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ABSTRACT

This study explores the practical application of fin-enhanced beeswax as a thermal energy storage (TES) medium in hybrid solar and liquefied petroleum gas (LPG) powered poultry egg incubators to enhance energy and hatchery efficiency. A system with a double-glazed flat plate solar collector, a fin-enhanced beeswax TES, an incubation chamber, and an LPG backup was designed and tested. The results show that the design effectively maintained incubation temperature between 37.2 and 38.6 °C and relative humidity between 50% and 65%, while that of the ambient environment ranged between 39% and 88%. The solar collector and TES material's thermal efficiency were 67% and 68%, respectively, while hatchery efficiency was 70%. This result suggests that the beeswax-integrated hybrid egg incubator is an efficient and viable energy solution for the sustainability of incubation practices in regions with unreliable grid electricity, particularly in developing countries. The system helps improve food security by reducing energy use and the environmental impact of traditional methods.

I. INTRODUCTION

The poultry industry is crucial in meeting the increasing global demand for protein-rich food, significantly enhancing food security and nutrition.[1] To address this demand, various incubation methods have been explored, including kerosene- and diesel-powered systems[2] and electric incubators.[3] However, these conventional technologies are often costly, environmentally harmful, and unreliable, particularly in regions with inconsistent electricity supply, such as Sub-Saharan Africa.[1,2,4] Solar thermal energy systems offer a sustainable solution by harnessing up to 70% of captured energy, thereby mitigating the limitations of traditional incubation methods.[5] Integrating thermal energy storage (TES) materials, especially phase change materials (PCMs), further improves system efficiency due to their excellent thermal properties, providing consistent and reliable heat management.[6,7] Paraffin-based PCMs have been widely used in egg incubation systems, showcasing excellent thermal performance.[8,9] However, concerns have been raised regarding the sustainability of paraffin wax, particularly due to its harmful emissions and the finite nature of petroleum resources.[10,11] This underscores the urgent need for sustainable alternatives in TES.

Beeswax emerges as a promising PCM due to its advantageous thermal properties, such as thermal stability, moderate melting point (60–66 °C), and high latent heat capacity (177–242 kJ/kg).[7,12] Moreover, beeswax is abundant, biodegradable, and environmentally friendly, presenting a more sustainable alternative to paraffin-based PCMs. Despite its favorable thermal properties, beeswax suffers from low thermal conductivity, which limits its efficiency in solar TES applications by slowing down the rate at which it absorbs and releases heat.[13] Abdulmunem *et al.*[14] studied the thermal performance of beeswax in a solar air heater, demonstrating its relatively low thermal efficiency and highlighting the need for enhancements in thermal conductivity. Numerous studies have investigated ways to improve the thermal conductivity of beeswax PCMs. For example, Mishra *et al.*[13] conducted a numerical study examining the effects of various annulus shapes with nanoparticles dispersed in beeswax at different concentrations, demonstrating significant improvements in heat transfer rates. Similarly, Yuan *et al.*[15] examined the effectiveness of silver bromide (AgBr) shell encapsulation on beeswax, while Putra *et al.*[16] analyzed the thermal properties of beeswax combined with copper oxide (CuO) nanoparticles in varying ratios. While these methods effectively enhance the thermal conductivity of beeswax and provide encapsulation, incorporating nanoparticles and nanoencapsulation techniques often involves complex processes and high costs, especially when scaled up for larger applications. In contrast, Choure *et al.*[17] and Diaconu *et al.*[18] investigated cost-effective fin geometries integrated into PCMs, and Balakrishnan *et al.*[19] and Josyula *et al.*[20] analyzed the application of fins in PCM-based flat plate solar collectors (FPSCs) for solar air heaters, assessing their efficiency in heat extraction and release. These studies demonstrated that fin geometries significantly enhance thermal conductivity, offer easy integration, and are relatively low-cost alternatives. Although fin-enhanced PCMs have been extensively researched for improving FPSCs in solar air heating, their application in beeswax-based egg incubation systems remains insufficiently explored. Given the critical need for precise thermal control in egg incubation, integrating fin-enhanced beeswax PCMs could provide a sustainable and reliable solution for maintaining consistent heat supply.

However, due to the intermittent nature of solar energy, finding sustainable and reliable backup energy becomes vital.[8] Liquefied Petroleum Gas (LPG) emerges as a promising solution due to its high thermal energy efficiency (65%–90%), high energy content (46–51 MJ/kg),[21] and fewer harmful emissions, such as SO_2, Nox, and CO.[22] In addition, LPG's accessibility, scalability, and successful integration into solar systems make it a practical and environmentally favorable choice for enhancing energy reliability and supporting the transition to cleaner energy systems in regions with abundant solar potential.

