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Using Thermochemical Materials as a Heat Source for Poultry Egg Incubation

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Abstract

This study aims to use one thermochemical storage materials system as a heat source for poultry egg incubation. Three types of activated thermochemical storage materials (TCMs) were used as an energy storage medium. These materials are Silica gel self-indicating (blue/pink), commercial white Silica gel, and Natural Zeolite. An open thermochemical system was applied inside a poultry egg incubator. The TCMs were humidified by the vapor produced from the evaporation of the water by an ultra-sonic humidifier at atmospheric pressure. The thermal recovery process aims to release the stored energy in TCMs. Two types of poultry egg incubator used during this study. The first one was the traditional poultry incubator (electricity incubator). The traditional egg incubator dimensions were 57×66×59 cm with capacity of 125 hen egg-76 hatching. The second one was the prototype of a thermochemical poultry egg incubator. The thermochemical poultry egg incubator contained sensors to control and measure the temperature and humidity inside the incubator. The designed incubator egg dimensions were 56x39x28.5 cm, with a capacity of 25 eggs. The total heat losses by the wall and ventilation were 9.8 and 1.5W, respectively. The heat production by 25 eggs due to metabolic activities was 3.65 W. The total energy needed for the incubation process was 36.09W. The container of storage material with dimensions of 35x35x5 cm with 3.5 kg capacity allocated inside the incubator. The container's surface is covered with aluminum sheet with 0.5 mm thickness supplied with fins. The egg tray is placed on the aluminum sheet, and the eggs were placed horizontally in the tray. The energy consumption for traditional and thermochemical incubators for 21 days was 19.25 kWh and 11.2 kWh, respectively. The energy-saving by thermochemical prototype incubator was 41.8%. The percentage of hatchability for traditional and prototype incubator was 80.9% and 71.4%, respectively.

Keywords: Energy storage; Hatchability; Incubation; Poultry incubator; Thermochemical system; Thermochemical materials.

1 Introduction

The thermochemical system is classified as adsorption and absorption heat storage. The adsorption means the interaction happens between the sorbate (as water usually) particles and the surface of TCMs (Vasta et al 2018).

The thermochemical system cycle includes endothermic and exothermic reactions; between two reactions, the storing energy happened. The endothermic reaction (charging process) happens by using heat to separate the sorbate from TCMs. After this process, The TCMs is active, and the energy is stored inside it. The sorbate and TCMs are connected one more time by the endothermic reaction (discharging process) (Haji 2010).

Silica gel and Zeolite are most used in the thermochemical system (Hauer 2007). The TCM Silica gel is widely used in thermochemical applications. It releases the energy inside it by the adsorption process (humidification process). It can be a good option for low expensive TCMs. The endothermic reaction happened by heat sources working with low temperatures (< 100◦C), as flat plate solar collectors (Ding, 2012; Mette et al 2012; Vasta et al 2018). There are two types of Zeolites, natural and synthetic. Natural Zeolite is an aluminosilicate mineral and exists in nature (Zhao 2010).

The process of poultry egg incubation consists of two periods, the incubating and hatching period. The incubation period starts from 1 to 18 days, and the three days after 18 days is the hatching period (19-21 days). The range of temperatures during the incubating and hatching period (37.7-39.3 ◦C) and (37.8-36°C), respectively. In general, the range of temperatures during incubation should be between (36-39°C) as mentioned by (Okonkwo and Chukwuezie 2012; Kyeremeh and Peprah 2017; Dalangin 2019).

(French 1997). The tolerance of incubation temperature depends on the temperature is low or high, the length of this period, the stage of embryo growth. The embryos are more sensitive to any changes in the first incubation period's temperature in the late period. (Wafadar and Puls 2011) mentioned that the drop in incubation temperature delays the chick hatching but the increase in temperature more harmful.

The relative humidity in the incubator ranged between (50 to 55%) during the incubated period. At the last three days must be reached to (65-75%) (Umar et al 2016).

Two types of poultry hatchery machines the first working by electricity and the second with fossil fuels. One of the most critical problems of hatcheries that operate with electricity is the high value of the electricity bill, the power outage, and the unavailability of electricity in remote areas. The hatcheries working by fossil fuel produce harmful gases that influence the embryos and the surrounding environment. As a result, attempts began to use renewable or clean energies to be the energy source needed for the incubation process (Okonkwo and Chukwuezie 2012; Abraham et al 2014; Uzodinma et al 2020). Therefore, from the previous studies, to avoid the electricity costs and negative effects of using fossil fuels. This study aims to apply the thermochemical system as a source of heat needed for the incubation process instead of the traditional source (electricity) or fossil fuel and create a prototype for a poultry incubator and try to provide the conditions for the incubation of poultry eggs.

2 Materials and Methods

This research was used as an open system with three types of TCMs that specifications showed in **Table 1**. The system consists of a working fluid (air) and a TCMs. The system operates at atmospheric pressure. The thermochemical poultry egg incubator prototype consists of three units, the basics component, the thermochemical unit, and the measuring and control unit, as shown in **Fig 1**.

The first unit consists of a Styrofoam box with dimensions (incubator frame) (56x39x28.5) cm. The egg tray with dimensions (31x31x5) cm with capacity of 25 eggs, the eggs located horizontally. Turning motor (4 W), (3-4 rpm) equipped with the egg tray to rolling the eggs in a straight line to forward and back as shown in **Fig 2**. A humidifier (19W), and spray volume 300ml/h was used as separate part outside the incubator to supply the incubator with the required humidity levels (55-75%) **Fig (1. No.10)**. The incubator is provided with three ventilation holes with a diameter of 1 cm for each hole and a fan (12V-0.14A) for ventilation and air circulation.

The second unit, the thermochemical unit, consists of four parts.1) The material storage container is made of wood, with dimensions (35x35x5) cm and capacity (3.5) kg from TCMs. 2) Vapor pipes, it is made from poly Ethelene **Fig (1. No. 8)**. Three pipes of 2.54 cm (1 inches/pipe) diameter pass through each hole in the material container. These pipes are perforated (1 mm/bore)**.** 3) The humidification storage material unit **Fig (1. No. 4, 5, 6, 7, 8)** consists of the water tank (2L capacity), ultrasonic humidifier, atomizer quantity (250-300 mL/h), water level (2.1cm above ultra-sonic humidifier body), working temperature (5-45◦C), float to maintain the water level in the tank, solenoid valve to supply the water tank by water. The fan (12V DC, 0.14A) pushes the water vapor to the perforated pipes. 4) Aluminum sheet, the storage material container is covered with an aluminum sheet (38.5x38.5) cm, thickness 0.5 mm, and supplied with fins (4x5) cm to increase heat exchange between the material and aluminum sheet.

The third unit, measuring unit, and control unit, monitoring unit, and data logging unit. 1) The measuring unit consists of two DHT22 - temperature and humidity sensors installed in storage material containers. The first is located in the upper layer of storage material; the second is located in the lower layer in storage material **Fig (3)**. Two DHT22 - temperature and humidity sensors to measure (incubator air and ambient air, temperature and humidity).

DS 18B20 temperature sensors are used DS 18B20 to measure (aluminum sheet surface temperature- temperature between eggs). Moreover, control unit as shown in **Fig (4),** DS1307 – real-time clock module (RTC) to control turning eggs for (3 seconds per hour). DS 18B20 temperature sensors to control ultrasonic material humidifier switch it off at 40 ◦C. Humidistat (SK3118-5(0.2) A-24-250V-made in Italy) to control in incubator humidifier at humidity level (55-75%). A bulb (40W) was functioned with switch off when the temperature ≥ 37.5 ◦C by the sensor DS 18B20 is located in the incubator center. 3) Monitoring unit, it used to show the temperature and humidity in various locations during the experiment. 4) Data logging unit, it is used to record the temperature and humidity value every minute. It consists of an Arduino Mega2650 board – microprocessor and microcontrollerDS1307 - real-time clock module (RTC) and SD card module. Generic benetech GM86 LCD display micropower monitor energy meter max 10A-220V Ac operating temperature 0-45°C was used to measure energy consumption.

