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Performance study of a solar poultry egg incubator with phase change heat storage subsystem

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ABSTRACT

The performance evaluation of a hybrid solar powered poultry egg incubator is presented in this study. The system consists of a double-glazed flat plate solar collector integrated with a paraffin type phase change material energy storage subsystem and incorporated with a PV subsystem. Results of the study showed that the chamber temperature was within the range of between 36-39 °C and relative humidity of 50–75%. The temperature ranges of between 42-106 °C and 38–99 °C respectively were observed at the storage medium and absorber plate respectively with an average egg hatchability of 62.37% using the hybrid solar powered poultry egg incubator.

1. Introduction

In most developing countries, epileptic power supply is a challenge in spite of several interventions. In poultry production the effect is low productivity and folding of industries. Thus, for poultry industry to advance there is need for alternative energy source. This is why energy experts favor the use of renewable energy which is relatively eco-friendly and at minimal cost of production [1].

Modern poultry farming developed when energy was cheap. But as exhaustibility of conventional energy sources has become clear, the dependence on fossil fuels for heat is uncertain [2,3]. Electrical incubators are efficient but high percentage of the population in developing nations is not on the electricity grid [4]. In the rural areas where 80% of the population lives, the poultry farmers operate their farms using bush lamps for heat leading to environmental and health hazards characterized by high mortality rate, low feed conversion efficiency, heavy parasitic and disease infection [5]. Among the indispensable requirements of the successful incubation is heat. Solar energy is an inexhaustible source capable of meeting this with virtually no environmental hazard.

The objective of this study is to undertake performance evaluation of a hybrid solar powered egg incubator and determine its hatchability using fertilized poultry eggs. It is believed that the success of the study and its utilization will boost poultry production in developing nations.

2. Description of the solar incubator

Ojike [6] has designed a solar air heater. It consists of the collector–storage and incubating chamber subsystems.

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2.1. Solar collector storage subsystem

The collector–storage subsystem consists of a double-glazed flat plate solar collector with paraffin (RT60 type) as phase change material (PCM) energy storage medium. The PCM, with a total mass of 50 kg and with known thermo-physical properties for energy storage [6,7] is contained in rectangular steel box neatly laid so that its top formed absorber plate (Fig. 1 where a-Air inlet vent, b-Air flow direction, c-Outer-glass cover, d-Inner-glass cover, e-Absorber plate, f-Base of the paraffin container, g-Collector casing, h-Paraffin wax, i-Fibre glass, j-Air flow out of the collector and k-Air outlet vent). By natural convection, ambient air enters the solar collector air inlet, after being heated moves into the incubating chamber, and is discharged to the environment through chamber air outlet.

2.2. Incubation chamber

The incubating chamber is shown in Fig. 2. To turn the eggs, the tray rotates 45° about the horizontal with the help of a lever at the lower right side of the chamber.

The incubator is constructed of a metal plate of 0.002 m thickness and lagged with fiber glass of 0.06 m thickness. At the back of the chamber are ten vents of area 0.000314 m^2 each for air ventilation. At the base of the chamber is a water pan with surface area of 0.09 m^2. The water pan is filled with water and the required relative humidity is provided by evaporation of water vapor from the water surface. The heat source for incubation is hot air from the solar collector into the chamber. However, during critical periods of rainy days and very low sunshine intensity, heat from hot air is increased by two DC 15Watts tungsten electric bulbs powered by a Photovoltaic (PV) module. The module rated 55Watts and 12 V connected through a 12 V solar charge controller charged a 60Ah 12 V battery. The battery powered a digital temperature controller which through a 50 W electric motor controlled the chamber air inlet shutter. The shutter closes whenever the sensor attached to the temperature controller senses a temperature of 39 °C within the chamber thereby preventing heated air from solar collector entering into the chamber. This is to avoid the chamber temperature exceeding incubation temperature and whenever the temperature falls to 36.5 °C the passage is opened again. However, if the temperature continues to fall down to 36 °C, DC bulbs come up to heat the chamber and go off when the temperature exceeds 36 °C. The whole process ensures that the chamber is maintained within the range of 36 °C and 39 °C necessary for egg incubation.

