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Stabilisation of Incubation Temperature in Hot Water Chicken Egg Incubator

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ABSTRACT

In this study, the existing egg incubator at Songwe Geothermal Hot Spring was improved by stabilising incubator temperature, hence improving hatching efficiency. The improved hot water egg incubator with a capacity of 280 eggs was designed, fabricated, and tested. Incubator temperature was stabilised by a variable flow rate of circulating hot water that corresponds to changes in incubator temperature. The flow rate of circulating hot water (1.5–2 litres/min) was proportional to the temperature of the incubator. A heat balance equation was formulated to quantify the heat transferred from hot water to circulating water, incubator circulating air, eggs, and the heat lost surrounding. Results revealed that the improved hot water egg incubator had an average hatching efficiency of 89% and a relatively stable temperature with a mean and standard deviation of 37.83°C and 0.1°C, respectively. The results showed a significant improvement as compared to the existing incubator, which had the capacity of 240 eggs, an average hatching efficiency of 84%, and relatively temperature stability with a mean and standard deviation of 37.3°C and 0.69°C, respectively. Results for the heat balance equation showed that most of the heat transferred from circulating water to the incubator was used to raise and maintain the temperature of the incubator at 37.8°C. The eggs absorbed a relatively small amount of heat, which was 3.136W. The improved incubator can also be operated by heat from geothermal resources and waste heat from industries and power plants in the 50°C-100°C temperature range.

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1.0 Introduction

Incubation in poultry is the process of maintaining favourable temperature and relative humidity surrounding the eggs until the eggs are hatched. This can be done naturally by mother hen or artificially by using an incubator (Aldair et al., 2018). An egg needs an average temperature of 37.8°C and a relative humidity range of 30-60% from the 1st up to the 18th day of incubation. After which, the relative humidity should be raised to 70%, and the temperature is lowered to 36°C until the chick is hatched (Adegbulugbe et al., 2013). In artificial incubation, the air is circulated in the incubator by using the fan, and eggs are tilted to ensure distribution of heat around the eggshells (Aldair et al., 2018). The favourable egg-tilting angle is 45° to influence the proper loss of water during the incubation and help to avoid the attachment of the embryo to the eggshell, hence reducing the death rate of chicks during the incubation (Kyeremeh, 2017). The temperature, relative humidity, and air ventilation are the main factors that affect the hatchability of eggs. The optimum incubation temperature for chicken eggs is 37.8°C; a small deviation can affect embryo development, hatching, and the life of chicks (Yilmaz, 2011; Sangole, 2021). Internal humidity in the incubator increases as the water comes out from the egg's porous shell. Therefore, the correct relative humidity should be maintained over time. Variations of relative humidity inside the incubator due to water from eggs and change in environmental conditions outside the incubator should not be out of range (Fredrick et al., 2021).

The heat for artificial incubation can be from various sources: electricity, solar energy, geothermal, burning oil or gas, and waste heat (Jr et al., 2018). Geothermal energy is the heat energy contained as heat in the Earth’s interior (Barbier, 2002; Dickson & Fanelli, 2004). Geothermal is a renewable energy source that is sustainable and with relatively fewer emissions. Geothermal energy can be utilised to improve people's living standards for geothermal heat pumps, electric power generation, agricultural ponds and raceway heating, agricultural crop drying, industrial process heat, snow melting, space cooling, bathing, and swimming (Ge et al., 2020). The energy can also be utilised for incubation in poultry farming (Lund et al., 2011; Jr et al., 2018). In these views, there is a need to develop technologies that harness the thermal energy from geothermal hot water. Heat exchangers are used to harness heat from geothermal resources. A heat exchanger is a device that is used to transfer heat between two or more fluids at different temperatures (Masoumpour et al., 2021; Khairul et al., 2013). The fluids can be single- or two-phase and can be separated or in direct contact. Depending on the type of heat exchanger utilised, the heat transfer process can be gas-to-gas, liquid-to-gas, or liquid-to-liquid, and it can happen through a solid separator that prevents the fluids from mixing or direct fluid contact (Uniyal, 2022). Heat exchangers can be classified based on their construction as shell and tube, plate, and air-cooled condensers. Shell and tube heat exchangers consist of a large number of small tubes that are located within a cylindrical shell (Masoumpour et al., 2021; Brogan, 2011). Plate heat exchangers operate in very much the same way as a shell and tube heat exchanger, using a series of stacked plates rather than tubes. Plate heat exchangers are usually brazed or gasketed depending on the application and fluids being used. Air-cooled heat exchangers are commonly used in vehicles or other mobile applications where no permanent cool water source is available. Cool air is provided either by a fan or by airflow caused by the movement of the vehicle.