Table 1. Specifications of thermochemical materials (TCMs)

Thermochemical materials (TCMs)			
Specifications	**Silica gel self-indicating**	**Silica gel-white**	**Natural Zeolite**
Synonyms	Adsorbent, Desiccant	Adsorbent, Desiccant	Adsorbent, Desiccant
Size	(0.841-3.36 mm)	2-5mm	3-10mm
Case number	112926-00-8	63231-674 1343-98-2221	————
Chemical Formula	SiO_2+$cocl_2$	SiO_2+nH_2o	(ca,k2,Na2,Mg)$_4$$Al_8Si_{40}O_{96}$.24$H_2o$
Bulk Density	650-850kg/m^3	450-750 kg/m^3	1150 kg/m^3
Color	Blue - pink	white	gray
Charging temperature	80-88◦c	80-88◦c	100◦c-130◦c
Discharging temperature	32-38◦c	32-38◦c	38-42◦c

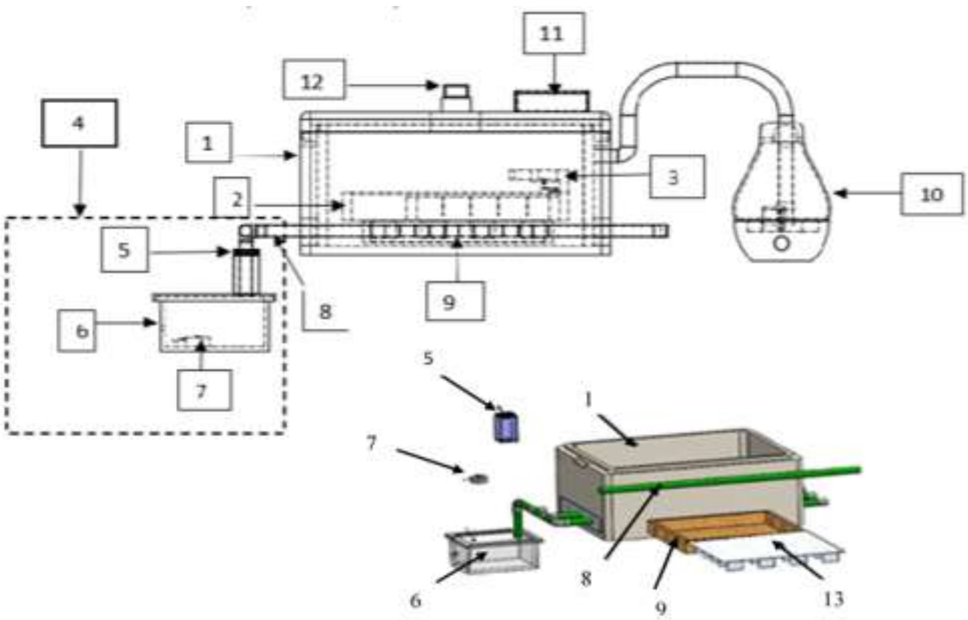

Fig 1. The thermochemical poultry egg incubator prototype components,1- The incubator frame, 2- eggs tray, 3- turning motor, 4- material humidification unit, 5- fan,6- water tank, 7- ultra-sonic humidifier, 8- vapor pipes (perforated pipes), 9- storage material container (TCMs), 10- humidifier for incubator atmosphere, 11,12- display for temperature and humidity,13- Aluminum sheet

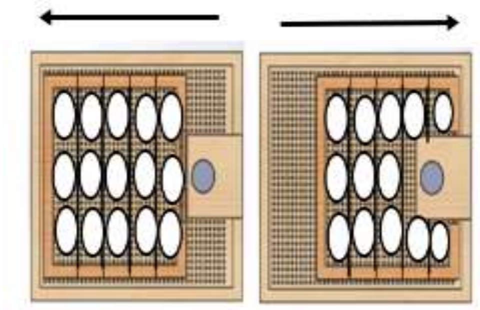

Fig 2. The egg tray with 25 eggs and turning motor capacity, the eggs turn straight forward and back.

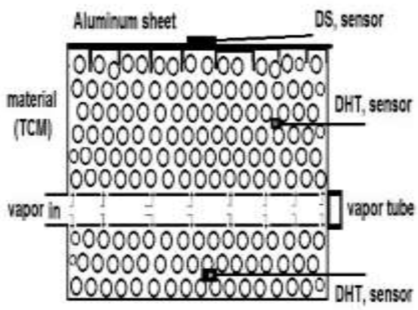

Fig 3. The storage material container covered with aluminum sheets and sensors locations, where: - DS measures aluminum sheet surface temperature, DHT sensor measures storage ma-

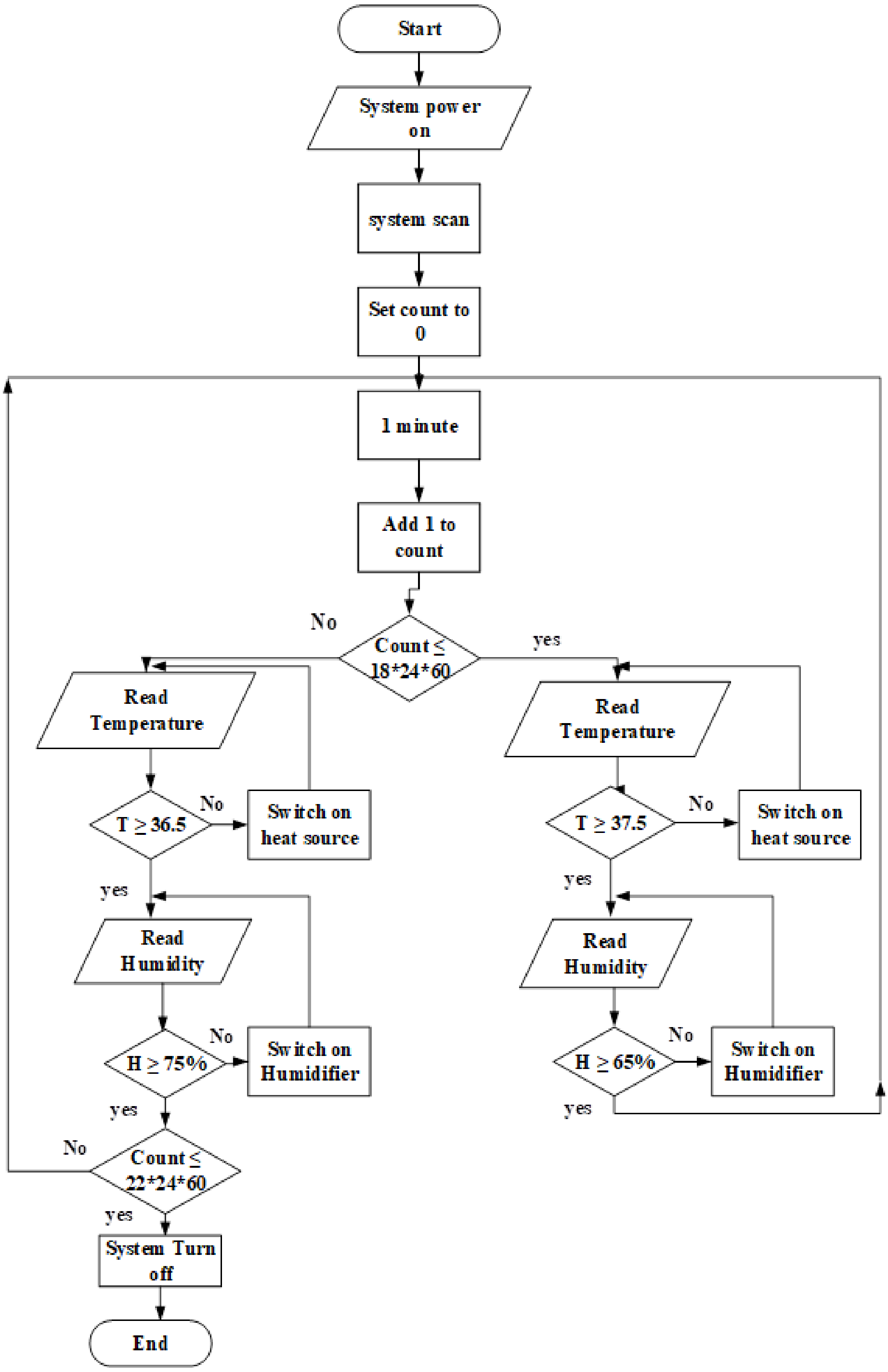

Fig 4. The control of the temperature and humidity inside the thermochemical poultry egg incubator flowchart

