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Construction and analysis of a solar incubator with thermosiphon flow for egg incubation

Construcción y análisis de una incubadora solar con flujos de termosifón para incubación de huevos

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ABSTRACT: This article describes the construction of a solar incubator with energy storage through sensible water heat, using thermosiphon flows for heat transfer. The objective is to provide a low-cost incubation solution for small and medium-sized farmers. The design and construction of the prototype, capable of incubating between 130 and 231 eggs, are detailed. The results of a fine mathematical modeling demonstrate the viability of the system to maintain adequate incubation temperatures. It is concluded that this technology offers a sustainable and economical alternative to conventional incubators.
Keywords: Low-Cost Incubation, Solar Thermal Energy, Low-tech.

RESUMEN: Este artículo describe la construcción de una incubadora solar con almacenamiento de energía por calor sensible del agua, utilizando flujos de termosifón para la transferencia de calor. El objetivo es proporcionar una solución de incubación de bajo costo para pequeños y medianos agricultores. Se detalla el diseño y la construcción del prototipo, capaz de incubar entre 130 y 231 huevos. Los resultados de un modelado matemático detallado muestran la viabilidad del sistema para mantener las temperaturas de incubación adecuadas.Se concluye que esta tecnología ofrece una alternativa sostenible y económica a las incubadoras convencionales
Palabras clave: incubación de bajo costo, energía solar térmica, baja tecnicidad.

INTRODUCTION

The system that is the subject of this technical note offers a very lucrative way to supplement the income of small and medium-sized farmers in tropical and equatorial regions. In fact, it produces the artificial incubation of chicken eggs only from free solar irradiation. In addition to this, the fact that its manufacture from ordinary carpentry and hardware building materials makes its manufacturing cost affordable and its production feasible at a craft level. It was initially called fair-trade sustainable hatchery (Onana *et al*., 2022).

Unlike solar incubators according to Djamin *et al.* (2001); Ikpeseni *et al*. (2022); Retamozo and Rojas (2022), which are in phase with contemporary technological facilities and consist of an electric incubator, a photovoltaic cell and a battery of accumulators, this system works without the use of any electrical phenomena. This gives it the advantage that, by not resorting to a limited life technology, it is practically unusable.

The choice of water as a storage means for solar radiant energy collected during the day has certainly been made to avoid the use of these sophisticated elements, but raised the question of the circulation of the heat transfer fluid between the solar collector and the hot water reserve and then between the hot water reserve and the incubation chamber. Its resolution was made using a process widely applied in solar water heaters according to Andrés and López (2002); Chuawittayawuth and Kumar (2002); Azzolin *et al.* (2018); Jasim *et al.* (2021): thermosiphon circulation, which fortunately is not the only possible application (Revichandran *et al*., 2019).

The application of the thermosiphon to the two loops in interaction of the present solar hatchery has nevertheless required the fine theoretical modelling done on to ensure that the dimensioning would maintain, permanently in an external environment at imposed temperature, a certain amount of eggs in an environment between 36 °C and 38.8 °C, conducive to incubation (Lourens *et al*., 2005). The question of temperature regulation of the incubation chamber was resolved by the application of bimetallic strip https://en.wikipedia.org/wiki/Bimetallic_strip.

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The hatchery referred to in this article has a capacity of 130 large to 231 small chicken eggs and outdoor temperatures of 12 °C and 35 °C.

Artificial hatching of chicken eggs represents an opportunity to supplement the incomes of small and medium-sized farmers in tropical and equatorial regions. Conventional solar incubators require electricity, which limits their accessibility. This work presents a solar hatchery that works without electricity, using thermosiphon flows for heat transfer, making it more accessible and sustainable. The aim of this study is to describe the design, construction and operation of this low-cost solar hatchery.