There is a notable gap in research concerning the performance of fin-enhanced beeswax in solar poultry egg incubators incorporating LPG backup systems, underscoring the need for further investigation in this area. This research explores the effectiveness of fin-enhanced beeswax TES in FPSCs for solar egg incubation incorporating LPG as an alternative backup, making a hybrid system. A hybrid solar/LPG poultry egg incubator integrated with fin-enhanced beeswax was developed and tested. The thermal performance was evaluated through temperature variation, collector efficiency, and beeswax storage efficiency. Chicken eggs were used to assess the hatchery performance. This comprehensive evaluation offers critical insights into the effectiveness of fin-enhanced beeswax in promoting sustainable egg incubation, focusing on improved temperature regulation and increased energy efficiency, thereby contributing to the advancement of TES technologies in agricultural applications.

II. MATERIALS AND METHODS

A. Beeswax preparation and characterization

The semi-clean and dry raw beeswax was strategically sourced from a local apiary and melted using a well-sealed mini water bath boiler designed for beeswax at a temperature of 65–70 °C for 45 min. This duration facilitated the sedimentation of heavy particles. The molten wax was subsequently filtered through a 200 μm gravity strainer, followed by a second filtration through a 100 μm gravity strainer to achieve maximum purity. The purified beeswax was then poured into molds to solidify, enabling subsequent characterization and remelting for use in TES blocks.

The purified beeswax was thermally analyzed using a Simultaneous Thermal Analyzer (STA8000, PerkinElmer), which enabled the simultaneous characterization through Differential Scanning

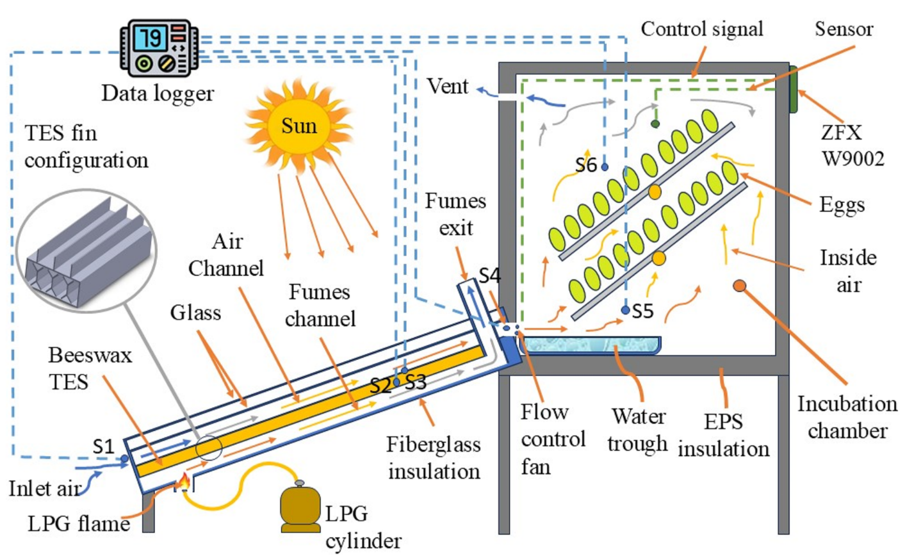

FIG. 1. Schematic diagram showing system configuration.

FIG. 2. Experimental setup: (a) system assembly, (b) egg setting, and (c) finned FPSC.

Calorimetry (DSC) and Thermogravimetric Analysis (TGA). DSC was conducted at 150 °C to analyze the melting behavior and phase transitions of the beeswax without causing degradation, while TGA was performed at 600 °C to assess its thermal stability and decomposition characteristics under high-temperature conditions.[12]

B. Design and fabrication of the incubator

The hybrid solar/LPG system included four main parts: an incubation chamber, a flat plate solar collector (FPSC), a beeswax TES unit, and an LPG backup system. The incubation chamber was built using an aluminum sheet and insulated with EPS foam. It housed two egg trays with a turning mechanism, a 12 V DC fan, and a ZFX W9002 controller for heat management. The double-glazed FPSC, with a surface area of 1.276 m^2, was constructed from mild steel, reinforced with angle iron, and insulated with fiberglass. The TES unit carries 41 kg of beeswax in finned aluminum blocks painted matte black. In addition, the LPG backup system was installed to support heating in solar incapacity. The system's design and layout are illustrated in Figs. 1 and 2, and the complete list of technical specifications is provided in Table I.

The FPSC captures solar energy and converts it into heat, which is transferred via an air channel to the incubation chamber using air as the heat transfer fluid. A suction fan and flow valve, controlled by the ZFX W9002 controller, precisely regulate airflow to maintain optimal incubation temperatures. Excess solar heat on sunny days is stored in a beeswax TES system for later use. When solar energy is depleted, an LPG system at the base of the FPSC can be manually activated to heat the beeswax TES, ensuring continuous operation. This combination ensures that the incubation chamber maintains optimal temperature, enhancing hatchery efficiency.