The second incubator was the traditional type of poultry egg incubator poultry model C2 as shown in **Fig 5** made by "PTO incubators industrial company" with maximum power 250 W. The dimensions of incubator were (57×66×59) cm, with capacity 125 hen egg- 76 hatching. The frame of the incubator has special fiber insulated (three layers of insulation) polystyrene panels in high density and reinforced inside. The eggs are turning one cycle/h with angle 45º clockwise and 45º anti-clockwise direction. The egg tray is made of plastic, with a capacity of 76 hen eggs with dimensions (34x48) cm. Fan located in the one side of incubator; this fan is working to circulate the air to improve temperatures. Electric resistance heater for incubators for the heating process. Digital thermal measurement (sensor) to measure temperature (Fº or Cº). Hygrometer used to read relative humidity. The ventilation happens by two holes, one on the left side and another in the incubator's backside.

During this experiment, using DHT22 - temperature & humidity sensors located in the poultry egg incubator center to measure incubator air temperature and humidity. DS 18B20 – temperature sensors located in the center of egg tray between eggs to measure the eggs' temperature. As shown in **Fig 6**.

2.1. Energy analysis for recovered thermal process

A working fluid can recover the energy released by the exothermic reaction in an open thermal energy storage (TES) system. The working fluid in the open system is humid air. When the ultra-sonic humidifier produces water vapor, the fan pushes it into the vapor pipes. The water vapor comes out of the holes in the perforated pipes located inside the material. The water vapor combines with the material, which produces heat that is transferred to the aluminum sheet that covers the material, then to the egg tray installed on the aluminum sheet.

The energy transferred by the material is happened by conduction between the layers of material (R_{cond1}) then between the material surface and the aluminum sheet (R_{cond2}), then from the aluminum sheet to the incubator air by convection (R_{conv}) as shown in **Fig 7**.

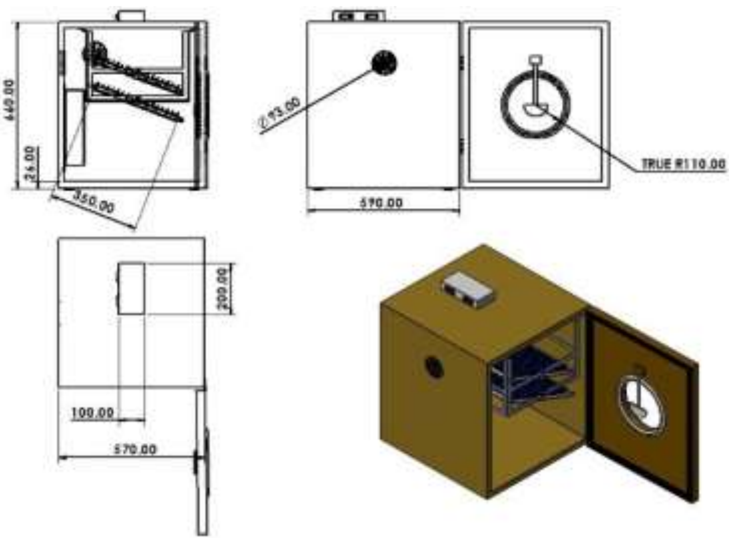

Fig 5. The traditional poultry egg incubator

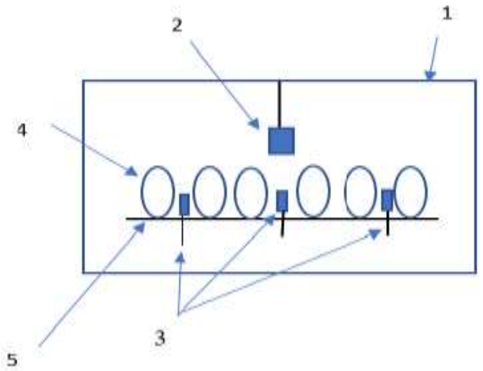

Fig 6. sensors location inside traditional poultry egg incubator, 1-incubator body, 2- DHT22 - temperature & humidity sensors, 3- DS 18B20 – temperature sensors, 4- egg, 5- egg tray

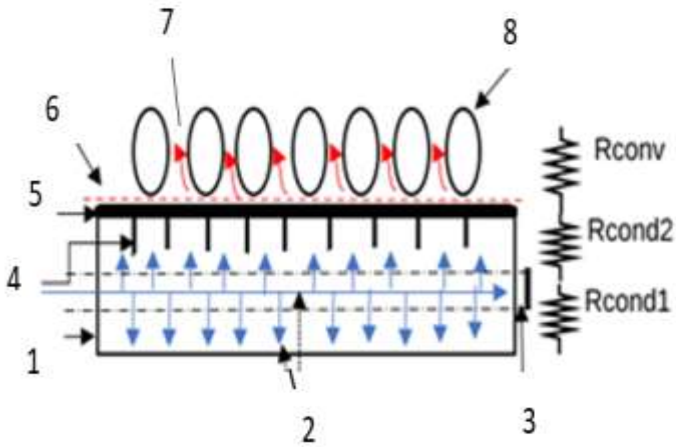

Fig 7. Illustration of the process of recovering thermal process and heat transfer from TCM to the aluminum sheet to eggs where: - 1- the storage material container, 2- vapor flow, 3- perforated vapor pipes, 4- fins, 5- aluminum sheet, 6- the egg tray, 7- heat flow, 8- egg

Where: $R_{cond1,2}$ is the thermal resistance by conduction, and R_{conv} is the thermal resistance by convection, ◦C/W. It can be expressed using the following equation to calculate the thermal energy recovered from the material:

$$Qout_{=}\, h_a\, A_{al}\, (T_{al} - T_{air}) \qquad (1)$$

Where: $Qout$ is the heat released by (TCMs), W. h_a is the convection heat transfer coefficient, (W/m^2. ◦C). A_{al} is the surface area of aluminum sheet, m^2. T_{al} and T_{air} is the temperature surface of aluminum sheet and the air temperature inside the incubator, ◦C. It can calculate h_a as forced convection as shown in the following equation:

$$h_a = \frac{N_u\ K_{air}}{l_c} \quad (2)$$

$$R_{e=}\frac{u_\infty\, l_c}{\upsilon} \qquad (3)$$

Where: N_u is the Nusselt number, K_{air} is the air thermal conductivity, W/m.◦C.l_c is the characteristic length, m. R_e is the Reynolds number. U_∞ is the air velocity, m/s. l_c is the characteristic length, m. υ is the air kinematic velocity, m^2/s.

2.2. The Total heat requirement for poultry egg incubator

The following equation can be used to calculate the total heat required for incubation (Victor Ukaamaka et al 2015; Osanyinpeju et al 2016; Demissie 2020).

$$Q_t = Q_a + Q_e + Q_v + Q_s \quad (4)$$

Where, Q_t is the total heat required for incubation, W. Q_a is the heat required to raise the temperature of incubator air, W. Qe is the heat required to raise the temperature of the egg from ambient temperature to incubation temperature, W. Qv is the heat loss by ventilation, W. Qs is the heat losses throw the walls of the incubator, W.

2.2.1. The heat required to raise the temperature of incubator air (Q_a)

$$Q_a = M_a\, C_p\, (T_f - T_i) \quad (5)$$

Where: Ma is the mass of air, kg. Cp is the specific heat of air, kJ/kg. ◦C. T_i is the initial air incubator temperature (20◦C). T_f the final incubator temperature or the incubation temperature (38◦C).