MATERIAL AND METHODS

The solar hatchery consists of the following main components: (1) a 870 mm x 912 mm flat solar collector constructed from corrugated iron; (2) a 177 liter hot water storage tank insulated with PVC; (3) an incubation chamber of 1100 mm x 560 mm x 520 mm with a temperature control system based on two bimetallic strip wound in helices; (4) a thermosiphon system for the circulation of water between the collector, the tank and the chamber. All these dimensions result from the theoretical model established by Onana *et al*. (2022), applied to the maintenance of a temperature between 36°C and 38.8°C in the incubation chamber by an outside temperature between 12°C and 35°C.

The functional subunits of this hatchery (Fig. 1) are installed in the wooden frame ⑦.

The functional subunits of the present incubator (Fig. 1) are installed on the wooden chassis ⑦. The eggs lie in the incubation chamber ② and the hatching temperature is maintained using hot water from the hot water reserve ③. The temperature is produced in the latter at a high level by means of the solar collector ⑧. In case of overheating in the solar collector, the water is diverted to the discharge radiator ⑤ to be cooled there. Air bubble evacuation lyres ④ are installed at the top of the heat exchangers ⑥ that make up the discharge radiator. All the water needs of the hatchery, loading and compensation for losses, are met from the water makeup tank ①.

The cylinder of the hot water reserve (Fig. 2) is thermally separated into two compartments by the athermanous shuttle ⑪. The water in the incubation loop leaves the hot water compartment, rises into the pipe which leaves vertically, passes through the coils of the incubation chamber, descends through the pipe that arrives vertically in the warm water compartment on the other side of the athermanous shuttle and arrives in the warm water compartment by pushing the shuttle. Its flow rate is regulated by the incubation temperature regulator ⑩. The water in the regeneration loop leaves the warm water compartment, passes through the pipe that runs horizontally at the bottom of the corresponding cylinder bottom, passes through the coil of the solar collector, passes through the pipe that horizontally joins the hot water compartment

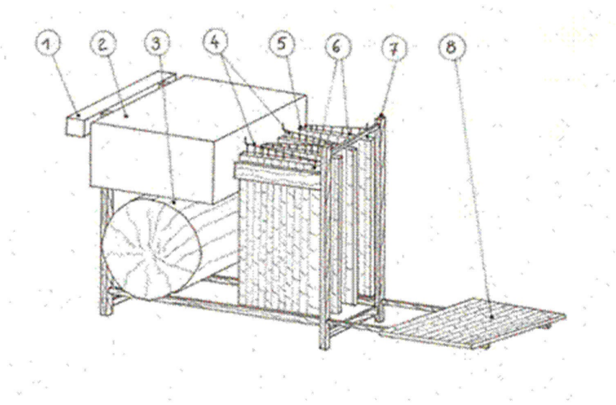

Figure 1. Functional subunits of the solar hatchery with thermosiphon flows.

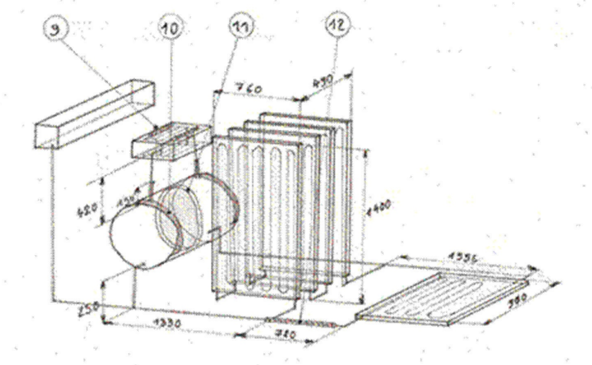

Figure 2. Network of pipes and devices for conducting thermosiphon flows.

from the bottom of the corresponding cylinder base. The overheating of the solar collector water causes the heat discharge regulator ⑫ to open; a part of the overheated water flow is then diverted to the heat exchangers of the heat discharge radiator.

The heat exchangers of the present solar hatcheries (Fig. 3) have their channels formed by two superposed corrugated sheets, offset and riveted on their contact lines. Sealing at the ends is obtained by welding a strip cut into the corrugated sheet and drilled for the passage of pipes. The resulting parallel channel configuration is reserved for the incubation radiator (Fig. 5). The series channel configuration is achieved by spacing apart, before sealing tape welding, the end plates to form an internal serpentine circuit. This last configuration is that of the solar collector and heat exchangers of the discharge radiator (Fig. 1).