TABLE I. Specifications of the developed hybrid solar/LPG egg incubator.

Items description	Unit	Size
Solar collector area	m^2	1.276
EPS insulation thickness	m	0.05
EPS insulation density	Kg/m^3	18
Fiberglass insulation thickness	m	0.05
Solar collector tilt angle	°	13.4
Thickness of solar collector glass	mm	5
Incubator egg capacity	Egg	176
Mass of beeswax TES	kg	41
Distance between glasses	m	0.02

C. Experimental setup

The system was positioned in an open area, with the collector oriented to absorb the maximum amount of solar energy. During these tests, the incubation temperature was set to 38.0 °C as recommended for chicken eggs.[23] The temperature at various system key points (S1–S6) is strategically recorded with a temperature data logger to monitor energy flow and identify losses. This arrangement enables a comprehensive energy distribution analysis across various system components, ensuring efficient performance evaluation. In addition, ambient and chamber relative humidity and solar irradiance were measured using calibrated instruments to evaluate the system's thermal performance. The technical standards of the employed instruments are presented in Table II. Afterward, the load test was done using chicken eggs to assess hatchability. The incubation was repeated three times to ensure consistent results.

TABLE II. Technical specifications of the measuring instruments.

Instrument	Range	Accuracy	Resolution	Uses
SSN-11E USB temperature data logger meter	−40–125 °C	±0.5 °C	±0.1 °C	Temperature
SSN-22 USB temperature humidity data logger meter	0%–100% RH	±0.3 RH	±0.1 RH	Humidity
	−35–80 °C	±0.3 °C	±0.1 °C	Temperature
TES 132 solar power meter	0–2000 W/m^2	±10 W/m^2	0.1 W/m^2	Solar radiance
Kestrel 3000 wind meter	0.6–40 m/s	±0.1 m/s	0.05 m/s	Wind speed

D. Thermal performance analysis

Thermal performance assesses how well the incubator maintains optimal conditions for embryo development. This was done to determine the extraction efficiency, collector efficiency, energy utilized, and TES storage capacity.

1. Heat energy

The heat energy (Qa) required to raise the incubation air temperature is calculated using Eq. (1) considering the mass flow rate of air ($\dot{m}a$), specific heat capacity of air (C_{pa}), and the temperature difference (ΔT),[24,25] where the variables t_1 and t_2 denote the start and end of each phase, respectively,

$$Qa = m_a cpa \int_{t1}^{t2} \Delta T(t)dt. \tag{1}$$

The solar charging phase was defined from 08:00 AM to 3:30 PM, when solar irradiance exceeded 300 W/m^2, leading to heat absorption by the PCM. The discharging phase followed from 3:30 PM to 9:00 PM, where the stored energy was gradually released. Afterward, the LPG charging (09:00 PM–01:00 AM) and LPG discharging (01:00 AM–08:00 PM) followed. Temperature readings were recorded every 5 min at six key points in the system (S1–S6). The utilized heat energy values for solar and LPG during PCM charging and discharging were computed using Eq. (1) at these specified time intervals. The recorded temperature variations were used to verify efficiency calculations.

2. Heat extraction efficiency

The heat extraction efficiency (η_E) of the beeswax TES unit, representing the ratio of the usable heat transferred to the incubation chamber, is calculated as[26]

$$\eta_E = \frac{E_{Discharge}}{E_{Charge}}, \tag{2}$$

where (i) E_{charge} is the total energy absorbed by beeswax during charging, recorded from 8:00 AM to 6:00 PM, when solar irradiance was above 300 W/m^2, and (ii) $E_{discharge}$ is the total energy released, measured between 6:00 PM and 9:00 AM, when the stored energy in beeswax gradually decreased.

Temperature and energy flow data were collected at 30-min intervals to track efficiency changes throughout the cycle.

3. Solar collector efficiency

The solar collector efficiency (η_c), showing the amount of solar energy converted to useful heat energy for incubator heating, is calculated as[26]

$$nc = \frac{ma \cdot Cpa \int_{ti}^{to} (To - Ti)t \cdot dt}{Ac \cdot \tau \cdot \alpha \int_{ty}^{tx} I \cdot t.dt}. \tag{3}$$

The variables ($To - Ti$) represent the temperature difference between outlet (S4) and inlet (S1) air recorded at intervals of 30 min, ti represents the start of solar charging time (08:00 AM), to shows the time for the end of discharge (09:00 PM), ty is time for the start of solar charging (08:00 AM), and tx is the end of the solar charging phase (06:00 PM). The variable τ represents the glass transmissivity, set at 0.9, while α denotes the absorptivity of the absorber plate, referred to as 0.9.