Heat exchangers can also be classified based on the mode of fluid flow configuration as parallel flow, cross flow, counter flow, and mixed flow (Brogan, 2011). In parallel-flow heat exchangers, the process and utility fluid streams flow in parallel directions. In cross-flow heat exchangers, the process and the utility fluids flow perpendicular to each other. In countercurrent flow heat exchangers, the process and utility fluid streams flow in opposite directions. Countercurrent flow in heat exchangers is the most efficient and the most utilised flow pattern. A large temperature difference of the fluids is maintained constant across the length of the heat exchanger. This provides a more uniform heat transfer rate and minimises thermal stress. The performance of the heat exchangers is affected by the following factors: flow rate, material, surface area, fouling, heat transfer surface enhancement, flow configuration, and temperature differential. Fouling is the accumulation of unwanted deposits on heat transfer surfaces that can significantly degrade heat exchanger performance. The surface area enhancements include fins, turbulators, corrugations, or extended surfaces to achieve improved heat transfer rates (Huminic & Huminic, 2011). Heat exchangers operate on thermodynamic principles and mechanisms of heat transfer. The following thermodynamic laws are applied to explain how heat exchangers work:The first law is referred to as the Law of Conservation of Energy, which states that energy in the form of heat and work can neither be created nor destroyed (Hernandez, 2024). It can only be transferred to another system or converted from one form to another. In heat exchangers, this statement is translated by the heat balance equation as shown in equation 1 (Granet & Bluestein, 2020):

$$Q_i + Q_G = Q_O + Q_A \qquad 1$$

Where: Q_i= Heat In, Q_G= Heat generated, Q_O= Heat out and Q_A= Heat accumulated.

Equation 1 assumes steady-state flow, where thermal properties remain constant at all points with time, and the system is adiabatic.

The second law of thermodynamics states that heat is always transferred from a body with a higher temperature to that with a lower temperature, which is the natural tendency of all systems. For heat exchangers, the cold fluid gains heat, and as a result, its temperature increases, while the hot fluid loses heat and decreases its temperature (Xue et al., 2024; Rajan, 2024; Silverstein, 2024).

The mode of heat transfer in heat exchangers is a combination of both conduction and convection, and the fluids temperature difference is the main driving force of heat transfer in heat exchangers.

Conduction is the transfer of heat energy by direct collision of adjacent molecules in solid matter, where a molecule with higher kinetic energy transfers thermal energy to a molecule with lower kinetic energy. For heat exchangers, conduction takes place on the wall separating the two fluids. Fourier's Law of heat conduction states that the rate of heat transfer normal to the material's cross-section is proportional to the negative temperature gradient as given in equation 2 (Frishman & Holland, 2024; Almutairi, 2024; Bell, 2017).

$$Q = -kA\,{}^{\mathrm{dT}}/_{\mathrm{dx}} \qquad 2$$

Where: Q is the rate of heat transfer, k is the material's thermal conductivity, A is the area normal to the direction of the flow of heat, and dT/dx is the temperature gradient.

Convection heat transfer in heat exchangers occurs through the bulk motion of the fluid against the surface of the wall, thus transferring thermal energy. This phenomenon is represented by Newton's Law of Cooling, which states that the rate of heat transfer is proportional to the body property and the difference of the temperature of the body and its surroundings, such as the wall and the fluids, and can be represented in equation 3 (Uysal, 2024; Ruta et al., 2024; Jain, 2024).

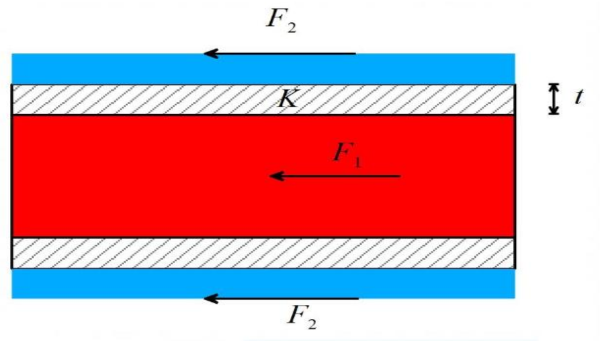
$$Q = hA\Delta\mathrm{T} \qquad 3$$

Where: Q is the rate of heat transfer h is the convective heat transfer coefficient, A is the area normal to the direction of the flow of heat, and ΔT is the temperature difference between the wall and bulk fluid.

The value of h is evaluated based on the wall dimensions, physical properties of the fluid, and fluid flow characteristics. The heat transfer in a combined mode of conduction and convection in heat exchanger represented in Figure 1 is given in equation 4 (Shah, 2003):

Figure 1

Combined Conduction and Convection



$$Q = UA\Delta T_{\mathrm{lm}} \qquad 4$$

Where: Q is the heat transfer rate, U is the overall heat transfer coefficient, A is the total surface area available for heat transfer, and ΔT_{lm} is the logarithmic mean temperature difference.