The hatchery is equipped (Fig. 4) with an egg drawer ①, driven in a horizontal axis rotation using a crank passing through the bores ②. It is inserted into a frame whose two arms ③ slide into the grooves of the sliding boards, which also serve as supports for the incubation chamber (Fig. 1). This system allows all the eggs to be turned in a single maneuver.

The crank passing through the bores ② as well as the mesh plates and separation boards for packaging eggs are not represented.

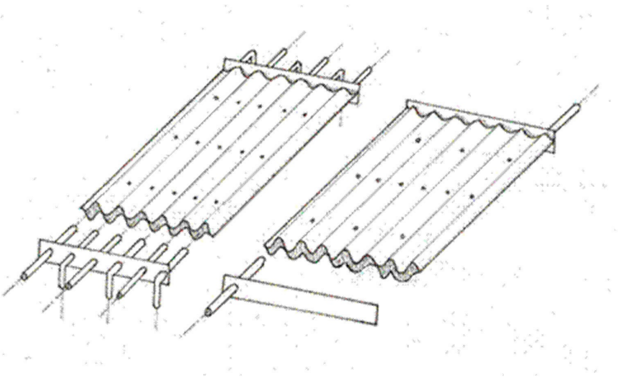

Figure 3. Corrugated plate heat exchangers with parallel channels (left) and series (right).

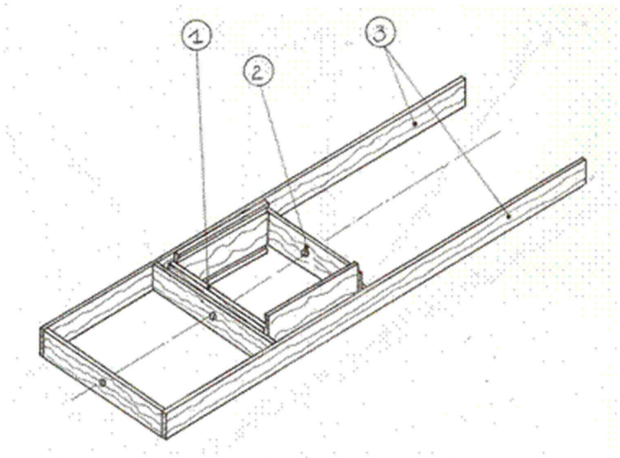

Figure 4. Drawer egg returns.

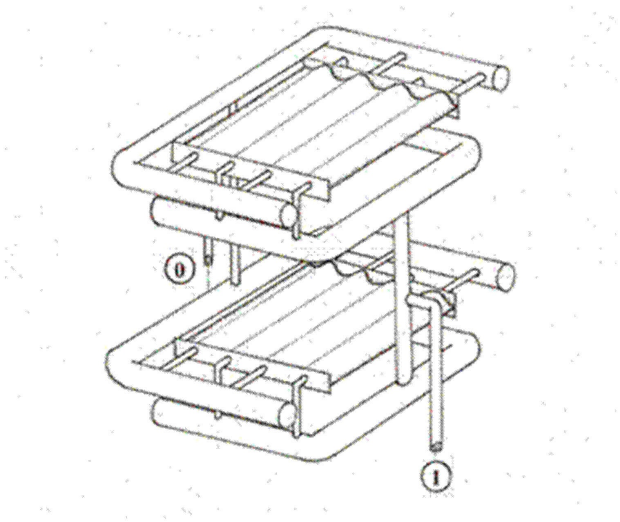

Figure 5. Incubation radiator.

The two parallel channel exchangers of the incubation radiator (Fig. 5) sandwich the egg drawer ①. The feeding and resumption of the flow of hot water are organized in such a way that the water is alternately distributed in one direction then the other in successive channels.

Installation of the incubation regulator indicated in Fig. 2; 6 undulations in the present case.