The warming rate expressed about the raising of egg temperature from room temperature to incubation temperature with the time. It can be calculated by the following equation (Woldegiorgis and Meyyappan, 2018).

$$The\ warming\ rate = \frac{(T_f - T_i)}{time\ needed\ for\ raising\ the\ temperature} \quad (6)$$

2.2.2. The heat required to raise the egg's temperature from ambient temperature to incubation temperature (Qe)

$$Q_e = n\, M_e\, C_p\, (T_{ie} - T_{oe}) \quad (7)$$

Where: n is the number of eggs. M_e is the weight for the egg as an average of 60g. C_p is the specific heat of egg (3.23 kJ/kg. ◦C) as mentioned in (ASHREA Handbook-Refrigeration 2014). T_{ie} is the egg temperature inside the incubator, ◦C. T_{oe} is the egg temperature outside the incubator, ◦C.

The warming rate expressed about the raising of egg temperature from room temperature to incubation temperature with the time. It can be calculated by the following equation.

$$The\ warming\ rate = \frac{(Toe - Tie)}{time\ needed\ for\ rasing\ the\ temperature} \quad (8)$$

(Lourens et al 2006) mentioned that, due to the activities of metabolic the embryo produced heat production at day18 137 mW/egg and 155mW/egg. In this study an average of heat production 146mW/egg was used.

2.2.3. The heat losses by ventilation (Qv)

The levels of oxygen, carbon oxide, and relative humidity affect the embryo development, so ventilation is so essential to keep these factors within the applicable limit (Daud et al 2019). The number of times the air is changed depends on the development of the embryos and their needs of O_2, CO_2 and relative humidity. So, the changes of air per hour (ACH) can be once/3h as mentioned by (Mauldin 2002; Osanyinpeju et al 2016) or once/2hours (Daud et al 2019) but (Woldegiorgis and Meyyappan 2018) showed that the suitable value 4 ACH. The losses of heat by ventilation can be expressed as follows:

$$Q_v = V\, \rho_a\, C_p\, (T_i - T_o) \quad (9)$$

To determine the mass of air, it can use this equation.

$$\rho_a = \frac{M_a}{V} \quad (10)$$

Where: V is the air volume changed, m^3. ρ_a is the density of outlet air (Agidi et al 2014). Cp is the air specific heat capacity kJ/kg. ◦C. T_i and T_O is the air temperature inside and outside the incubator, °C.

2.2.4. The heat losses through the walls of incubator Qs

The heat losses through the incubator walls happen in three ways conduction, convection, and radiation. It can use the following equation to calculate the heat losses through the incubator walls.

$$Q_s = \frac{T_{\infty 1} - T_{\infty 2}}{\sum R_{th}} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{rad} + R_{conv} + R_{cond}} \quad (11)$$

Where: $T_{\infty 1}$ is the ambient temperature (room temperature), °C. $T_{\infty 2}$ is the air temperature inside the incubator, °C. R_{rad}, $R_{conv,}$ and R_{cond} are the thermal resistance by radiation, convection, and conduction, °C/W.

The following equation was used to calculate the losses through incubator walls that happens by radiation.

$$R_{rad} = \frac{1}{h_{rad}\ A} \quad (12)$$

Where: R_{rad} is the thermal resistance by radiation, °C/W. h_{rad} is the radiation heat transfer coefficient (W/m^2. K). A_1 is the surface area of the incubator wall, m^2.

$$h_{rad} = \varepsilon\, A_s\, \delta\, (T_{s1} + T_{sur})(T_{s1}^2 + T_{sur}^2) \quad (13)$$

Where: $\boldsymbol{\varepsilon}$ is the surface emissivity, $0 \leq \varepsilon \leq 1$. A_S is the surface area, m^2. δ is the Stefan-Boltzmann constant; $\delta = 5.67*10^{-8}$ W/m^2. K^4. Ts is the surface temperature, K. T_{sur} is the surrounding temperature, K.

The radiation and convection losses happen to parallel, so; it must calculate equivalent resistance R_{eq}.

$$R_{eq} = \left(\frac{1}{R_{conv} + R_{rad}}\right)^{-1} \quad (14)$$

The losses through incubator walls that happen by forced convection can be calculated by the following equations.

$$R_{conv} = \frac{1}{h\ A} \quad (15)$$

Where: R_{conv} is the thermal resistance by convection, ◦C/W. h is the convection heat transfer coefficient (W/m^2. °C). A_1 is the surface area, m^2.

$$h_1 = \frac{N_u\ K_{air}}{l_c} \quad (16)$$

Where: N_u is the Nusselt number, K_{air} is the air thermal conductivity, W/m. ◦C. l_c is the characteristic length, m.

$$R_{e=} \frac{u_\infty\, l_c}{\upsilon} \quad (17)$$

Where: R_e is the Reynolds number. u_∞ is the air velocity, m/s. l_c is the characteristic length, m. υ is the air kinematic velocity, m^2/s.

2.3. The energy consumption and costs

Total operating cost = total power consumption (kW.h) x the cost of unity (LE/ kW.h). (18)

Energy saving = (traditional incubator total energy consumption – thermochemical incubator total energy consumption) / traditional incubator total energy consumption. (19)

2.4. The biological performance for the incubation process

It can be expressed the biological performance by calculating the percentage of hatchability the poultry eggs as shown in Eq. (20). (Osanyinpeju et al 2016; Saravanan and Pasupathy 2016; Dalangin 2019; Uzodinma et al 2020).

$$\text{Hatchability \%} = \frac{\textit{the total number of eggs hatched}}{\textit{the total number of fertile eggs}}\ x\ 100 \quad (20)$$

3 Results and Discussions

This study contains two experiments. The first experiment's target was to test the storage materials or TCMs ability to provide suitable thermal conditions for the incubation process without eggs. To achieve this target, 1) The TCMs was humidified to release the recovered thermal that stored inside it and measured the temperature of the material, the surface of aluminum sheet and the places where the eggs were located, 2) The calculation of both the rate of humidification and the recovered thermal. The recovered thermal period (retention time) for storage materials. 3) Select the suitable storage material for the incubation process.

The second experiment was incubation eggs by TCMs as the source of heat. The temperature and relative humidity were measured and controlled around 21 days of incubation.

3.1. The first experiment without egg

3.1.1. The thermal energy recovered from TCMs

The optimal thermal energy recovered as shown in **Fig (8)** from thermal storage materials (Silica gel self-indicating, white Silica gel, and Natural Zeolite) were 0.0612, 0.0437 and, 0.074 kWh/kg, respectively. It can be observed that the amount of recovered thermal is small in the beginning because the amount of moisture saturation is also small. With time, the saturation of material increases, and the amount of recovered thermal increases to reach its maximum value and then begin to decrease. This curve can help determine the time needs to replace the saturated storage material with a new activated TCM.

The recovered thermal process lasted for six days for storage materials Silica gel self-indicting and Natural Zeolite. The cumulative recovered thermal energy from storage media (Silica gel self-indication, Silica gel white, and Natural Zeolite) were 0.165, 0.080, and 0.124 kWh/kg, respectively. In general, the cumulative recovered thermal for Silica gel self-indicating higher than Natural Zeolite and white Silica gel by 0.041, 0.085 kWh/kg, respectively. Commercial white Silica gel recovered thermal did not remain more than three days. The thermal energy recovered decrease after the second day, due to the non-reversible damage happened to the particles of commercial white Silica gel (broke into minimal parts).

3.1.2. Calculation thermal recovery through storage materials humidification rate

With an increasing humidification rate of storage material, the thermal recovered energy of storage material increases as the storage material temperature increases. The temperature of TCMs and recovered thermal reach to the maximum value decreases with increasing humidification rate, as shown in **Figs (9, 10, 11)**. This result means that the storage material does not need to be fully saturated to release all the energy inside it. This curve can be helped to determine the humidification rate required for the storage material to produce the maximum temperature and recovered thermal.