3. Materials and methods

The performance of the solar incubator was carried out at the University of Nigeria, Nsukka which includes the physical and biological testing of the incubator. The physical aspect involves monitoring the temperature and the relative humidity of the incubator as well as that of the ambient in order to determine the suitability of the system to hatch poultry eggs. This was done on November 15, January 17 and February 16 which were the mean solar radiation day for the months, respectively [8]. These days were taken to study the effects of the collector temperature on the chamber temperature without loading it with eggs and without any active supplementary heating system attached to it. The biological performance was by loading the incubator with eggs and monitoring the system till the eggs hatch to determine the efficiency of the system. This was done from December 1 to 22 and then replicated in the months of February, April and May. The hourly total solar radiation was obtained from the Centre for Basic Space Studies of the university.

The hourly temperature measurements were done by using k-type thermocouples fixed at different components of the system. The relative humidity was recorded with the Vaisala relative humidity-temperature indicator. The relative humidity of the incubating chamber was read at egg top level in the chamber.

3.1. Biological performance

The biological testing was used to determine the hatchability of the incubator and the percentage fertility of the poultry eggs. The eggs were turned five times daily at intervals of 3 h to avoid egg yolk from sticking on the shell. However, turning of the eggs was

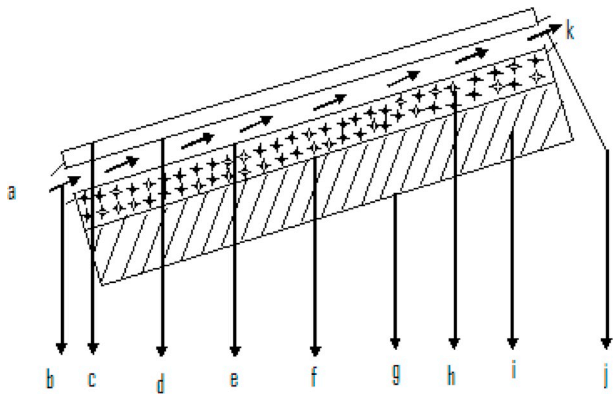

Fig. 1. Schematic diagram of the collector and heat storage subsystem.

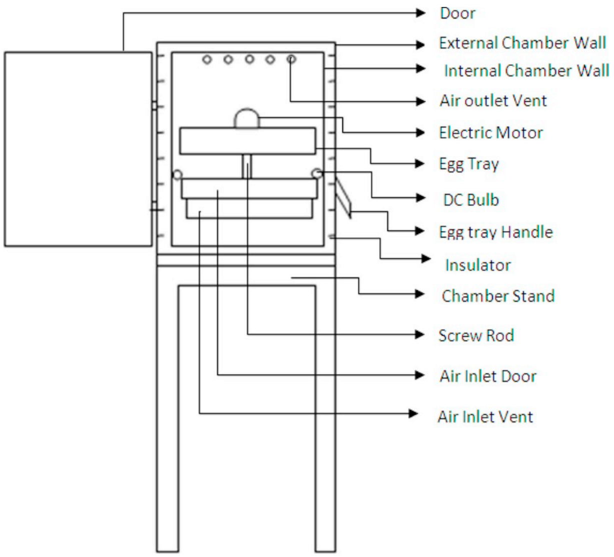

Fig. 2. Cross sectional view of the incubating chamber.

stopped after day 18 to allow the embryos time to start piping. A Candler was used to determine the percentage fertility of the eggs on the 5th day and on the 14th day in which crack, infertile and dead embryos were identified [6].

The percentage fertility and hatchability were obtained from equations (1) and (2) respectively as

$$\%\text{fertility} = \left(\frac{\text{Number of fertile eggs}}{\text{Total number of eggs in the incubator}}\right) \text{x } 100 \tag{1}$$

$$\%\text{hatchability} = \frac{\text{Number of chicks}}{\text{Number of fertile eggs}} \times 100 \tag{2}$$

4. Results and discussion

4.1. Solar radiation

Fig. 3 gives a graphical representation of the hourly solar radiation collected on three selected days out of the 21 days of incubation

