38.0	55%	60%	No Candling	Feb 13	No Candling
5	Jan 19	37.8	38.0	55%	60%	15 (Infertile)	Feb 14	27 (Infertile)
6	Jan 20	37.8	38.0	55%	60%	No Candling	Feb 15	No Candling
7	Jan 21	37.8	38.0	55%	60%	No Candling	Feb 16	No Candling
8	Jan 22	37.8	38.0	55%	60%	No Candling	Feb 17	No Candling
9	Jan 23	37.8	38.0	55%	60%	No Candling	Feb 18	No Candling
10	Jan 24	37.8	38.0	55%	60%	3 (Dead in Shell)	Feb 19	8 (Dead in Shell)
11	Jan 25	37.8	38.0	55%	60%	No Candling	Feb 21	No Candling
12	Jan 26	37.8	38.0	55%	60%	No Candling	Feb 22	No Candling
13	Jan 27	37.8	38.0	55%	60%	No Candling	Feb 23	No Candling
14	Jan 28	37.8	38.0	55%	60%	7 (Dead in Shell)	Feb 24	10 (Dead in Shell)
15	Jan 29	37.8	38.0	55%	60%	No Candling	Feb 25	No Candling
16	Jan 30	37.8	38.0	55%	60%	No Candling	Feb 26	No Candling
17	Jan 31	37.8	38.0	55%	60%	No Candling	Feb 27	No Candling
18	Feb 1	37.8	38.0	55%	60%	2 (Dead in Shell)	Feb 28	5 (Dead in Shell)
19	Feb 2	37.8	38.0	60%	65%	No Candling	Mar 01	No Candling
20	Feb 3	37.8	38.0	60%	65%	No Candling	Mar 02	No Candling
21	Feb 4	37.8	38.0	60%	65%	5 (Dead in Shell)	Mar 03	2 (Dead in Shell)

No of eggs placed = 350

Infertile eggs = 15

Fertile eggs = 335

Dead in shell eggs = 17

Hatch efficiency = $\frac{(Fertile\ eggs - Dead\ in\ Shell\ Eggs)}{Fertile\ eggs} = \frac{(335-17)}{335} = 94.9\%$

The incubator had no issues with maintaining temperature as there were no overheating issues and the humidifier was able to maintain the humidity of around 65%. With the temperature variation of, the TRIAC was able to maintain vary the power source in accordance with the heat requirements.

4.3 Candling Methodology & Diagnosis

The troubleshooting of the problems encountered in this experiment is based on Table 2.2. The eggs were candled through a flashlight and were compared to the collage of ovo-development presented in Figure 2.6.

4.3.1 Candling Results Day 1-4:

No candling was done to check the fertility or the development of embryos inside the egg as during the first three days there is no visible development inside the egg through which we can deduce whether the egg is fertile or not. So, due to unpredictability no effort for candling the eggs was made during the first four days of incubation.

4.3.2 Candling Results Day 5:

The results obtained on the fifth day were rather convincing and were a sign of encouragement to move the experiment forward. Out of 350 eggs being placed only 15 were infertile as shown in Figure 4.3. All the other eggs showed development signs with a small heart pumping as soon as the light is lit beneath the egg.

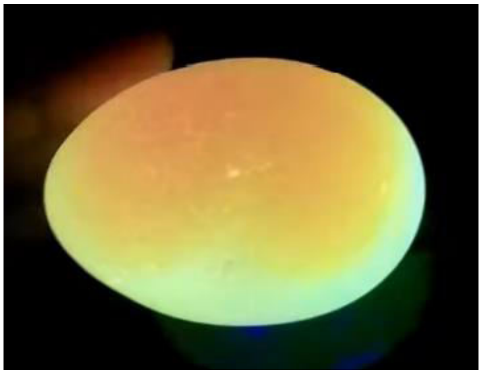


Figure 4.3: Candling Result for Infertile Egg

4.3.3 Candling Results Day 10:

Candling was then done on 10th day and was rather successful and reassuring as there were only 3 dead in shell chicks. The three non-viable dead in shell eggs as shown in Figure 4.4 below were all from different cells within the incubator.

Figure 4.4: Candling Result of Dead in Shell Embryo Day 10

4.3.4 Candling Results Day 14

Candling was done on day 14 where 7 dead in shell eggs were found and the results of non-viable as shown in Figure 4.5. This was the greatest number of dead shell eggs found during this whole experiment. The dead in shell eggs were not concentrated in a single cell to draw any conclusion.

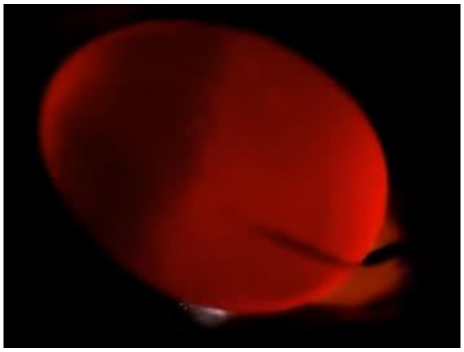


Figure 4.5: Candling of a Dead in Shell Embryo Day 14

4.3.5 Candling at day 18

The last phase of candling was done on day 18 just before stopping rotation of eggs stopped. There were only 2 dead in shell chicks shown in Figure 4.6 which showed that the hatching was going in the right track and no major issues were found.