3.1.3. The storage material temperatures and incubation temperature.

The optimal temperature difference between the incubating and hatching period around 1.5°C (37.5 – 36°C), so the incubation thermal tolerance ± 0.75°C. As shown in **Fig (12)**, the delta temperature fluctuations for the storage material Natural Zeolite are located between the range of incubation thermal tolerance. On the other side, the delta temperature fluctuations of storage materials (Silica gel self-indicating and white Silica gel) were out of the range of incubation thermal tolerance in some periods.

When following storage materials temperatures as shown in **Fig (13)** during the recovered thermal process, it can be observed that the maximum and minimum temperatures for (Silica gel self-indicating, white Silica gel, and Natural Zeolite) were (33.52-37.3°C), (32.5-

35.67°C), and (34.83-36.4°C), respectively. The TCM Silica gel self-indicating has the advantage that its temperature increases gradually and reaches the maximum and gradually decreases. The TCMs Natural Zeolite and white Silica gel temperature at the first increase, then decrease then increase again. So, it can say the temperature distribution for storage material Silica gel self-indicating better than Natural Zeolite and white Silica gel. From the previous results, the total recovered thermal of storage material Silica gel self-indicating was bigger than Natural Zeolite and white Silica gel. After the recovered thermal process, Silica gel self-indicating did not experience any kind of damage as happened in white Silica, which makes it suitable for a new cycle. The age of recovered thermal process for white Silica gel did not exceed three days compared with the age of recovered thermal process for Silica gel self-indicating and Natural Zeolite were six days. The temperature distribution of Silica gel self-indicating was better, as shown in **Fig (13)**.

3.1.4. The aluminum sheet surface and eggs location temperature with storage materials

The egg location temperature with storage materials (Silica gel self-indicating, Silica gel white, Natural Zeolite) used as heat source for heating prototype incubator as shown in **Fig (14)**. The closest temperature to the reference (incubation temperature) where the Silica gel, which means low additional heat required for heating process.

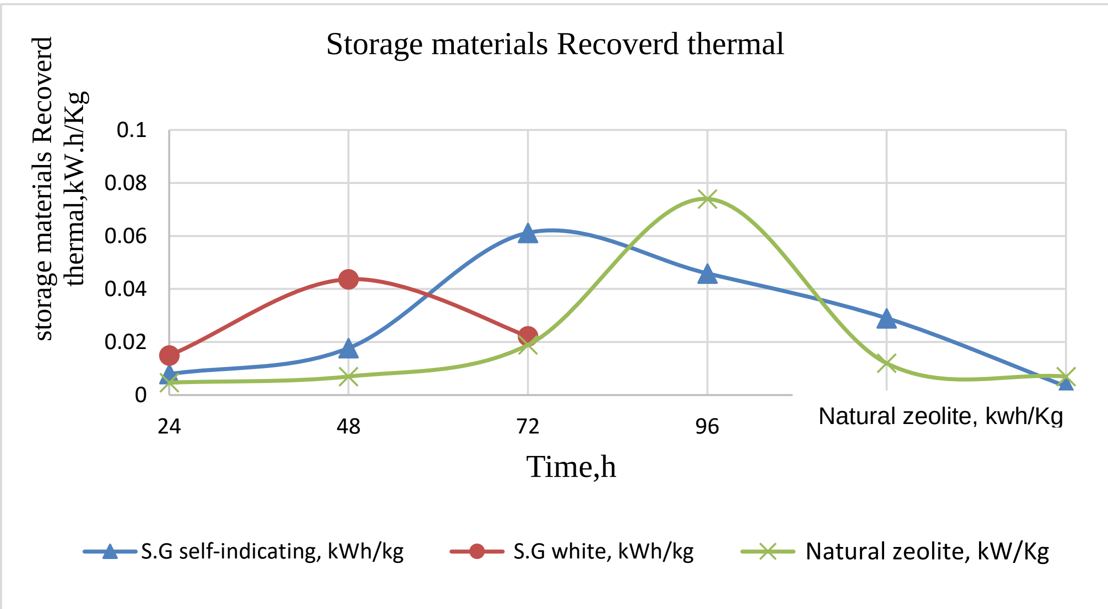

Fig 8. Illustrate the recovered thermal, in (kW.h/kg) of storage materials (Silica gel self-indicating, Silica gel white, and Natural Zeolite) during the time

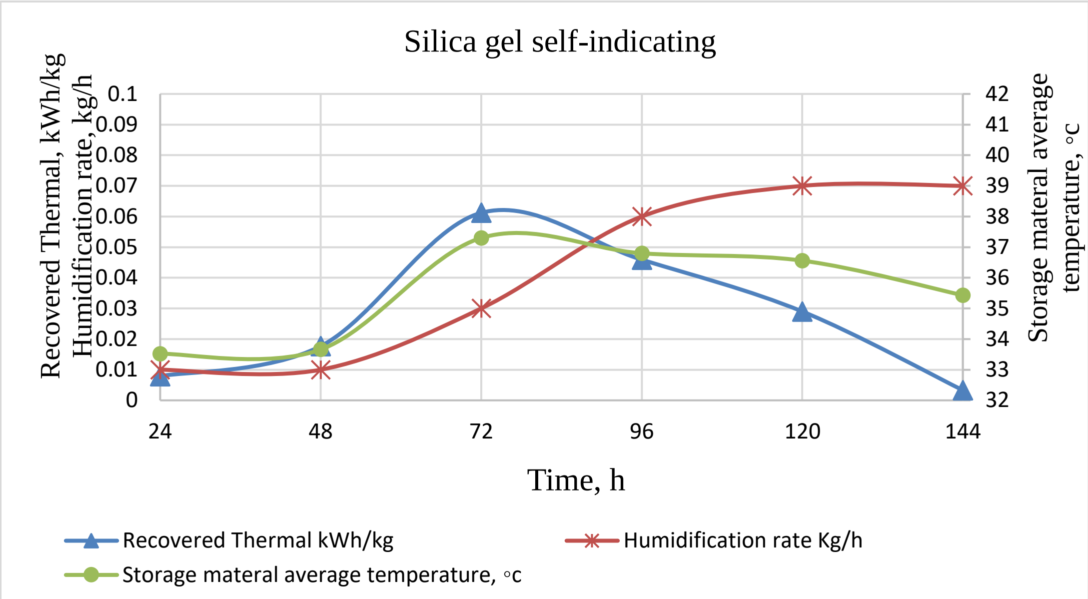

Fig 9. The recovered thermal and temperature of storage material with humidification rate of storage material (Silica gel self-indicating)

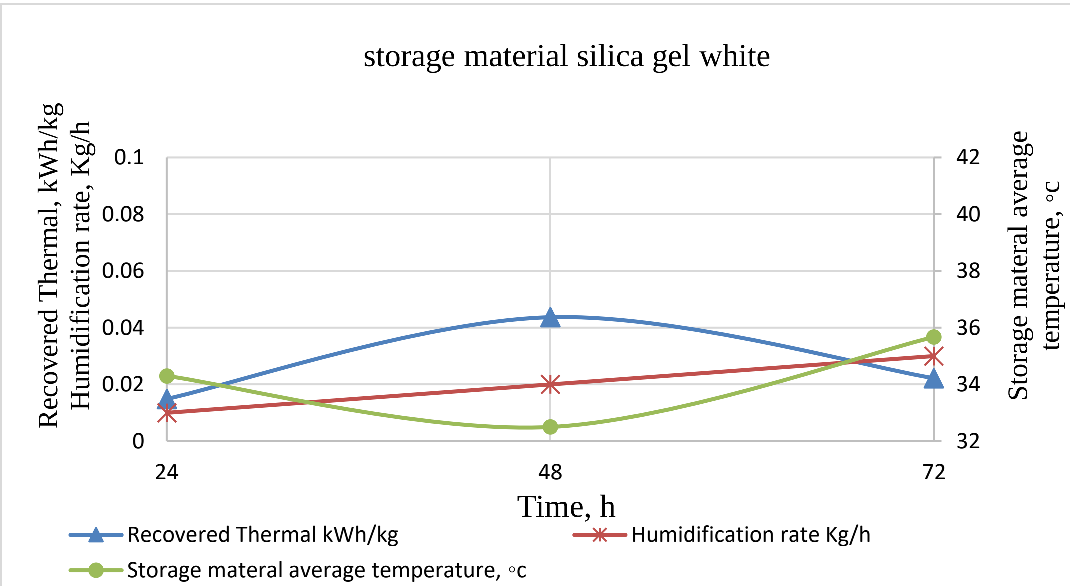

Fig 10. The recovered thermal and temperature of storage material with humidification rate of storage material (commercial white Silica gel)