E. Measurement error and uncertainty analysis

The errors in this experiment are expected to arise from measuring instruments' precision and accuracy. Air velocity (v), inlet and outlet temperatures (T), and solar irradiance (I) were consistently recorded to attain maximum accuracy. The uncertainties associated with density ρ, area A, and specific heat capacity C_{pa} in the computation of mass flow rate (m_a) are considered negligible. Therefore, the error arising from heat energy and collector efficiency is computed, respectively, as

$$\delta Q = Q\sqrt{\left(\frac{\delta v}{v}\right)^2 + \left(\frac{\delta T}{T}\right)^2}, \tag{4}$$

$$\delta \eta = \eta\sqrt{\left(\frac{\delta v}{v}\right)^2 + \left(\frac{\delta T}{T}\right)^2 + \left(\frac{\delta I}{I}\right)^2}. \tag{5}$$

The uncertainties in each variable (X) are due to measurement accuracy and device resolution as computed in the following equation:

$$\delta X = \sqrt{(X_{accuracy})^2 + (X_{resolution})^2}. \tag{6}$$

For the given device specification in Table I, the uncertainties in utilized energy are 0.057, and for collector efficiency, it is 0.0578.

F. Hatchery performance analysis

Hatchery performance refers to the effectiveness of an incubator in producing healthy, viable chicks from eggs. The key parameters to consider include hatchability and fertility rate, which are calculated, respectively, using the following equations:[27]

$$Hatchability(\%) = \left(\frac{Number\ of\ chicks\ hatched}{Total\ number\ of\ fertile\ eggs}\right) \times 100, \quad (7)$$

$$Fertility\ Rate(\%) = \left(\frac{Number\ of\ fertile\ eggs}{Total\ number\ of\ eggs\ set}\right) \times 100. \quad (8)$$

G. Statistical analysis

To improve the reliability of the findings, statistical analysis was applied to assess the range within which the true values for hatchability and fertility rates are expected to fall. This approach helps to reduce uncertainty and adds more credibility to the results.[28] In this regard, confidence intervals (CIs), with a 95% confidence level, were introduced. Due to small sample sizes or extreme values, the Wilson score interval was used, as outlined in the following equation:[29]

$$\text{Confidence interval (CI)} = \frac{p + \frac{z^2}{2n} \pm z\sqrt{\frac{p(1-p)}{n} + \frac{z^2}{4n^2}}}{1 + \frac{z^2}{n}}, \quad (9)$$

where p is the sample proportion, z is the standard value for 95% CIs ($z = 1.96$), and n is the sample size.

III. RESULTS AND DISCUSSION

A. DSC and TGA results

Figure 3 presents the DSC results, showing that beeswax has a melting point of 62.2 °C and a latent heat of 203.79 J/g. This is consistent with the literature on PCMs, where beeswax has been identified as a suitable material for thermal energy storage due to its moderate melting point and high latent heat capacity.[7,12] These properties enable beeswax to absorb and release thermal energy effectively, making it ideal for systems like this hybrid solar/LPG incubator.

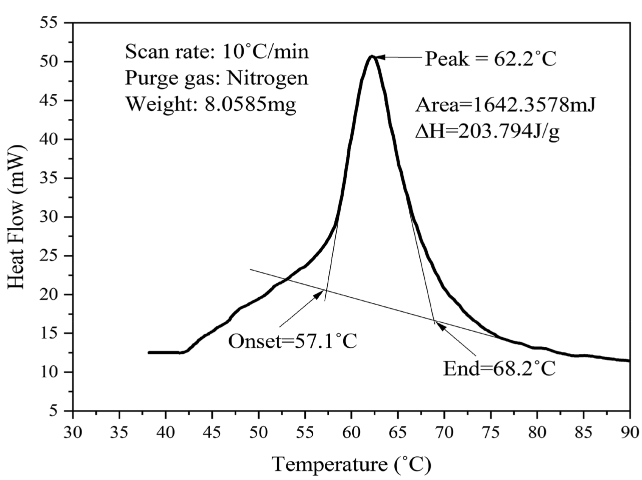

FIG. 3. DSC results for beeswax.