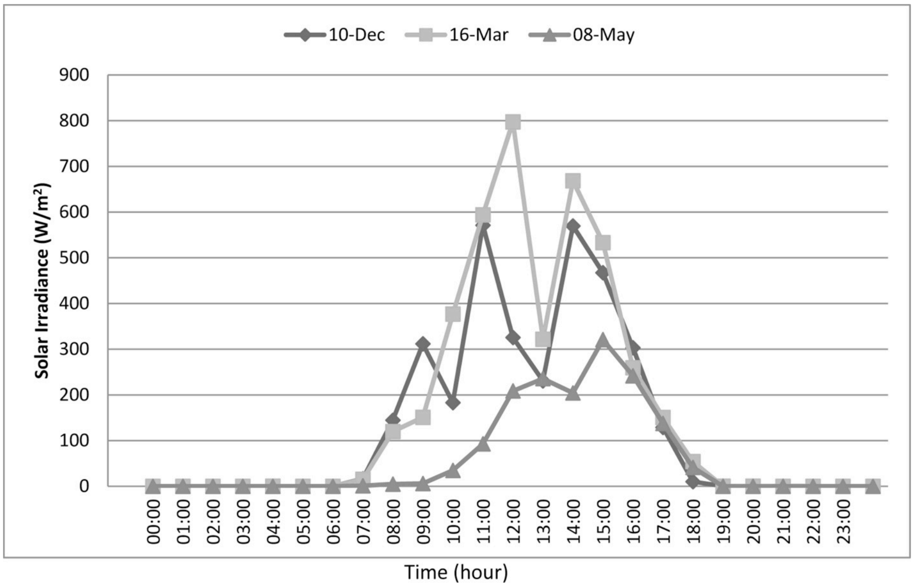

Fig. 3. Solar irradiance against time.

for three different incubation periods. The three selected days were 10th December, 16th March and 8th May and for these reasons: December 10 was a sunny-dry and windy day (harmattan period), March 16 was a sunny-dry day and May 8 was rainy-chilly day. From Fig. 3, it is observed that the hourly solar radiation is maximum between the hours of 12:00 and 15:00 when the sun is vertically overhead[7] while lowest at sunset periods.

Among the selected days, May 8 recorded lowest radiation values. These low values were as a result of the cloudiness of the weather on that day while the highest values recorded on March 16 were as a result of equinox. The effect of equinox is felt in Nsukka (latitude 6.8°) because of its closeness to the equator.

4.2. Temperature of the solar collector/heat storage system

Fig. 4 shows the hourly solar collector/heat storage system temperatures where ambient, storage medium, absorber plate, inner

