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Experimental Performance Evaluation of Geothermal Egg Incubator for Hen Egg

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Abstract

The experimental performance evaluation of geothermal egg incubator was conducted with the aim of improving the capacity and efficiency. The study determines the accuracy of the measuring instruments in an incubator, test control parameters (temperature and relative humidity) and evaluates the overall performance of the incubator by examining the number of hatched and unhatched eggs. The data analysis was done and the results show that the measuring instruments, tilting mechanism and ventilation fan performed well. The relative humidity showed to be in proper range while the temperature found to have fluctuations of more than 2˚C from set value and took longer time to restore which led defecting eggs. The improvement will enhance more productions and increase income to individual farmers and Government at large.

Keywords

Temperature, Relative Humidity, Heat Exchanger, Flow Rate, Heat

1. Introduction

In Tanzania, the projections of annual meat and domestic white meat production are expected to rise from 130,000 tonnes in 2017 to 465,600 tonnes in 2020 and from 22,000 in 2017 to 37,200 tons in 2022, respectively [1]. This rise of demands for meat needs a means to overcome it and this can be overcome by developing poultry industry. From poultry activities, poultry products like egg and meat can be obtained and these products have high nutritional value [2] [3] and [4]. Poultry feathers are also used for making pillows, fancy articles and curios. Poultry droppings are rich in nitrogen and organic material and hence, are con-

sidered valuable manures [3]. Poultry offers good full time or part-time employment opportunity to farmers and selling of chicken products such as meat, eggs, feathers and manure can help farmer's economy [3].

The key solution to achieve the rise of poultry production demands is artificial hatcheries which occur after incubation. Incubation is the management of a fertilized egg to ensure the satisfactory development of the embryo inside into a normal chick by ensuring uniform condition of temperature and relative humidity are maintained [5]. This process keeps the fertilized eggs warm in order to allow proper development of the embryo into chick [6]. This process can be achieved by natural way or artificial method. Natural incubation is carried on by mother bird, she lays on the eggs and by doing so the required conditions are achieved until the eggs are hatched in open space [6] and it takes the chicken about 20 - 21 days [7]. This method has some limitations such as low productivity and uncertainty of chicken life. The artificial method is achieved by the use of special designed equipment (incubator) to aid hatching [7]. The incubator is a thermal system that is expected to maintain an amount of heat required to achieve high percentage hatchability of any kind of birds incubated in it with high energy efficiency and at an affordable cost [2]. Artificial method is most preferably especially in large scale poultry production since can hatch more eggs at once, provides a sense of accomplishment and doesn't have to wait for a broody hen to incubate the eggs after laying. The egg with correct conditions (temperature, humidity and ventilation) the biological process of incubation commences and the embryo begins to grow, so correct range of conditions must be sustained throughout the incubation period in order to achieve a higher rate of hatchability [8]. So, the system in an incubator should be modelled properly so as to achieve the correct range of conditions in an incubator as the temperature range from 37˚C to 38˚C [9] and relative humidity range (RH) of 30% - 60% from 1st day up to 18th day [10] and increased to 70% - 80% during the last three days [11] with proper air movement and turning of the egg [5]. For proper air circulation so as to cool overheating and exchange of carbon dioxide and oxygen inside the incubator chamber the speed of the fan can be around 7200 rpm [12]. Artificial method of incubation involves use of energy to generate heat inside the incubator and these sources of energy can be electricity, solar energy, fossil fuels such as kerosene or natural gas and geothermal resource [13].

The existing geothermal egg incubator as shown in **Figure 1** uses hot water which has 74˚C as a source of heat to power incubator. Temperature inside the incubator is controlled by using circulation fan which ensures evenly distribution of heat throughout the chamber. Also, hot water from external heat exchanger to the internal heat exchanger is pumped by circulation pump which stops when there is maximum temperature and starts if the temperature decreases but runs with constant speed. Ventilation fan is used to draw fresh air from outside and sends inside the incubator while removing dirt and hot air from inside the incubator and sends out, this is done when the temperature increases beyond the set value [11]. Humidity is controlled by extracting vapors

Figure 1. Existed geothermal egg incubator for hen egg.