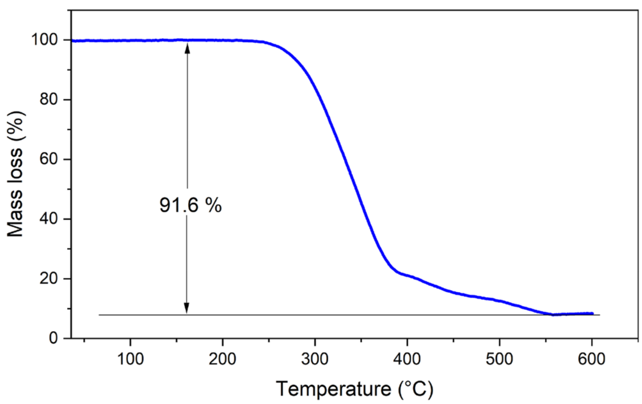

FIG. 4. TGA curve showing the mass loss of beeswax.

Figure 4 shows the TGA results, illustrating that beeswax is stable up to 250 °C, beyond which a significant mass loss occurs. The 91.1% mass loss at temperatures above 250 °C confirms that beeswax can operate reliably within the system's temperature range, aligning with other studies where beeswax has been used for TES in moderate-temperature applications.[15]

The DSC and TGA results support beeswax as a sustainable PCM for solar energy storage applications. Its latent heat capacity and thermal stability allow it to maintain consistent temperatures for egg incubation, even during periods of low solar irradiance.

B. Effect of fin enhancement on beeswax-based TES for solar egg incubation

Figure 5 highlights that the integration of fin enhancements markedly improves the thermal performance of a beeswax-based thermal energy storage (TES) system, demonstrating its effectiveness in applications such as egg hatching. The experiment evaluated the impact of fin enhancements on the thermal performance of a beeswax-based TES system, particularly for egg incubation. The integration of fins into the beeswax-based TES system significantly enhanced its thermal performance by improving heat absorption, storage, and release efficiency. Comparative analysis showed that the finned TES system retained heat 50% longer, extending the effective heat supply duration from 6 hours (non-finned) to 9 h (finned). Furthermore, the finned TES exhibited 12%–15% higher outlet temperatures than the non-finned system during the discharge phase, ensuring more stable incubation conditions, particularly during low-sunlight hours. This improvement resulted in a more consistent thermal environment, reducing the need for auxiliary heating and improving overall energy efficiency.

In addition, the experiment assessed the maximum discharge time, revealing that the fin-enhanced TES prolonged heat availability, optimizing thermal energy use. Fins help overcome beeswax's low thermal conductivity, enhancing system efficiency. However, reliance on solar irradiance necessitates a sustainable backup like LPG, and further optimization of fin designs is needed to improve heat transfer while minimizing losses.

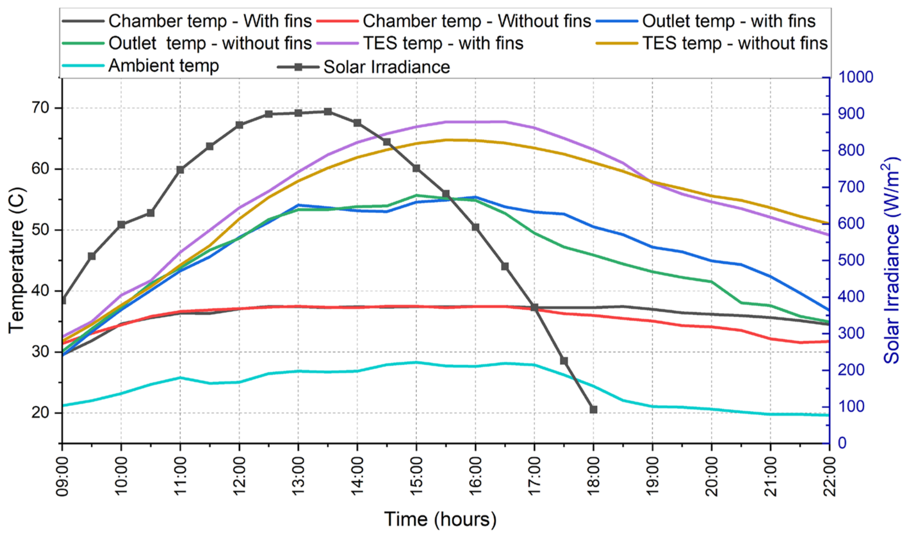

FIG. 5. Thermal performance of fin-enhanced beeswax-based TES vs non-enhanced TES.

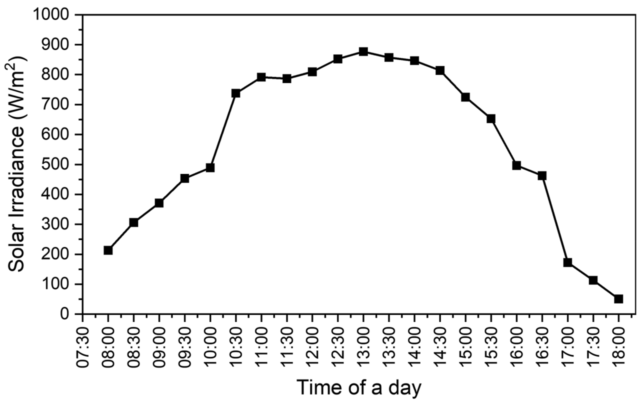

FIG. 6. Average variation of solar irradiance over time.