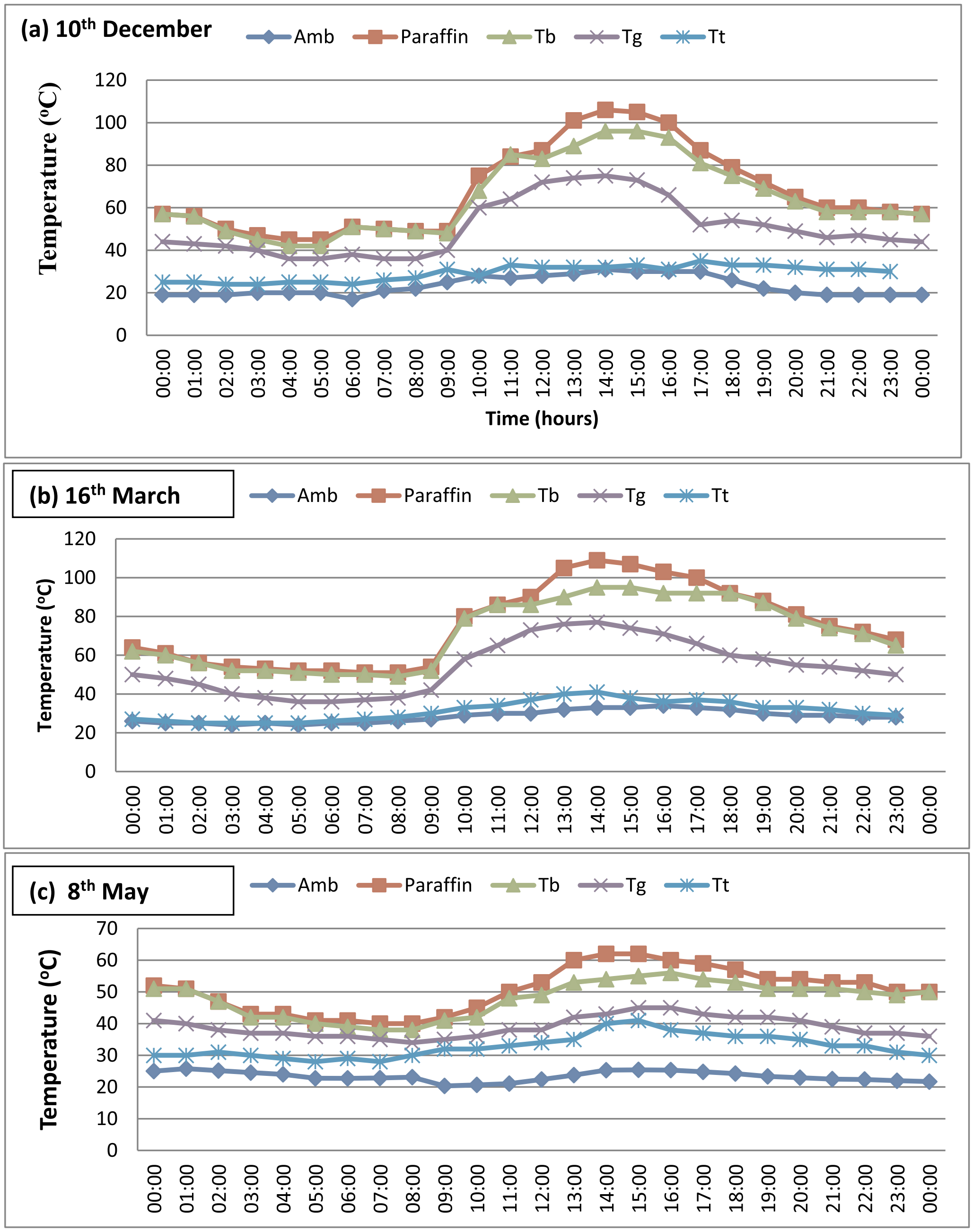

Fig. 4. Temperature readings of the solar collector/heat storage system against time.

glass cover and outer glass cover are represented by A_{mb}, P_{arafin}, T_b, T_g and T_t respectively. Comparing Figs. 3 and 4 it could easily be observed that the values in Fig. 4 are directly affected by solar radiation available at any given time. When solar radiation falls on the collector, the absorber plate absorbs solar radiation and converts it to heat energy. As air flows across the absorber plate, it conveys heat from the absorber plate and moves it in to the incubating chamber. The rest of the heat on the plate is absorbed by the storage medium thereby increasing the temperature of the paraffin until around 2:00pm. However, as solar irradiance starts reducing from the peak period less heat energy is available for storage medium and increasing quantity of stored energy is conveyed by the moving air into the incubating chamber. This continues till the minimum value is attained around 6:00a.m when solar radiation starts heating up the system again.

4.3. Ambient and incubating chamber temperatures

Table 1 compares the ambient and incubating chamber temperatures (without loading it with eggs and without any active supplementary heating system attached) for November 15, January 17 and February 16 which represent the mean solar radiation day for the months, respectively [8].

From Table 1 it could be observed that there is the need to moderate the flow of heated air during high temperature periods and to supplement the heated air during the periods of low temperatures.

Table 2 shows the summary of the incubating chamber temperatures for December 10, March 16 and May 8 (during the actual incubation process). The temperatures were within the temperature requirement for poultry egg incubation.

4.4. Ambient and incubating chamber relative humidity

Considering Fig. 5, the daily average chamber relative humidity are 52.1%, 71.8% and 68% for December 10, March 17 and may 8 respectively which are within range of relative humidity (50–75%) required for poultry egg incubation. The graphs show that the highest maximum ambient relative humidity among the days under consideration was that of the May 8 which denotes a rainy day. The lowest relative humidity among the three days is on December 10 which was a harmattan day.

4.5. Biological performance

The results of the percentage fertility and hatchability of the eggs for the three replications are as presented in Table 3. The incubator performed creditably well when compared to other works on the hatchability of incubators. De-Smit et al. [8] recorded a range of 36.23%–79.72% using Tibetan chickens and Dwarf chickens, while Fayeye et al. [9] observed a hatchability range of 47%–76% using Fulani-ecotype chicken. A number of factors including egg age, storage condition, age of flock, system of husbandry and rearing technology, mating system, incubation relative humidity and eggs turning angle have been shown to influence the hatchability of poultry eggs [10–13]. The infertility of the eggs procured from the farm is high which may be attributed to low fertility resulting from frequency of mating in the farm. Other factors may be as a result of wrong mating ratio, age of breeders and poor management/social stress like inadequate floor, feeding and drinking space etc may be implicated [12,13].

5. Conclusions

The performance evaluation of a hybrid solar powered poultry egg incubator with phase change material energy storage has been successfully undertaken. It consists of PV/thermal power source. From the study, the average percentage hatchability and incubation temperature after three replications were 62.3% and 37.6 °C respectively. The relative humidity recorded was within the required range of 50%–75%. Hence, successful poultry egg incubation is achievable with a hybrid Photovoltaic/thermal system.

Declaration of competing interest

None.