The overall heat transfer coefficient considers the resistance to heat transfer on both sides of the tube walls and within the fluids themselves. The overall heat transfer coefficient is influenced by the thickness and thermal conductivity of the mediums through which heat is transferred. The larger the coefficient, the easier heat is transferred from its source to the product being heated (Donoso-García et al., 2024).

The overall heat transfer coefficient can be expressed in equation 5 (Donoso-García et al., 2024; Yu et al., 2024):

$$^{1}/_{U} = ^{1}/_{h_1} + ^{L}/_{k} + ^{1}/_{h_2} \qquad 5$$

Where: h_1 = convective heat transfer coefficient of hot fluid W/(m^{2}K), h_2 = convective heat transfer coefficient of cold fluid W/(m^{2}K), L = thickness of the wall (m) and λ = thermal conductivity, W/(mK)

The logarithmic mean temperature difference, ΔT_{lm}, measures the average temperature difference between the two fluids throughout the length of the heat exchanger (Ragadhita et al., 2024).ΔT_{lm}can be calculated using the equation 6 (Maulik *et al.*, 2024;Yang *et al.*, 2024).

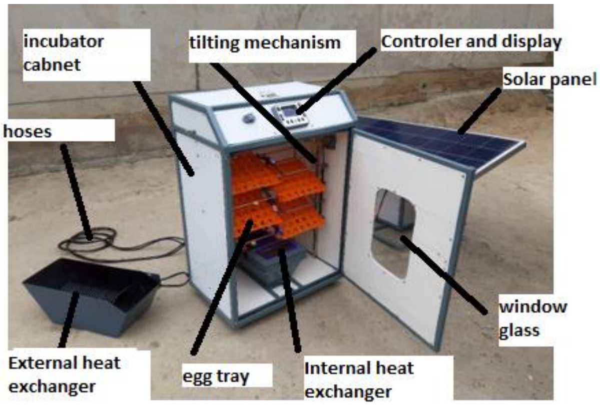
$$\Delta T_{\mathrm{lm}} = (\Delta T_1 - \Delta T_2)/\ln(\Delta T_1/\Delta T_2) \qquad 6$$

where: ΔT_1 is the temperature difference between the hot fluid entering and leaving the heat exchanger and ΔT_2 is the temperature difference between the cold fluid entering and leaving the heat exchanger.

Various works have been presented on the use of geothermal energy for egg incubation. Taplah *et al.,* (2018) built a geothermal egg incubator where temperature was controlled by adjustable ventilation opening and closing of the hot water supply waste valve. Sumatera *et al.,* (2017) built a geothermal egg incubator where temperature was controlled by multistage extraction of heat from hot water; first excess heat was extracted for drying cocoa beans, and later the remaining heat was utilised for egg incubation. El *et al.,* (2022) also designed a geothermal egg incubator in which temperature was controlled by closing and opening the waste gate, which allowed circulation of hot water to the incubator.

The works done by the mentioned authors did not demonstrate analysis of temperature stability with time. Therefore, the temperature control mechanisms employed do not guarantee stable temperature conditions in the incubator in response to changes in environmental conditions. The existing incubator at the Songwe Geothermal hot spring, represented in Figure 2, consists of a microcontroller, a circulation fan, a ventilation fan, a constant flow rate circulation water pump, and temperature and humidity sensors. In this design, the temperature is controlled by using a ventilation fan and circulation pump. The ventilating fan removes hot air in case the temperature rises above the set value inside the incubator, whereby the circulation pump stops the flow of hot water from the external to the internal heat exchanger. The performance of the existing incubator was done by Mbawala & Omary (2022), and results showed unstable temperature conditions in the incubator.

Figure 2
Existing Egg Incubator



In all mentioned studies, no analysis was presented on the quantity of heat transferred from hot water to the incubator. In this study, the improved hot water egg incubator was designed and fabricated. It consists temperature and humidity sensors, micro controller, variable flow rate water circulating pump, ventilation fan and air circulating fan. The temperature was controlled by using ventilation fan and circulation water pump, the ventilating fan removes hot air in case the temperature rises above the set value inside the incubator whereby the circulation pump varies the flow rate of hot water corresponding to temperature changes. Analysis of temperature stability was done, Heat transferred from hot water to the incubator was quantified.

2.0 Materials and Methods

2.1 *Design and Selection of Hot Water Egg Incubator Components*

The major components were incubator cabinet, heat exchanger, circulating water pump, controller, and temperature and relative humidity sensors.

2.1.1 *Incubator Cabinet*

The incubator cabinet was made up of melamine material of 1-inch thickness. The choice of the material was based on the suitability of the design conditions, which are temperature and humidity. The reason to use melamine material is that melamine foam reduces convection and conduction heat transfer of air, making it an excellent insulator (Inc., 2016). Its foam has a thermal conductivity of 17.72816 W/mk at 20°C and is often used for heating, ventilation, and air conditioning duct lining.