Figure 4.6: Candling of Dead in Shell Embryo Day 18

4.3.6 Result at day 21:

The result was rather successful with an almost 95% hatch rate, which was certainly more than expected. There was certainly no egg that needed help in hatching. Only 5 eggs were not able to hatch and were dead. The chicks after hatching were all healthy and kept inside the incubator for 24 hours in the setter tray and there was no mortality.

4.4 Experimentation (Hatch 2)

The second experiment was done with 360 eggs, to further verify the results of hatch 1. The experiments were conducted in February, the ambient temperature was around 20ºC. It took the incubator 70 mins to reach the required temperature of 38ºC. The results of Hatch 2 are presented in Table 4.2.

Table 4-2: Results for Hatch 2

Days	Date	Minimum Temperature ºC (Heat Source = ON)	Maximum Temperature ºC (Heat Source = OFF)	Minimum Relative Humidity	Maximum Relative Humidity	Non-Viable Eggs
1	Feb 10	37.8	38.0	55%	60%	No Candling
2	Feb 11	37.8	38.0	55%	60%	No Candling
3	Feb 12	37.8	38.0	55%	60%	No Candling
4	Feb 13	37.8	38.0	55%	60%	No Candling
5	Feb 14	37.8	38.0	55%	60%	27 (Infertile)
6	Feb 15	37.8	38.0	55%	60%	No Candling
7	Feb 16	37.8	38.0	55%	60%	No Candling
8	Feb 17	37.8	38.0	55%	60%	No Candling
9	Feb 18	37.8	38.0	55%	60%	No Candling
10	Feb 19	37.8	38.0	55%	60%	8 (Dead in Shell)
11	Feb 21	37.8	38.0	55%	60%	No Candling
12	Feb 22	37.8	38.0	55%	60%	No Candling
13	Feb 23	37.8	38.0	55%	60%	No Candling
14	Feb 24	37.8	38.0	55%	60%	10 (Dead in Shell)
15	Feb 25	37.8	38.0	55%	60%	No Candling
16	Feb 26	37.8	38.0	55%	60%	No Candling
17	Feb 27	37.8	38.0	55%	60%	No Candling

18	Feb 28	37.8	38.0	55%	60%	5 (Dead in Shell)
19	Mar 01	37.8	38.0	60%	65%	No Candling
20	Mar 02	37.8	38.0	60%	65%	No Candling
21	Mar 03	37.8	38.0	60%	65%	2 (Dead in Shell)

No of eggs placed = 360

Infertile eggs = 27

Fertile eggs = 337

Dead in shell eggs = 25

Hatch efficiency = $\frac{(Fertile\ eggs - Dead\ in\ Shell\ Eggs)}{Fertile\ eggs} = \frac{(337-25)}{337} = 92.6\%$

4.5 Possible Reasons for Chicks Dead in Shell

The possible reasons for non-viable eggs were.

- The flock had a ratio of 1/10 of male female ratio, which might be the probable reason of infertile eggs.
- The dead in shell eggs were all below average weight, weighing less than 50 grams which shows that the eggs were not healthy enough.

4.6 Flexibility

The incubator was planned to be designed keeping in mind a very important feature: flexibility in terms of capacity as well as functionality.

- The incubator can easily be converted into a brooder as the ventilation fans have enough capacity to maintain adequate levels of CO_2 inside the incubator even after hatching eggs for 48 hours.
- The design is flexible, the rotating mechanism can be easily removed from the incubator for better cleaning.
- Separate chamber allows easy access to water container for refilling purposes and for easy maintenance if there incur any malfunctions without inducing thermal shock to eggs.
- Everything is easily replaceable in case anything malfunctions.
- The incubator is portable and can easily be moved.

CONCLUSION

The project covers design, fabrication, analysis, and experimentation on egg incubator and based on the results of this study, it can be concluded that the use of a TRIAC for regulating the power of the heater in an egg incubator can provide an accurate and consistent amount of heat, which prevents the eggs from overheating. The calculation for humidity and ventilation also helps to create an optimal environment for egg incubation.

The division of the incubator into equal cells in three layers and monitoring for cold spots helped ensure that the temperature was evenly distributed throughout the incubator. The separate heating and incubating chambers further helped maintain a stable temperature inside the incubator.

The results of this study demonstrated that the lowest temperature inside the incubator was 37.8 ºC, and the highest temperature was 38.23 ºC, indicating a very narrow range of temperature variation. The hatch rate of 94.9% and 92.6% for the two hatches also indicates that the incubator provided a suitable environment for egg incubation.

Overall, the use of a TRIAC for regulating the power of the heater, calculation for humidity and ventilation, monitoring for cold spots, and separate heating and incubating chambers all contributed to the success of this egg incubator design.

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