C. Solar irradiance variation for hybrid egg incubator evaluation

Figure 6 illustrates the solar irradiance fluctuations during the experiment, with values ranging between 50 and 876 W/m^2, peaking around 13:30. Wind speeds fluctuated between 0 and 3 m/s, likely impacting the heat retention in the system. Solar irradiance is critical for the system's energy collection. Even under variable solar conditions, the system could capture and store sufficient energy to maintain incubation temperatures, comparable to findings in similar systems that use PCMs for solar energy storage.[30]

D. Thermal performance of hybrid egg incubator

Figure 7 depicts the average temperature fluctuations at multiple points in the system, including the ambient temperature (S1), TES midway (S2), absorber plate (S3), output air (S4), and bottom and top of the incubation chamber temperatures (S5 and S6). The air mass flow rate ($\dot{m}_a$) was maintained at 0.01 kg/s. The absorber plate temperature peaked around 01:00 PM and TES around 01:30 PM during solar changing, while the peaking occurred at 01:00 AM for LPG changing. At peak solar irradiance, the outlet temperature of the solar collector reached 58.17 °C, while the ambient temperature was 28.3 °C. The beeswax phase change occurred at 62.03 °C, showing stable heat absorption and release, allowing the system to maintain incubation temperatures over the daytime without relying on LPG until later. The finned beeswax TES provided adequate thermal storage and release, as seen in other PCM studies,[19,20,31] where fins or nanomaterial additives were used to improve heat transfer. The phase change stability at 62.03 °C demonstrates the system's capacity to store heat efficiently, extending the available energy during non-solar hours. However, future work could explore alternative fin designs or multi-layer PCM systems to improve the heat storage and discharge capacity further.[7,18]

E. Energy efficiency of PCMs

The solar collector efficiency was calculated as 67%, and the heat extraction efficiency of TES unit was calculated as 68%. These efficiency values align with similar studies on solar collectors integrated with PCMs. For instance, Yang *et al.*[25] found a collector efficiency between 30% and 34.5% and a TES efficiency between 60.99% and 69.42% when the thermal performance of double glazed FPSCs with PCMs was analyzed. Sharma *et al.*[6] further studied the thermal performance of thermally improved PCMs and found a collector efficiency of 55%–75% and a TES efficiency of 60%–80%. These studies concluded that the said efficiencies greatly depend on airflow rate, insulation, type of PCM, collector configuration, and the thermal improvement mechanism used. Therefore, beeswax efficiencies are attributed to higher TES thermal capacity, thermal insulation,[32] regulated airflow,[6,33] and fin enhancement.

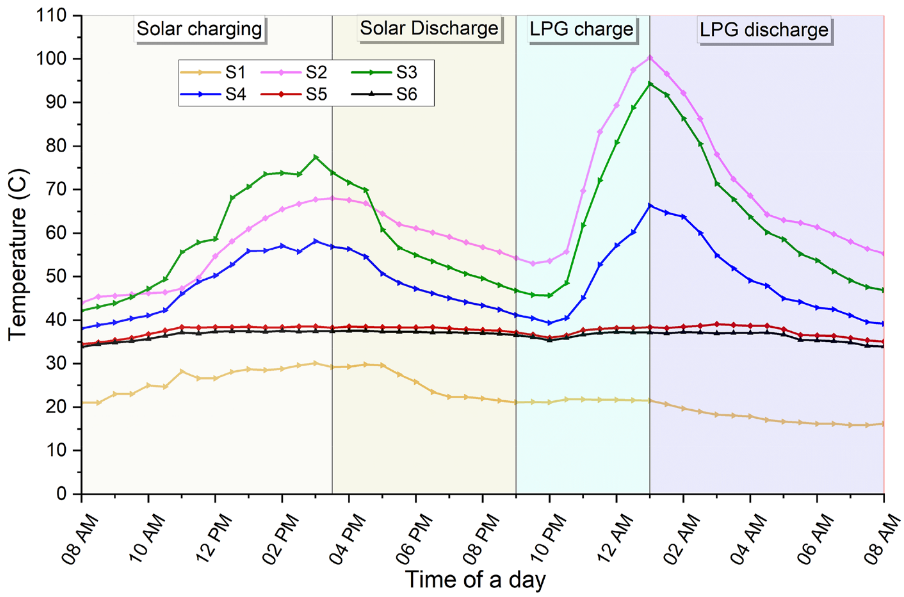

FIG. 7. Average temperature of the solar incubator system at different points.