Melamine is extremely lightweight, which makes the incubator portable. Flame resistance does not drip or melt in the presence of open flame and exudes little smoke; the foam is soft with a sponge-like texture, which absorbs vibrations from the turning motor and has open cells, which make excellent noise-reducing insulation of the incubator (Inc., 2016). The outer dimensions of the incubator cabinet had a length of 80 cm, a width of 80 cm, and a height of 130 cm. The cabinet consists of three egg tray holders with a length of 60 cm, a width of 55 cm, and 10 cm as the space between one tray holder and another. This egg tray holder can accommodate 1 egg tray with a capacity of 110 eggs. The cabinet also consists of the window glass cover, which is fitted on the front side of the cabinet at a height of 40 cm from the bottom of the incubator. This helps with monitoring and inspection of the incubator chamber from outside without opening the incubator door.

2.1.2 *Selection of Controller and Sensors*

The control mechanism of the incubator consists of a humidity sensor, a temperature sensor, and a controller. These components were employed in the incubator for the purpose of controlling the incubator automatically. The temperature and humidity sensors were positioned within the egg trays so as to pick and send information to the controller. The controller was used to receive information from sensors, process it, and command the circulation pump, tilting motor, circulation, and ventilation fans. The controller used in the incubator was Model 18EK 230AC 230V AC, while the temperature sensor used was an NTC thermistor sensor with a display range of 0-99°C and a measurement precision of ±0.1°C, and the humidity sensor was AM 2120 with a display range of 0-99% RH and a measurement precision of ± 3% RH.

2.1.3 *Circulation and Ventilation Fans*

The circulation fans used in an incubator were NIDEC 6Y15B3 12V, 0.06A, 1850 RPM, and were positioned just below the internal heat exchanger, where they drew fresh and hot air and circulated it to the eggs. The ventilation fan used was a low-noise, high-power motor, 12V, 0.25A, 12x12x2.5cm size, and 2000RPM/H speed. It was positioned at the top corner on the right side of the incubator, 10 cm from the top, and its function is to draw fresh air to the incubator and send out hot air when the incubator temperature reaches 38.0°C.

2.1.4 Incubator Heat Exchangers

Copper pipe was used to construct internal and external heat exchangers. The reason to use copper material for a heat exchanger is that copper has a high thermal conductivity of heat. Copper has a thermal conductivity of 400 W/mk. This is higher than all other metals except silver. It also has high corrosion resistance and ease of deformation. Copper is also incorporated into the bottoms of high-quality cookware because the metal conducts heat quickly and distributes it evenly (Wikipedia, 2023). The copper pipe of 8mm outer diameter and 7mm internal diameter was used to construct both inner and outer heat exchangers. The outer heat exchanger is coil-shaped, and the inner heat exchanger is in circular shape, 1.5 m long each.

2.1.5 Circulating Water Pump

The circulating water pump shown in Figure 3 was used with a 12V priming diaphragm min spray motor pump with a suction head of 3 meters and a flow rate of 1.5 to 2 litres/min.

Figure 3
Circulating Water Pump

2.2 Control of Temperature in Incubator

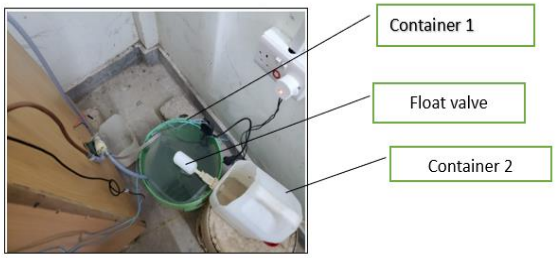
The completely assembled improved hot water incubator is shown in Figure 4. In this incubator, the control of temperature was achieved by variable flow rates of hot water from an external heat exchanger to an internal heat exchanger. The pump speed increased when the temperature was below 37°C and progressively decreased as the temperature neared the set point of 37.8°C. When the temperature reaches 38°C, the pump stops, and the ventilation fan starts to expel out hot, dirty air, which also stops when the temperature decreases to 37.8°C.

Fig 4
Assembled Hot Water Chicken Egg Incubator

To obtain constant hot water, an electric heater was used to heat the water up to 75°C, and this heater was controlled by the special circuit that was designed to ensure constant water temperature as shown in Figure 5. The circuit included a temperature sensor (DS1820), a controller (Arduino UNO), and a relay. The external heat exchanger was connected to the internal heat exchanger through an 8.2 mm diameter hose pipe and pump to make a closed system. Then water was fed into the closed system, and an external heat exchanger was immersed in the container containing hot water. The water in container number 1 was vaporising when it became hot, hence the decrease in volume, so container number 2 with a float valve was provided to allow the water to flow into container number 1 when the water vaporised.