from heat exchanger and there is an evaporating pan inside the incubator which uses hot water to produce vapors. Tilting mechanism with geared motor and chain and sprocket is used to turn eggs at 45˚ clockwise and anticlockwise. The last option in cases of failure of controlling the parameters is alarm which alerts the operator that the system has failed to control parameters and needed to be checked. This incubator can turn 200 eggs into chicks out of 240 eggs which is equal to 84% only, this makes a difference of 16% from 100% which is big loss for production. Temperature, relative humidity, ventilation and turning of eggs during the incubation period significantly affect the hatchability of fertile eggs and chicks' quality sometimes hatcheries can lag behind or lean due to poor incubation conditions controlling [10]. The controller in an existed geothermal egg incubator controls all these parameters but it takes time to stabilize the parameters (much more settling time) in case of fluctuations. This incubator needs evaluation on its performance so as to improve its efficiency.

Research done by [14] in analysis of heat loss and heat exchange in cascade system during development of Smart geo-energy by using cascade direct use of geothermal energy with three applications which are cocoa drying, egg hatching incubation machine and new tourism site called Terapi Panas Bumi in West Sumatera. The temperature and humidity were controlled by allowing the hot water to pass stage after stage from cocoa drier to the tourism potential. The study shows that in heat transfer calculation, it is possible to maintain the required temperature for every stage but did not show the fluctuations of temperature and how long did it take to stabilize the parameters especially in area of interest which is incubator. Then suggests heat exchanger design for optimal temperature control in this cascade system. Another study by (Jr *et al.*, 2018) on examining the use of hot spring as a renewable energy source to replace conventional electrical energy for suitable agricultural process in the Los Baňos area. Utilization of hot spring for agriculture process was explored by use of two fabricated prototypes for water hyacinth drying and incubation of duck eggs for balut. (Balut is the fertilized duck egg that has been incubated for a period of 14 to 18 days, then steamed or cooked for about 20 to 30 min) (Jr *et al.*, 2018). Through

use hot spring incubator, no load test was conducted to explore balut production in an incubator the aim of conducting no load test was to observe the temperature in the hot spring incubator which was closed with three equal evaporating pans while varying the supply of hot spring water in the incubator using the waste valve to monitor the temperature. The findings were duck egg air cell temperatures reached 41.5˚C several times during the study. Study concluded that, further studies should be conducted so as to optimizing the hot spring incubator for duck eggs in order to reduce the operational cost of balut production. On the other hand [9] evaluates the performance of duck egg incubator which uses geothermal source after design. The experiment was conducted by using water header to ensure constant flow rate of hot water to the heat exchanger while varying ventilation opening (three levels 30˚, 45˚ and 60˚) for temperature control and number of evaporating pan (3, 4 and 5 placed at the bottom of incubator) for humidity control. The results show that although the temperature was optimized but it took 1 hour to stabilize temperature. The study suggests that there should be further experiment on developing geothermal incubator, for instance using temperature sensor control sensors (thermostat to open or close the ventilation), controlling the flow rate of the hot spring water to incubator or using an exhaust fan for cooling to maintaining the optimum incubation temperature. Also separating heat exchanger from incubator to increase the size of incubator.

Extensive studies on incubator which uses geothermal as the energy source have offered valuable understanding on geothermal resource utilization for eggs incubation however all of them did not considering control of temperature by type and material used for heat exchanger and flow rate of hot water to the heat exchanger as admitted by [9]. This research was done as the among of the specific objectives so as to improve the capacity of geothermal egg incubator at Songwe hot spring.

2. Materials and Methods

2.1. Description of Study Area

A potential study area was located and conditions of the site such as the temperature of the hot spring, ambient temperature and the wet bulb temperature was measured. The potential study area selected was located at hot spring which is found in Momba village 30 km North East of Mbeya Tanzania. The hot spring is characterized with temperature between 30˚C to 80˚C.

2.2. Experimental Set-Up

The existing geothermal egg incubator with capacity of 240 eggs were prepared and tested by conducting three separate types of experiments so as to evaluate performance of geothermal egg incubator at Songwe hot spring.

Firstly, experiment to determine the functionality of the measuring instruments in an incubator (sensory unit test) was conducted by connecting positive and negative terminals of the temperature sensor to 5 V supply and ground respec-

tively and the output terminal to microcontroller then microcontroller was activated and took the reading from surrounding as initial reading sensed by sensors. The matches were lightened up and placed near the temperature sensor while reading on the display to observe increase in temperature and then taken away from sensor to observe decrease in temperature. Then, a piece of cloth was wrapped around a small stick and dipped into water bowl then placed near the humidity sensor while taking the reading from the display to observe increase in humidity and then taken away from sensor to observe decrease in humidity as shown in Figure 2 below.