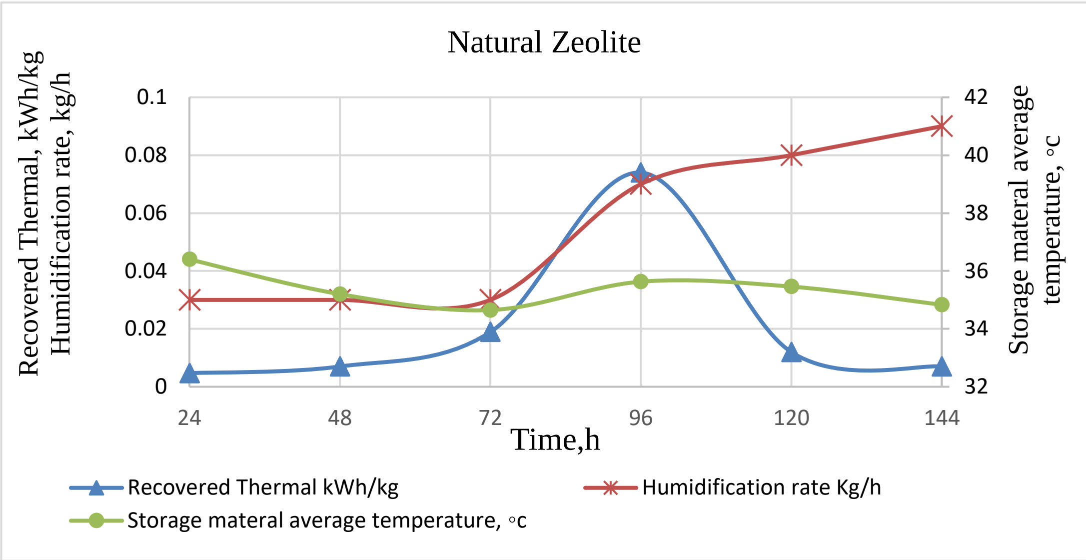

Fig 11. The recovered thermal and temperature of storage material with the humidification rate of storage material (Natural Zeolite)

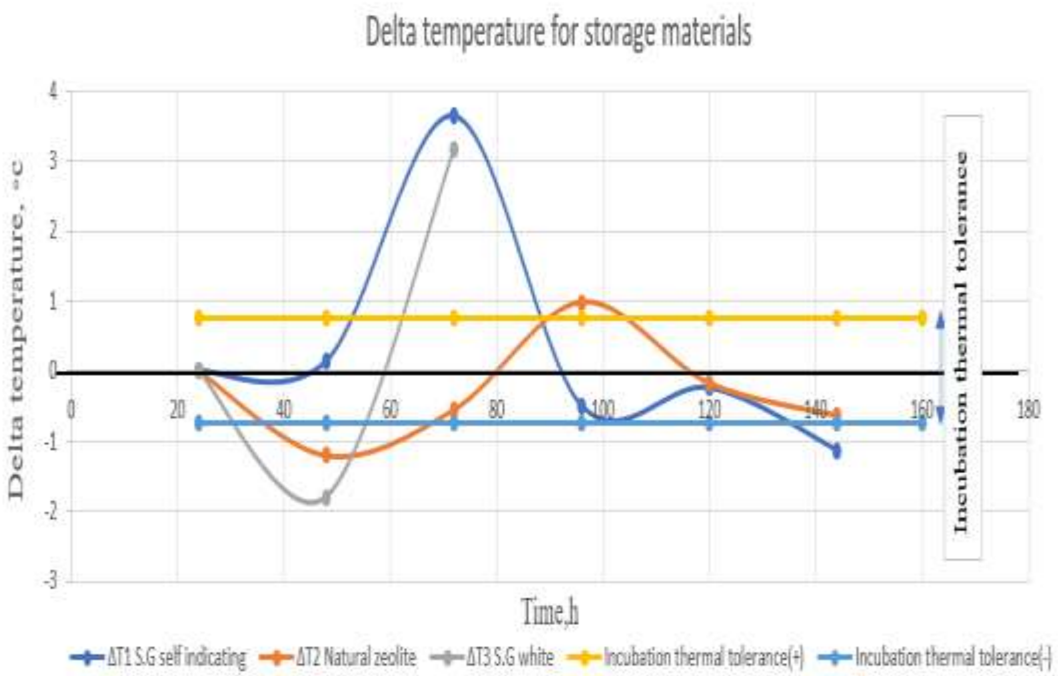

Fig 12. Delta temperature for storage material (Silica gel self-indicating, white Silica gel and Natural Zeolite) and incubation thermal tolerance for chicken eggs

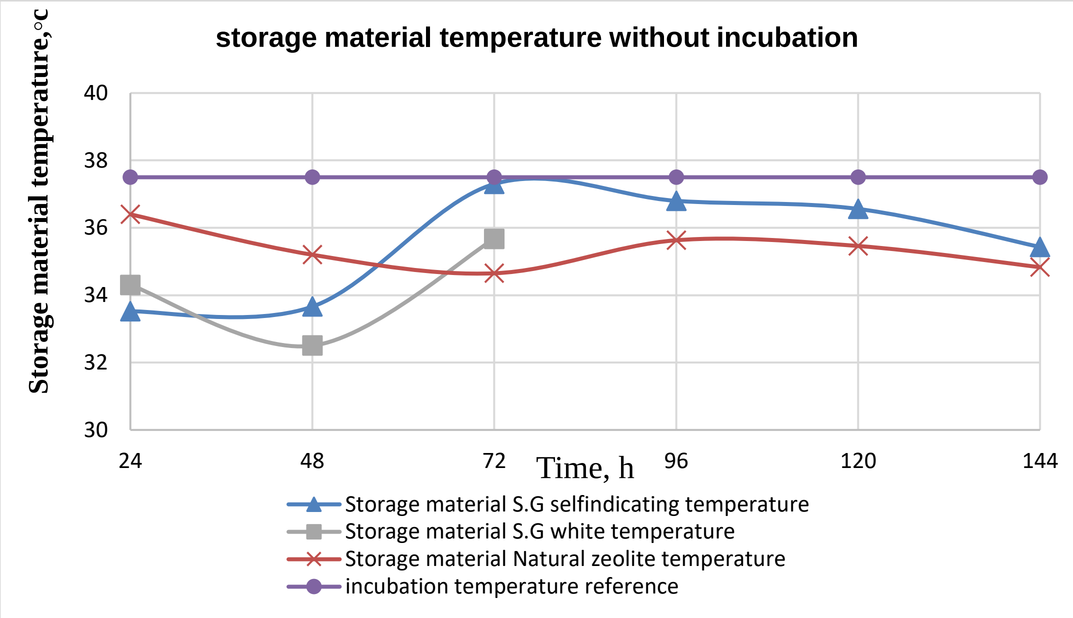

Fig 13. Storage material temperatures during recovered thermal process and incubation temperature