Figure 5

Layout of Controlled Hot Water



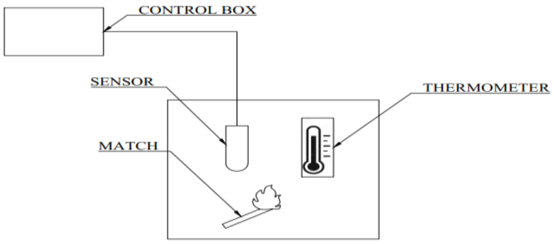
2.3 Evaluation of Performance of Improved Incubator

2.3.1 Temperature Sensory Unit Test

The objective of conducting this test was to assess the functionality and accuracy of the temperature sensor and the controller in order to reduce erratic results. The temperature sensory unit test consisted of a controller, a temperature sensor, a thermometer, and a match, as shown in Figure 6. After connecting the temperature sensor terminals to the controller, the supply was connected and the controller activated for the test. The thermometer was used to measure temperature at the sensor surrounding. The match was used as a source of heat, where it was lighted up and placed near the temperature sensor at a gap of 1 cm and then was taken away from the sensor. Six temperature values were recorded on the controller and thermometer at the sensor surroundings, respectively, as shown in Table 1, three readings at ambient temperature and at heated sensor surroundings, respectively. In each case the average of three temperature readings was determined.

Figure 6

Arrangement of Temperature Sensory Unit Test



2.3.2 Temperature Stability and Hatching Efficiency Test

Temperature stability and hatching efficiency tests were conducted three times in April, May, and June 2023. Where in each trial, 280 clean eggs, well-developed, matured, fertilised, and healthy, were selected and candled to check the size of the air cell, placed in the incubator, and the incubator was started. During each of the incubation tests, the values of ambient, incubation, and water temperature were recorded as shown in Table 2. The eggs were timely tilted during the incubation process. This stage lasted from the 1st day to the 18th day, and the eggs were candled at various stages of incubation to explore the size of the air cell. After the 18th day, the temperature was set at 36°C, relative humidity was set at 70%, and this process lasted to the 21st day. The final step was to assist chicks during the hatch for the chicks that failed to break the shell. The larger holes were broken on the eggs, starting with two holes from the air cell end of the eggs. Then the chicks and unhatched eggs were counted and recorded as shown in Table 3. The average values of hatched eggs and temperature were determined.

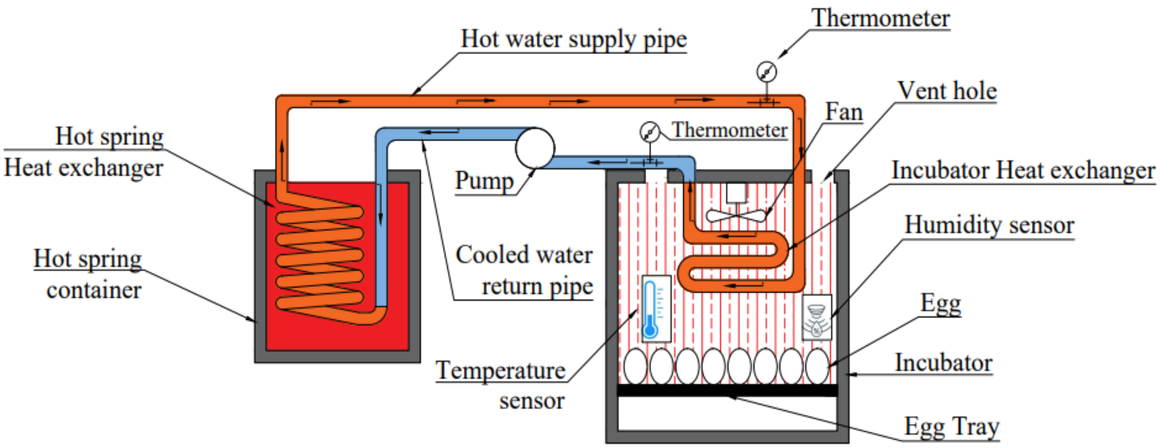
2.4 Development of Heat Balance Model in the Incubation System

The heat balance model was developed for the proposed incubation system that uses hot water as a source of heat. The objective of the model was to establish a constitutive equation of the heat balance that quantifies the amount of heat transferred from hot water to circulating water, to the incubator circulating air, to the eggs and the heat lost to the surrounding. The experimental data as shown in Table 4 was used to validate the model.

The heat balance equation consists of variables: the temperature of water and air media, material properties, the number of eggs, and air flow characteristics. The layout of the incubation system is shown in Figure 7. The assumptions made for the heat balance model were that the copper pipe was relatively thin, the heat transfer was in one dimension radially, the airflow velocity in and out of the incubator was constant, there was no phase change in the hot water and circulating water, and the heat conductivity of heat exchanger materials was constant.