Secondly, experiment to test controlled parameters of the incubator (no load test) was conducted. This experiment involves starting the incubator and testing overall systems performances of measurement and control of temperature, humidity, turning system and air ventilation system. The incubator was started and left to run without eggs placed in it (no load) by setting the temperature 37.8˚C, relative humidity set 58%, 7200 rpm speed of ventilation fan and the time interval of tilting as 4 times a day which is every 6 hours. The incubator left running for 2 days (48 hours) while observing for stabilizing the parameters and the time it takes to increase or decrease the values in case changes occurred after every three hours and values obtained was recorded as described in Figure 3 below. During the experiment the ambient temperature were recorded correspondingly to temperature in incubator display and calculated the average which was 16.9˚C.

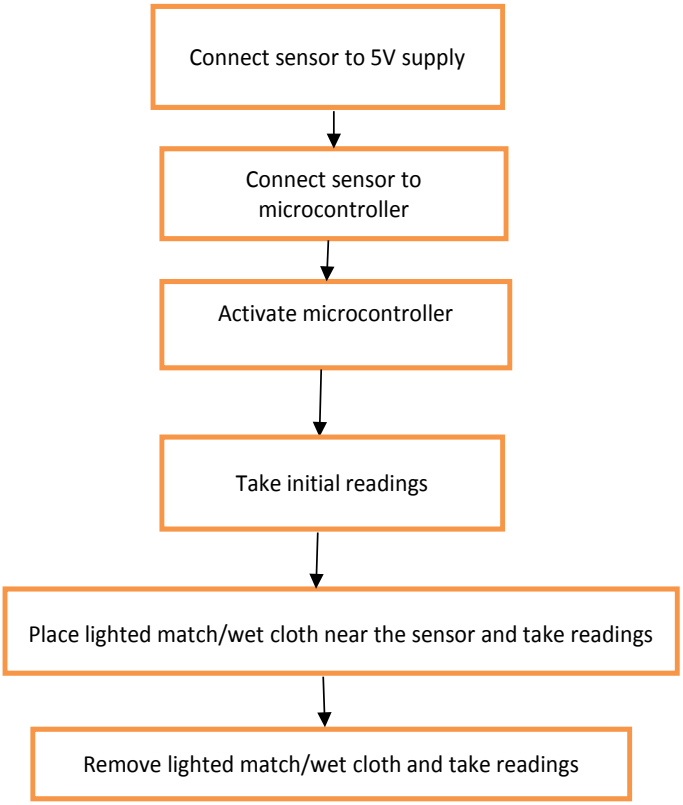

Figure 2. Experiment 1 set up.

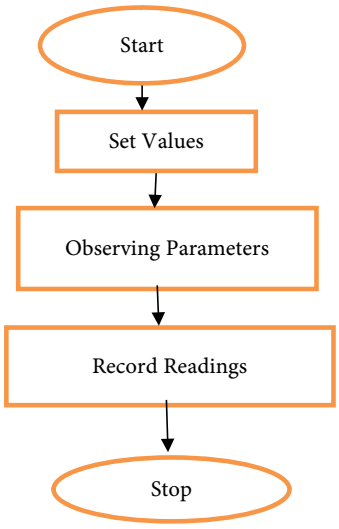

Figure 3. Experiment 2 set up.

Lastly experiment to test overall performance of incubator by checking the number of hatched and unhatched eggs was carried out. In this experiment, 240 clean eggs which are well developed, matured, fertilized and healthy was selected and candled to check size of air cell and placed in the incubator and the incubator was started. During the incubation the values of temperature and relative humidity was checked while insuring if the eggs are tilted. This stage lasts from 1st day up to 18th day and the eggs were candled at various stages of incubation to explore the size of the air cell. After 18th day the temperature was reduced to 36˚C and relative humidity increased to 70% and this last up to 21st day. The final step was to assisting chicks during the hatch for those chicks failed to break the shell. The larger holes were broken on the eggs starting with two holes from the air cell end of the egg. Then the number chicks and unhatched eggs was counted and recorded.