CRediT authorship contribution statement

E.O. Uzodinma: Writing - review & editing, Funding acquisition, Resources. **O. Ojike:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing - original draft, Writing - review & editing. **U.J. Etoamaihe:** Funding acquisition, Resources, Writing - review & editing. **W.I.**

Table 1
Unaugumented chamber Temperature.

Days	Maximum Ambient Temperature	Maximum Chamber Temperature	Minimum Ambient Temperature	Minimum Chamber Temperature
November 15	31	46	20	32.8
January 17	32.9	49	21.3	33.1
February 16	34.6	51.8	22.8	33.4

Table 2
Temperature of the augmented chamber.

Days	Maximum Temperature (^{0}C)	Minimum Temperature (^{0}C)	Mean Temperature (^{0}C)
December 10	39.0	37.2	38.1
March 16	39.0	36.7	37.7
May 8	36.0	38.1	36.9

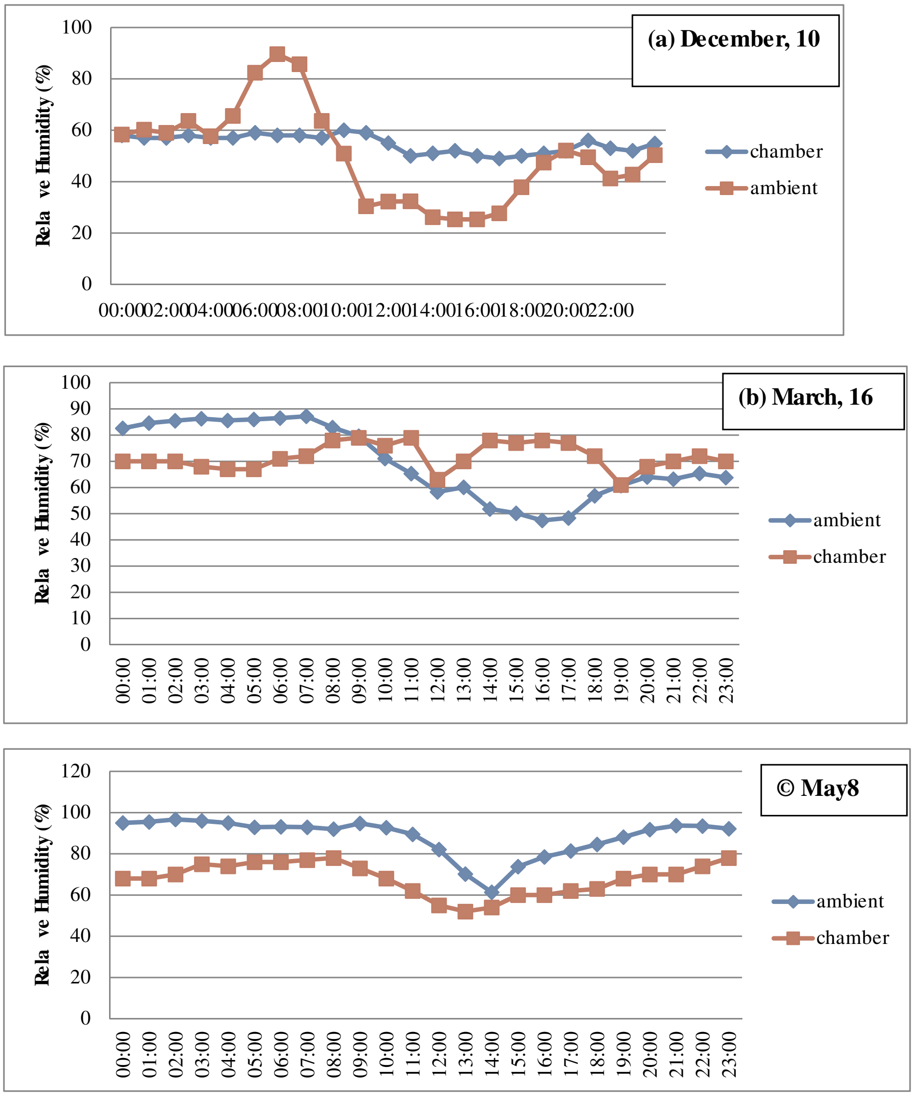

Fig. 5. Relative Humidity (ambient and chamber).

Table 3
Biological egg performance results.

Number of Incubation	Percentage Fertility (%)	Percentage Hatchability (%)
First incubation	32.14	56
Second incubation	80	67
Third incubation	72	64
Total	184.14	187
Average	61.3	62.3

Okonkwo: Supervision, Validation.

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