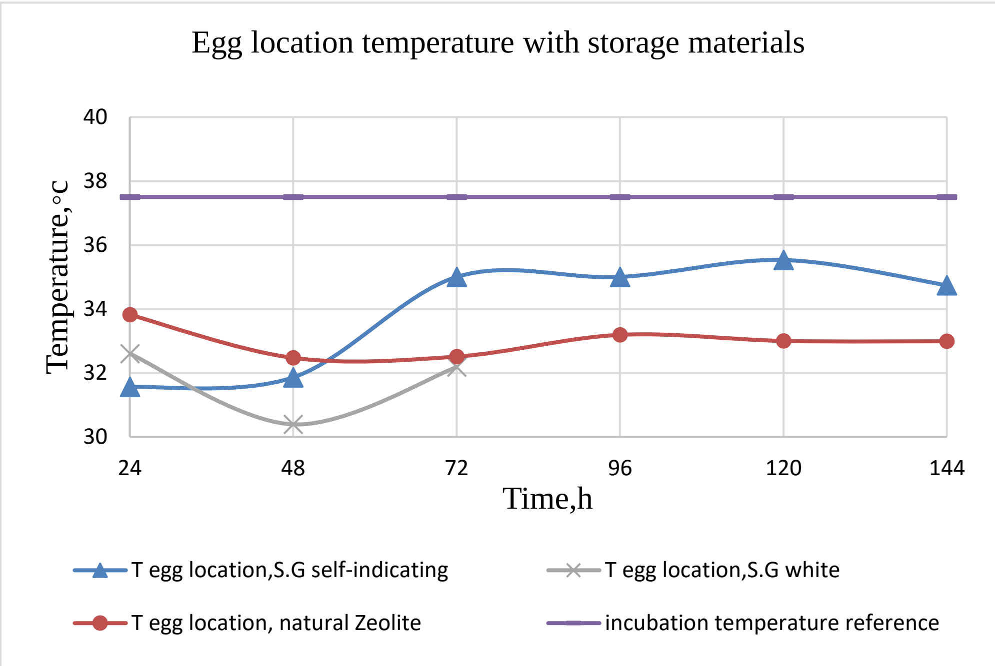

Fig 14. The egg location temperature with storage materials (Silica gel self-indicating, Silica gel white, Natural Zeolite)

The range of temperatures in egg location (31.56-35.53°C) was less than the optimal incubation temperature (37.5◦C) by using Silica gel self-indicating**.** as shown in **Fig 15**. This result due to the maximum average temperature of Silica gel self-indicating was 37.3◦C, as shown in **Fig 9**. Before and after this period, Silica gel self-indicating's average temperature was (33.52, 33.66°C) and (36.8, 35.43◦C). This decrease in material temperature influences by aluminum's temperature sheet surface and egg location. As a result of this, it is necessary to use an additional heat source with the thermochemical system to maintain the temperature at its desired levels during the incubation process.

3.2. The poultry egg incubation with TCM

3.2.1. The total heat required for poultry egg incubator

The total energy needed for the incubation process was (36.09W) calculated by Eq. No. (4). The results showed that the total heat required to raise the air temperature calculated by Eq. No. (5, 6) from ambient temperature to incubation temperature was 0.56 W. The energy required to raise the egg temperature calculated by Eq. No. (7, 8) from room temperature to incubation temperature was 24.23W. The heat loss by ventilation calculated by Eq. No. (9-10) was 1.5 W at ACH (air change per hour) 4 ACH. The total loss calculated by Eq. No. (11:17) from the incubator wall by conduction, convection, and radiation was 9.8 W. The embryo heat production due to metabolic was 3.65W for 25 eggs.

3.2.2. The temperatures inside thermochemical prototype and traditional incubator

The average temperature between eggs in the thermochemical prototype and traditional incubator as shown in **Fig 16** at incubation period (1-18 day) was (35.1-37.6◦C) and (37.9-38.5◦C), respectively. The average temperature between eggs at the hatching period (18-21) was (36.4-37.0°C) and (38.0-38.4°C), respectively, at average ambient temperature (23.5-29.5°C). The average temperature between eggs in prototype was more fluctiuation compared to the traditional incubator. The range of temperature flactiuation in prototype and traditional incubator was 2.5°C and 0.6°C, respectively.

3.2.3. The relative humidity inside the thermochemical prototype and traditional incubator

The relative humidity inside the poultry egg incubator one of the factors affecting on hatchability process. As shown in **Fig 17**, the average relative humidity inside the thermochemical prototype and traditional incubator during the incubation period was (55.7-61.5%) and (57-65.5%), respectively. During hatching period was (61.4-69.4%) and (59-62.3%), respectively, at an ambient relative humidity (37.4-54.4%). (Ogunwande et al 2015) mentioned that, the moisture level must be in the range (50-55%) for the first 18 days and (65%) during hatching period. The levels of moisture inside the prototype were controlled around 21 days of incubation. So, the level of humidity required can be controlled according to the stage of growth of the embryos. The levels in humidity inside the traditional incubator not controlled but depend on suppling the evaporation pan by water manually, due to that, it is difficult to raise the humidity levels in the hatching period.

3.2.4. The biological performance of thermochemical prototype and traditional incubator

The two incubators have the same capacity of eggs (total incubated eggs=25 eggs/incubator). The average weight was 60g were obtained from a commercial layer breeder flock (Hy-Line W-36) at 38 weeks of age (WOA). The results of hatching showed in **Table (2)**.

The percent of hatchability calculated by Eq. No. (20). The percent of hatchability of prototype incubator lower than traditional incubator due to the temperature fluctuations inside prototype more than traditional incubator. (Wafadar and Puls 2011) showed that, the optimal temperature during the first two weeks of incubation process is 38.5°C with tolerance ± 0.5°C. The temperature fluctuation more than 0.5 ◦C effect on the hatchability percentage. (Decuypere et al 2001) mentioned that, the range of the temperature achieves the highest hatchability is (37°C-38°C). As shown in the previous results the temperature fluctuations in prototype incubator were more than 0.5°C which affected on the percent of hatchability.

3.2.5. The energy consumption and operation costs for thermochemical prototype and traditional incubator

The energy consumption for thermochemical prototype and traditional incubator was measured by the energy meter. The total energy consumption (for 21 days), thermochemical prototype and traditional incubator was 11.2 kWh and 19.25 kWh, respectively. The ratio of energy saving was calculated by Eq. No (19) and the value was 41.8%.

The total operating cost for incubation process can be calculated by Eq. No. (18). The total cost for thermochemical prototype and traditional incubator was 7.28 and 12.51 L.E, respectively at unity cost 0.65 L.E as cited in the Ministry of Electricity and Energy's official website.

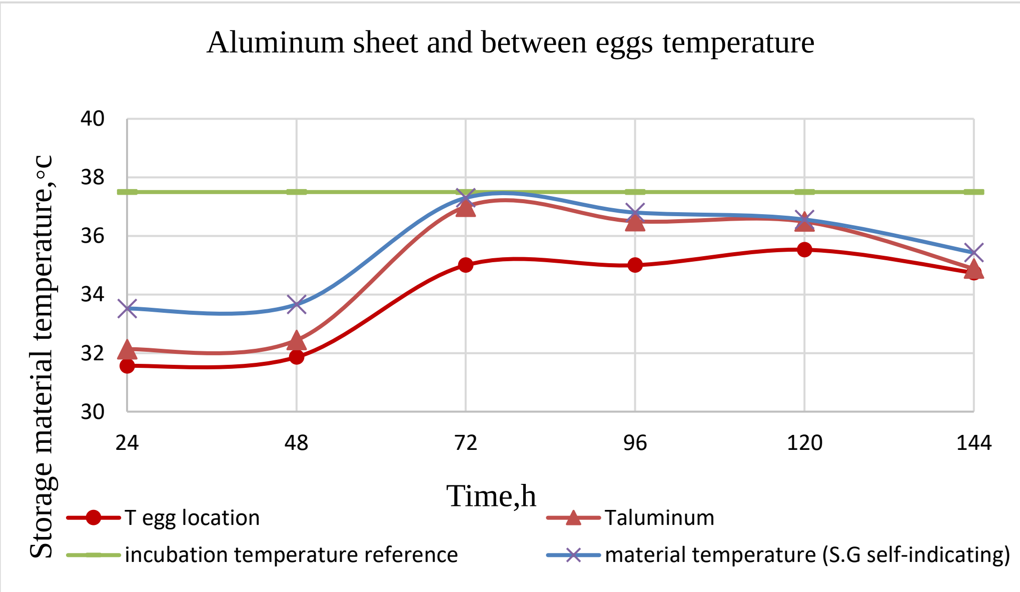

Fig 15. The average temperature for aluminum sheet and eggs location with storage material Silica gel self-indicating