3. Results and Discussion

3.1. Sensory Unit Test

Results in determining functionality of measuring instruments in an incubator shows that temperature sensor and humidity sensor performing the intended functions properly since the temperature was increasing as source of heat was placed near to the sensor and decreased as taken away from the sensor as well as humidity was increasing as the wet cloth placed near to the sensor and decreased as taken away from the sensor. This implies that there is no problem with sensor and controller.

3.2. Temperature and Relative Humidity Analysis

Results in experiment to test controlled parameters of the incubator in measuring and controlling of temperature, humidity, turning system and air ventilation system are described below

3.2.1. Temperature Analysis

This was the main experiment and results shows fluctuations of temperature and it took some minutes to retain into set value as presented in **Figure 4** and **Figure 5** below. **Figure 4** based on one hour and **Figure 5** shows average temperature based on two days at interval of three hours

The change in ambient temperature affects the temperature inside the incubator as when the ambient temperature decreased the incubator temperature was also decreased and vice versa resulting to frequent fluctuations of temperature in the chamber. These fluctuations are due to change in external whether conditions which caused by amount of sun rays in morning time, day time, evening time and night time and purposively the door was opened and closed to distract the conditions inside the incubator. The controller was trying to compensate the change to restore the set value, which was 37.8˚C. When the temperature was increased, the controller stopped the hot water circulation pump and starting the ventilation fan to send hot air outside and circulation fan was kept on running to ensure evenly distribution of temperature in the chamber. When the temperature in the chamber decreased the controller stopping, the ventilation fan and starting the hot water circulation pump to send hot water in the internal heat exchanger. The starting and stopping make many fluctuations although there were some times the temperature was stabilized but it took some minutes to restore set value when there were deviations. The speed of the pump was constant hence was not increasing and decreasing the mass flow rate of hot water to affect change in temperature progressively at short time since the heat transfer increasing with increase water flow rate and decrease with decrease in water flow rate [15].

3.2.2. Relative Humidity

The results of relative humidity are as presented in **Figure 6** below.

The fluctuations in relative humidity were within the range although the set value was constant value but for incubation of hen eggs, there is a range of relative humidity that is effective for incubation. The relative humidity (RH) of 30% - 60% is needed for effective incubation [10].

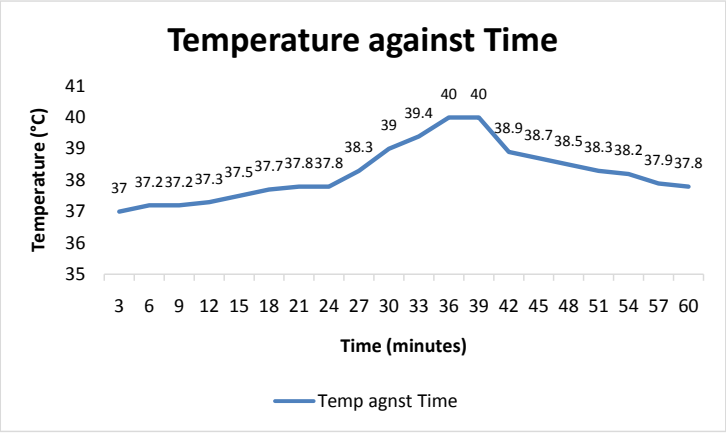

Figure 4. Graph of Temperature against Time for period of 1 hour.

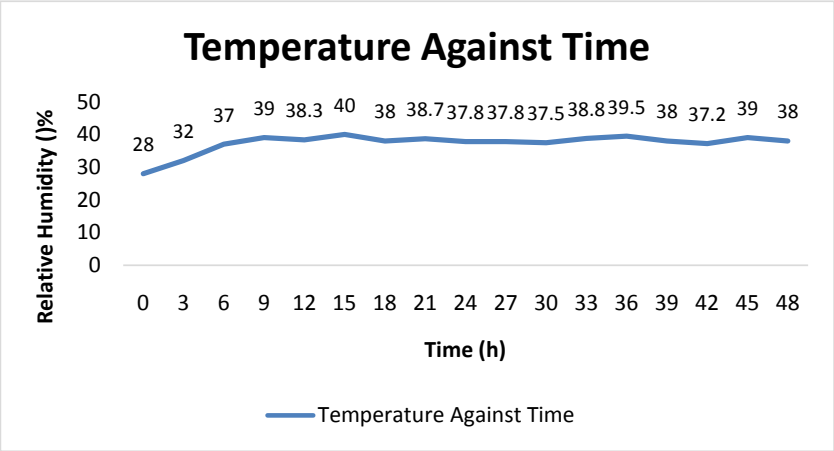

Figure 5. Graph of Temperature against Time for period of 2 days.