Figure 7

Schematic Diagram of Hot Water Egg Incubator System



3.0 Results and Discussion

3.1 Results from Sensory Unit Test on Improved Incubator

This test was done to find out if the temperature sensor and controller functioned as intended. It was found that, the temperature was increasing as the source of heat was placed near the sensor and decreased as it was moved away from the sensor. The average values of temperature in the sensor surrounding and controller when not heated and when heated were almost equal, respectively, as shown in Table 1. These results showed that the temperature sensor and controller in the improved incubator were functioning accurately.

Table 1

Results on Sensor Surrounding and Controller Temperature Readings

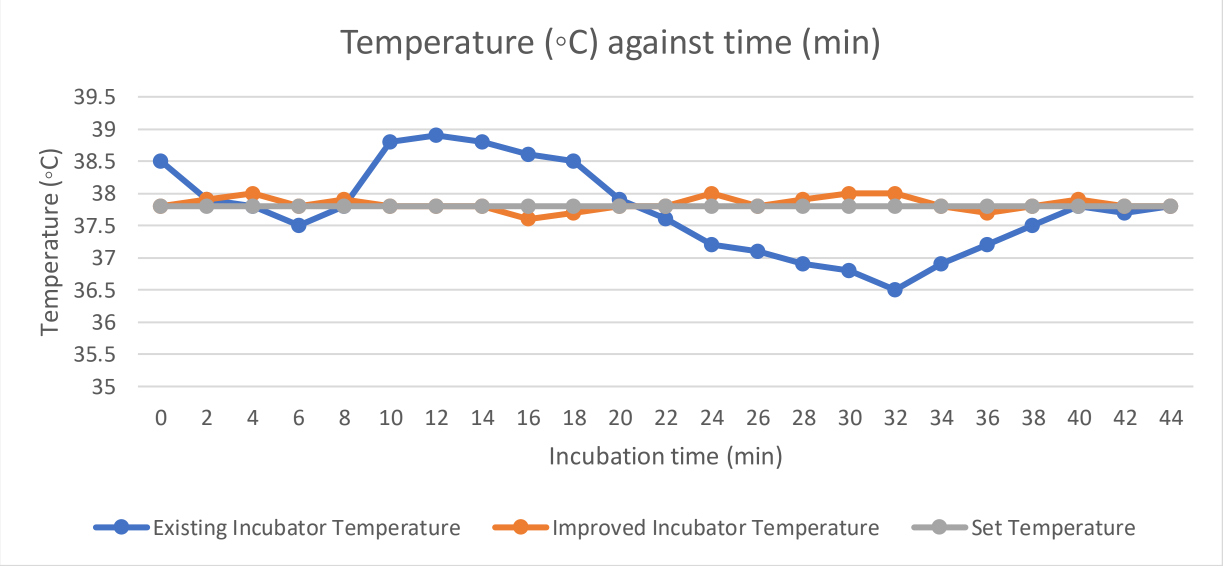
Trial	Not heated		Heated	
	Sensor surrounding temperature (°C)	Controller temperature (°C)	Sensor surrounding temperature (°C)	Controller temperature (°C)
1	25.8	25.8	37.8	37.8
2	26.6	26.5	39	39.1
3	26.5	26.5	39.1	39
Average	26.3	26.22	38.63	38.63

3.2 Results of Temperature Stability

Fluctuation of incubator temperature is mainly attributed to variation of ambient temperature; the fluctuation is due to the change in external weather conditions, which is caused by the amount of sun rays in the morning, day, evening, and nighttime. The temperature distribution curves for existing and improved incubators are represented in Figure 8. In the improved incubator, the temperature had a mean value of 37.83°C and a standard deviation of 0.10°C, while that of the existing incubator had a temperature mean value of 37.3°C and a standard deviation of 0.69°C. The closeness of the mean value to the set value of temperature and the relatively lower standard deviation imply that the temperature in the improved incubator was stable.

Figure 8

Temperature against Time for the Existing Geothermal and the Improved Hot Water Chicken Egg Incubator



The controller in the improved geothermal incubator compensated for the change in temperature and restored it to the set value (37.8°C).

When the temperature in the incubator increased above the set value, the controller progressively decreased the speed of the hot water circulation pump until it stopped, and the ventilation fan started to send hot air outside, and the circulation fan was kept on running to ensure even distribution of temperature in the incubator.

When the temperature in the chamber is decreased below the set value (37.8°C), the controller commands the ventilation fan to stop, and it commands the hot water circulation pump to run with send hot water in the water in internal heat exchanger. The progressive decreasing and increasing of the circulation pump speed reduces temperature fluctuations and the time the incubator takes to restore to set value. This is different from the existing incubator, which is that the controller did not command a variation of speed of the circulation water pump corresponding to temperature change, which led to more temperature variation than in the improved incubator.