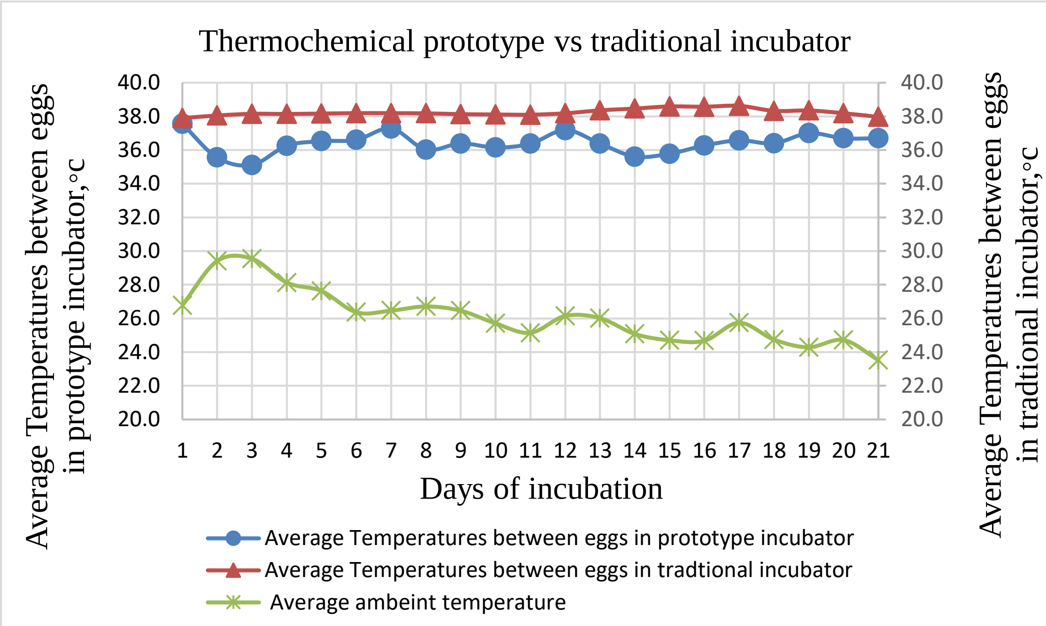

Fig 16. The average of temperature between eggs in thermochemical prototype and traditional incubator

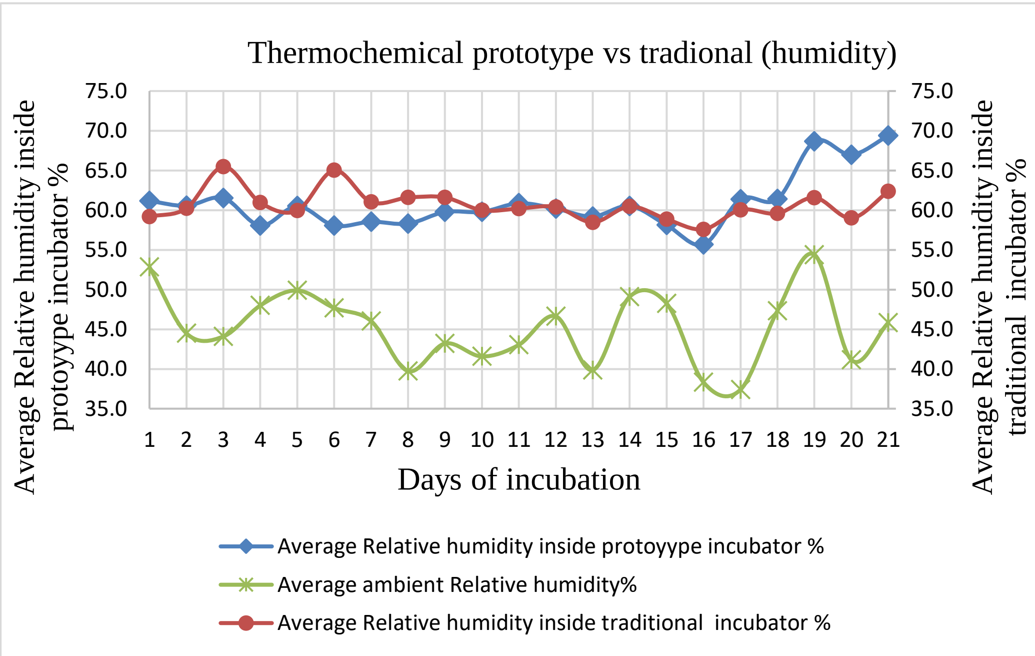

Fig 17. The average relative humidity inside the thermochemical prototype and traditional incubator

Table 2. The results of hatching in prototype and traditional incubator

Incubator	No. of fertile egg	No. of infertile egg	Early death	Late death	No. of hatched egg	Psercentage of hatchability %
Prototype	14	11	non	4	10	71.4
Traditional	21	4	1	3	17	80.95

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استخدام المواد الكيميائية الحرارية كمصدر حرارة لحضانة بيض الدواجن

[15]

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الموجـــــــز

تهدف هذه الدراسة الى الاستفادة من قدرة بعض المواد الكيميائية على تخزين الطاقة الحرارية (TCMs) لإستخدامها كمصدر للحرارة في عملية تفريخ بيض الدواجن. تم إستخدام ثلاث أنواع من الـ (TCMs) كوسط تخزين حراري (حبيبات السيليكا ذاتية الدليل (ازرق/وردي) – حبيبات السيليكا البيضاء التجارية – الزيوليت الطبيعي) في حالتها النشطة. تم استخدم النظام الكيميائى الحرارى المفتوح لإتمام عملية التفريخ حيث تم ترطيب المواد ببخار ماء ناتج عن مرطب يعمل بالموجات فوق الصوتية عند الضغط الجوي. وكانت عملية الإسترداد الحراري تهدف الى إطلاق الطاقة المختزنة في هذه المواد (TCMs). تم إستخدام مفرخان خلال التجربة. مفرخ تقليدي يعمل بالكهرباء بأبعاد (57*66*59) سم بسعة بلغت 125 بيضة دواجن وسعة تفقيس 76 بيضة. نموذج لمفرخ يعمل بمواد التخزين الحراري (TCMs) والذي احتوى على مستشعرات للقياس والتحكم في الحرارة والرطوبة داخل المفرخ، وكانت ابعاد نموذج المفرخ (56*39*28.5) سم بسعة بلغت 25 بيضة. كانت ابعاد صندوق مواد التخزين الحراري (35*35*5) سم بسعة 3.5 كجم داخل المفرخ وتم تغطيته بلوح الومنيوم سمكه 0.5 مم مزود بزعانف يعلوه رف البيض حيث تم وضع البيض بشكل أفقي. أظهرت النتائج المتحصل عليها أن الفاقد الحراري خلال الجدران والتهوية كانت 9.8 و1.5 وات على التوالي بينما كان الناتج الحراري للبيض خلال عمليات الايض 3.65 وات. الطاقة الكلية اللازمة لعملية التفريخ كانت 36.09 وات. بلغ استهلاك الطاقة خلال 21 يوم للمفرخ التقليدي 19.25 كيلووات.ساعة وللنموذج 11.2 كيلووات.ساعة. وحقق المفرخ التجريبي وفر للطاقة بنسبة 41.8% وذلك بالمقارنة مع المفرخ التقليدى. كانت نسبة الفقس للمفرخ التقليدي 80.9% وللتجريبي 71.4%.