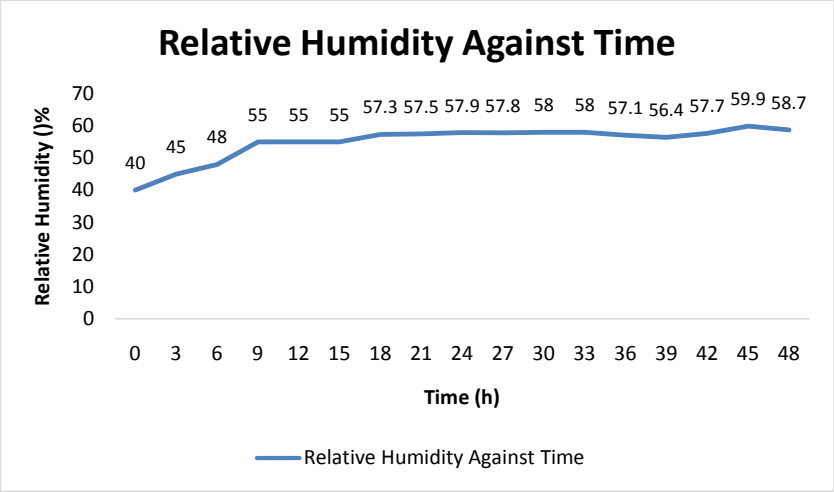

Figure 6. Graph of Relative Humidity against Time.

These fluctuations are due to change in external whether conditions which caused also by amount of sun rays in morning time, day time, evening time and night time and purposively the door was opened and closed to distract the conditions inside the incubator. Results in relative humidity imply that there is problem in achieving relative humidity control in required range.

3.3. Egg Turning and Air Ventilation System

The results of tilting mechanism showed that there is very minimum delay and advancing of tilting eggs by 0.05 seconds, which is negligible since it has no effect in effectiveness of egg hatching. The ventilation fan also run properly with 7200 rpm hence the circulation of air was standard.

3.4. Overall Performance of Incubator

Results in this experiment shows number of chicks hatched and number of eggs, which are not hatched as shown in **Table 1** below.

Table 1. Shows descriptions of eggs after experiment.

Eggs in Incubator	Hatched Eggs	Unhatched Eggs
240	200	40

The control mechanism which includes sensors (temperature and humidity sensor) micro-controller and actuators (ventilation fan and water pump) has tried to restore set values which are temperature 37.8˚C and relative humidity 58% every time the deviations occurred, but as it took (16 - 20) minutes to restore to the set values some eggs are unhatched. This is because the incubator run at above range of temperature required for incubation for average of 18 minutes. Although if the incubator drops below or rises above the range for number of hours high mortality is occurred or all of the eggs may not hatch [16] so some eggs were not hatched because incubator deviates the range and took average of 18 minutes to restore. The efficiency of the incubator is 84%, which is 16% from 100%.

4. Conclusions

The measuring instruments have demonstrated proper functionality since there were corresponding change (rise and decrease) of temperature and relative humidity when tested. This implies that both temperature and humidity sensor was in good condition. Temperature fluctuations took average of 16 - 20 minutes to retain to set value and this was due to control mechanism that only allows the flow of hot water with constant flow rates.

These fluctuations and the time it took to restore the set value was the reason for egg defecting that is other eggs were not hatched although were clean, healthy and fertilized. This was due to constant flow rate of hot water between heat exchangers which if it was controlled and flow changes depending on temperature requirements the time to retain into set value would be short.

The part of tilting and ventilation were in proper functionality since the eggs were tilted 4 times after every 6 hours as intended. Ventilation fans also were performing properly around set value, which is 7200 rpm, and at required time. The overall performance of an incubator was 84%, this was due to death and unhatched eggs in an incubator which was caused by improper control of parameters required for effective hatchery especially temperature.

Recommendations

There should be further researches so as to improve stabilization of parameters inside the incubator especially temperature by ensuring the control mechanism takes very short time to restore into set value after fluctuations. This can be solved by controlling flow rate of hot water from external heat exchanger into internal heat exchanger.

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Conflicts of Interest

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

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