F. Energy utilized

Figure 8 represents the amount of energy output for each source supplied to the incubation chamber. The total energy captured from solar irradiance during the experiment was 11.4 MJ, with 5.35 ± 0.305 MJ during charging and 6.08 ± 0.346 MJ during discharging of the beeswax TES. The LPG system provided an additional 3.787 ± 0.216 MJ during charging and 7.284 ± 0.415 MJ during discharging. The system effectively utilized the energy stored in the TES in both scenarios. The higher energy output during the discharge phase of the beeswax TES highlights its effectiveness as a long-duration heat storage medium. However, LPG consumption still plays a role in ensuring continuous performance.

G. Energy contribution for solar/LPG

The experiment aimed to evaluate the contribution of different energy sources under various weather conditions over a 24-h period. It involved the charging and discharging cycles of the PCM for solar

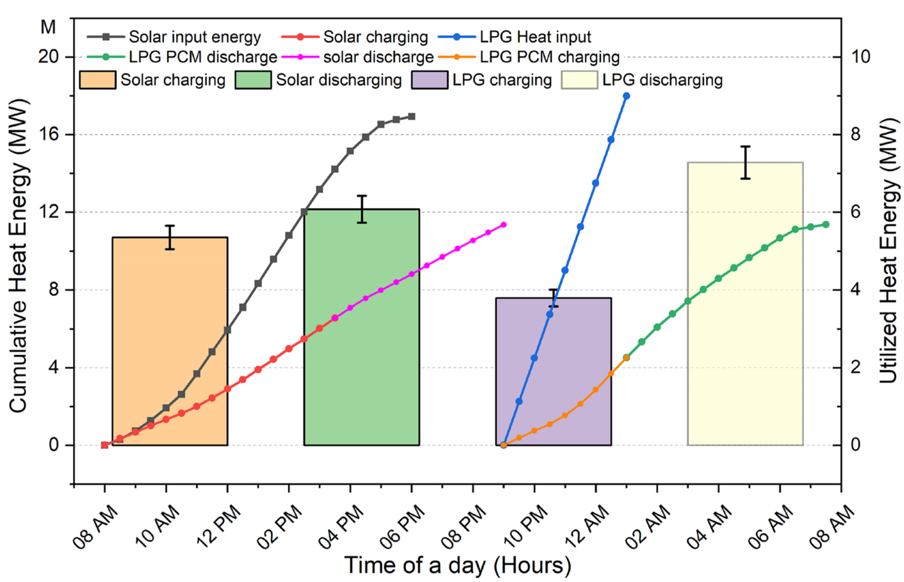

FIG. 8. Energy utilization across energy sources.

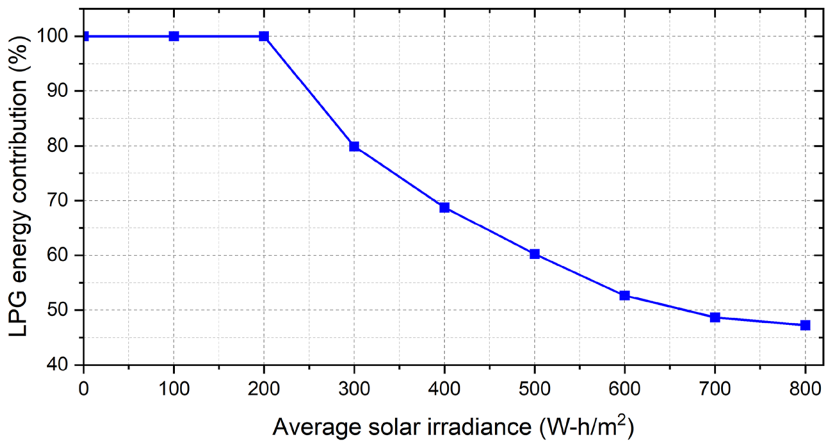

FIG. 9. LPG and solar energy contribution.

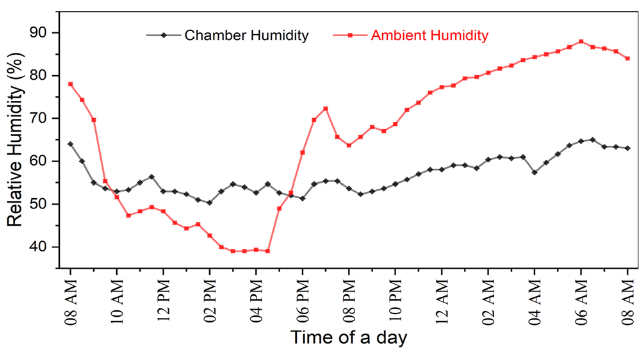

FIG. 10. Average ambient and chamber relative humidity.

energy followed by LPG energy. Each run began after the PCM was fully discharged. The results in Fig. 9 illustrate that the average irradiance below 200 W-h/m^2 has no significant contribution, while a higher value reduced the LPG consumption by up to 46%. Interestingly, at irradiance levels above 800 W-h/m^2, there is no additional significant reduction in the LPG energy contribution due to higher energy losses during the night. This suggests further research on improving thermal insulation. This demonstrates that the effective use of solar TES can significantly reduce reliance on auxiliary sources like LPG, promoting a more sustainable incubation process.