3.3 Results on Hatching Efficiency of Improved Incubator

Results from the hatching efficiency test on the number of eggs incubated, chicks hatched, and eggs that were not hatched in the hot water incubator are as shown in Table 3.

Table 3

Number of Hatched and Unhatched Eggs in the Hot Water Incubator

Trial	Total Incubated Eggs	Hatched Eggs	%Hatched Eggs	Unhatched Eggs	%Unhatched Eggs
1	280	248	88.6	32	11.4
2	280	249	88.9	31	11.07
3	280	251	89.6	29	10.4
Average	280	249	89	31	11.07

The improved incubator has a capacity of 280 eggs and an average hatching efficiency of 89%; these are relatively higher than 240 eggs and 84% of the existing incubator, respectively.

3.4 Results of the Heat Balance Model

The results of the heat balance model showed that the heat transferred from hot water to circulating water was 959.77 W, while the heat transferred from circulating water to the incubator was 906.096 W, the heat transferred to the air in the incubator was 902.96 W, and the amount of heat absorbed by eggs in the incubator was estimated as 3.136 W. It was noted that the sum of heat absorbed by the eggs and that transferred to the air equals the total heat transferred from circulating water to the incubator. Results showed that the heat transferred to the incubator from circulating water was less than the heat transferred from hot water to the circulating water by 53.81 W; this was attributed to heat losses by circulating air in and out of the incubator and some insulation losses. Results revealed that most of the heat transferred from circulating water to the incubator was utilised to maintain the temperature of the incubator at 37.8°C as the eggs absorbed a relatively small amount of heat.

4.0 Conclusion

A hot water incubator was designed, fabricated, and tested, focused on improving capacity, stability of temperature, and hatching efficiency. In the improved incubator, egg capacity increased from 240-280 eggs, and hatching efficiency from 84%-89%. The temperature stability was improved from mean 37.3°Cto 37.83°C and standard deviation from 0.69°Cto 0.1°C.

A heat balance model for the hot water egg incubator was developed for the heat transferred from hot water to circulating water, from circulating water to air, and from air to eggs. Results revealed that most of the heat transferred from circulating water to the incubator was utilised to maintain the temperature of the incubator at 37.8°C as the eggs absorbed a relatively small amount of heat, 3.136W. The heat model showed that there was a significant heat loss between circulating water and the incubator, attributed to circulating air in and out of the incubator and some insulation losses.

5.0 Recommendations

The following are recommended as future work to improve the hot water egg incubator. The liquid used for heat transfer in heat exchangers was water. Future study should evaluate heat transfer characteristics by using media other than water. During the experiment, some of the heat was lost through incubator cabinet materials. Future work should evaluate the heat loss in cabinet material.

The improved incubator can also be operated by heat from geothermal resources and waste heat from industries and power plants in the 50°C-100°C temperature range.

6.0 Funding Statement

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8.0 Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix 1

Ambient Temperature, Incubator Temperature and Incubator Water Temp against Time in Improved Incubator

Time (Min)	T_{A1} (°C)	T_{A2} (°C)	T_{A3} (°C)	T_{AA} (°C)	T_{In1} (°C)	T_{In2} (°C)	T_{In3} (°C)	T_{InA} (°C)	T_{W1} (°C)	T_{W2} (°C)	T_{W3} (°C)	T_{WA} (°C)
0	16.4	16.6	16.5	16.5	37.7	37.8	37.9	37.8	44.4	42.2	43.2	43.2
2	16.8	16.7	16.6	16.7	38.0	37.8	37.7	37.9	43.3	43.5	43.1	43.3
4	16.6	16.5	16.3	16.5	38	37.9	38.1	38	42.9	43.8	42.0	42.9
6	16.8	17	16.7	16.8	37.9	37.7	37.8	37.8	42.8	41.9	42.2	42.3
8	17	17.2	17.1	17.2	37.9	37.8	38.0	37.9	44.6	42.8	44.3	43.9
10	17.8	17.9	17.7	17.9	37.7	37.9	37.8	37.8	47.5	46.8	48.5	47.6
12	17.9	17.6	17.9	17.8	37.9	37.8	37.7	37.8	41.4	43.2	43.8	42.8
14	16.4	16.2	17.1	16.6	38.1	37.9	38.0	37.8	41.9	42.3	41.8	42
16	16.3	17.1	16.1	16.5	37.8	37.6	37.4	37.6	43.2	42.7	43.4	43.1
18	16.4	16.9	16.2	16.5	37.7	37.9	37.5	37.7	44.0	43.6	44.1	43.9
20	16.7	16.9	16.5	16.7	38.0	37.8	37.7	37.8	42.6	43.6	43.6	43.1
22	16.5	16.7	16.6	16.6	37.7	37.9	37.8	37.8	43.2	41.2	42.2	42.2
24	16.8	17.2	17.6	17.2	38.1	37.9	38.0	38	42.4	42.2	42.6	42.4
26	17.3	17.1	16.9	17.1	37.7	37.8	37.9	37.8	43.9	40.1	42	42
28	17.1	16.5	16.8	16.8	37.9	37.8	38.0	37.9	42.3	44.2	40.4	42.3
30	16.9	1.2	17.1	17.0	38	37.9	38.1	38	42.3	42.5	42.1	42.3
32	16.8	17.2	17.6	17.2	37.9	37.9	38.0	38	42.4	42.2	42.6	42.4
34	17.0	17.2	17.4	17.2	37.9	37.7	37.8	37.8	43.3	43.4	43.0	43.2
36	17.5	16.8	17.2	17.1	37.7	37.5	37.9	37.7	43.2	42.7	43.4	43.1
38	16.4	16.9	17.1	16.8	37.8	37.9	37.7	37.8	43.1	42.9	43.3	43.1
40	16.4	16.6	16.8	16.6	37.9	37.8	38.0	37.9	43.9	43.4	42.9	43.4
42	16.5	16.7	17.1	16.7	37.7	37.9	37.8	37.8	44.2	43.2	43.7	43.7
44	17.1	16.8	17.1	17	38.0	37.8	37.7	37.8	45.6	45.2	46.0	45.6

Where

T_{A1}- Ambient temperature (°C) for experiment 1

T_{A2}- Ambient temperature (°C) for experiment 2

T_{A3}- Ambient temperature (°C) for experiment 3

T_{In1}- Incubator temperature (°C) for experiment 1

T_{In2}- Incubator temperature (°C) for experiment 2

T_{InA}- Incubator temperature (°C) for experiment 3

T_{W1}- Incubator Water Temp (°C for experiment 1

T_{W2}- Incubator Water Temp (°C for experiment 2

T_{W3}- Incubator Water Temp (°C) for experiment 3

T_{AA}- Average Ambient temperature (°C)

T_{InA} - Average Incubator temperature (°C)

T_{WA} - Average Incubator Water Temp (°C

Appendix 2

Parameters and respective values used in heat balance model calculations

N (R.P.M)	*1850*	*k (W/mK)*	*400*	T_{HH} (°C)	*75*	Q_{HS} (W)	*959.77*
D (m)	0.008	k_A	6.76×10^{-2}	T_{HC} (°C)	70	Q_{in} (W)	906.096
R_f (m)	0.065	v (Ns/m^2)	1.48×10^{-5}	T_{EH} (°C)	62.4	Q_L (W)	53.674
L (m)	1.5	Re	212.8×10^3	T_{EC} (°C)	43.1	Q_A (W)	902.96
t (m)	0.0091	Pr	0.71	T_{A1} (°C)	20	Q_{Eg}(W)	3.136
L_C (m)	0.002	h_A (W/m^{2}K)	2450.23	T_{A2} (°C)	37.8	N_{Eg}	280
A (m²)	0.0377	h_W(W/m^{2}K)	3000	ΔT_{lmHS}(°C)	17.03		
U (m/s)	12.6	U_1 (W/m^{2}K)	1494.9	ΔT_{lmin}(°C)	17.8		
w (rad/sec)	193.73	U_2 (W/m^{2}K)	1344.56				

Key

N-Revolution per minute of the circulation fan

D-Diameter of heat exchanger copper pipe inside the incubator

R_f-Radius of fan

L-Length of heat exchanger copper pipe inside the incubator

t-Thickness of copper pipe

L_C-Characteristic linear dimension of the pipe

A-Surface Area of copper pipe heat exchanger

U-velocity of air

k-Thermal conductivity of copper material

k_A-Thermal conductivity of air

v-Dynamic viscosity of air

Re-Reynold number

Pr-Prandtl number for Air

hA- Convective heat transfer coefficient of air outside the pipe

hw- Convective heat transfer coefficient of liquid inside the pipe

U1- Overall convective heat transfer coefficient in external heat exchanger and container

U2- Overall convective heat transfer coefficient in inside heat exchanger

THH-Temperature of heated water/hos spring before heat exchanger

THC-Temperature of heated water after heat exchanger

T_{EH}–Temperature of supply hot water

T_{EC} –Temperature of return cooled water

T_{A1} –Temperature of ambient Air

T_{A2}–Temperature of heated incubator Air

QHS-Heat transfer from hot spring to the heat exchanger

Qin- Heat transferred from heat exchanger to the incubator

Q_A- Heat transferred to the incubator air

Q_L-Heat lost to the surrounding

Q_{Eg}-Heat transfer from incubator air to the eggs