H. Relative humidity

Figure 10 shows that the relative humidity (RH) inside the incubation chamber was controlled between 50% and 65%, while the ambient RH fluctuated between 39% and 88%. Despite external variations, the system's ability to regulate humidity within the desired range demonstrates its reliability. Studies on similar systems report that maintaining RH between 45% and 70% is critical for optimal hatchability.[2,34]

I. Hatchery performance

The study reported an average hatchability rate of 70% and a fertility rate of 81%. With 95% CIs, the actual values fall between 65% and 75% for hatchability and between 76% and 86% for fertility. These narrow CIs indicate high precision and consistency in the trials, strengthening the system's reliability.[28] The system's performance aligns well with other solar-powered incubators, which report hatchability rates between 56% and 77%,[2,4,8,23,35] as summarized in Table III.

TABLE III. Comparison of prior research on solar poultry egg incubators with the beeswax egg incubator.

No.	Study/energy used	Hatchery (%)	Temp range (C)	Reference
1	PV powered poultry egg incubator	74	36–39	Okonkwo and Chukwuezie[4]
2	Solar-powered with water TES and PV	56	36–42.9	Andoha *et al.*[2]
3	Solar powered with paraffin TES and PV	62.37	36–39	Uzodinma *et al.*[8]
4	Low-income solar PV powered	77	36–39	Ikpeseni *et al.*[35]
5	Solar with thermochemical battery TES	56	36~37.5	Hassan *et al.*[36]
6	PV solar powered for chicken eggs	73	37.7–38.7	Mansaray and Yansaneh[23]
7	Solar with beeswax TES and LPG	70	37.2–38.6	The current study

IV. CONCLUSION

The hybrid solar and LPG incubator with fin-enhanced beeswax performed well in maintaining optimal conditions for egg incubation. Based on the results, the following statements are drawn:

i. The DSC and TGA characterization results indicate that beeswax possesses excellent thermal properties, with a heat of fusion of 203.79 J/g at 62.2 °C and mass loss at 250 °C. These findings suggest that beeswax is an effective thermal energy storage medium in the FPSC of a hybrid egg incubation system.
ii. With fin-enhanced beeswax PCMs, the solar heat hours were extended by up to 4 h.
iii. The solar collector's thermal efficiency was 67%, while the PCM extraction efficiency was 68%. This shows that solar heat was effectively utilized to reduce LPG consumption.
iv. The average energy utilized was 11.43 MJ on days when solar irradiance ranged from 50 to 876 W/m^2 with a wind speed of 3 m/s, demonstrating the higher effectiveness of the beeswax-integrated FPSC.
v. The maximum heat loss recorded was 772.3 kJ for conduction, 763.1 kJ for convection, and 2.2 MJ for radiation. This overall heat loss is lower than conventional single-glazed FPSCs, with or without PCMs, indicating that fiberglass and double-glazing offer better thermal insulation. The enhanced performance is also due to the fin's higher heat extraction efficiency.
vi. Solar irradiance levels below 300 Wh/m^2 do not significantly impact LPG consumption. However, at higher irradiance levels, up to 800 Wh/m^2, LPG consumption can be reduced by as much as 46%. This finding underscores the effectiveness of solar energy in mitigating LPG usage.
vii. In three replicates of hatchery experiments, an efficiency of 70% was achieved. This efficiency level reflects the system's exceptional performance and underscores its potential to enhance production outcomes.

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AUTHOR DECLARATIONS

Conflict of Interest

The authors have no conflicts to disclose.

Author Contributions

Paulo Zebedayo Sulley: Conceptualization (equal); Data curation (equal); Investigation (equal); Methodology (equal); Resources (equal); Validation (equal); Writing – original draft (equal). **Mtaki Thomas Maagi**: Methodology (equal); Supervision (equal); Validation (equal); Visualization (equal); Writing – review & editing (equal). **Baraka Kichonge**: Investigation (equal); Methodology (equal); Resources (equal); Supervision (equal); Validation (equal); Visualization (equal); Writing – review & editing (equal). **Yusufu Abeid Chande Jande**: Investigation (equal); Methodology (equal); Supervision (lead); Validation (equal); Visualization (equal); Writing – review & editing (equal).

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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