The temperature-sensitive parts of the flow controllers (Fig. 6) are the helically wound bimetallic ribbon ①. In the incubation regulator ⑨ installed on the upper radiator (Fig. 2), two such bimetallic ribbons drive by their free end, the two cylindrical operculum ③, taken in opposite vertical translations using the capillary tube ⑤ and the fishing line ⑥. The water that seeps through the passage of the hanging rods of the lids supplies the humidification tank placed under the incubation radiator. In the heat discharge regulator, the helically wound bimetallic ribbon ① dips into the water of the regeneration loop and drives the semi-cylindrical operculum ④ located under the bypass line to rotate.

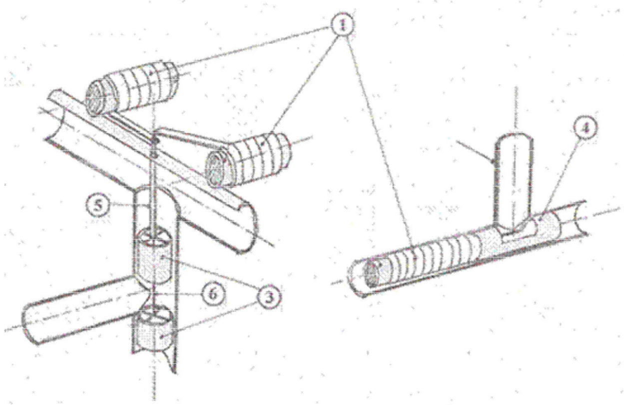

Figure 6. Bimetal incubation (left) and heat discharge (right) thermal regulators.

The two highly heat-conducting metal sheets of the incubation initiators ⑩ (Fig. 2) are in intimate thermal contact with the cylinder of the hot water reserve and the vertical pipe of the incubation loop (Fig. 7). The two sheets, carefully welded at their juncture, bring the water in the vertical pipe to the same temperature of that of the corresponding compartment of the hot water reserve.

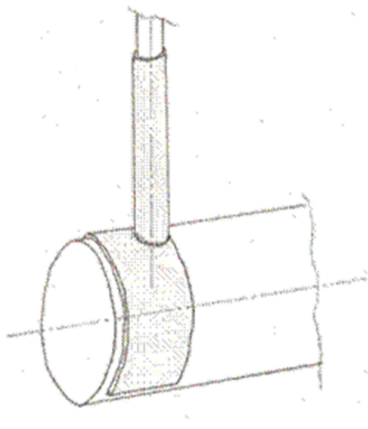

Figure 7. Initiator of the incubation thermosiphon.

The athermanous shuttle (Fig. 8) undergoes a vertical upward thrust due to the cylindrical slice ① cut in an insulating material, therefore of low density (polyurethane foam, for example); this thrust is reduced to its functional value by the ballasts formed by the square metal plates ②.

These are off-centered and fixed to the cylindrical edge by the two pins ④. The assembly is covered with the layer of paint ③.

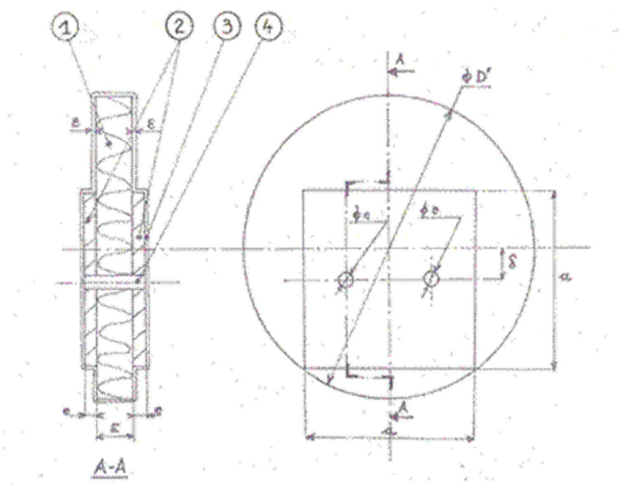

Figure 8. Athermanous shuttle.

RESULTS

The circulation of water between the numbered sub-assemblies (Fig. 1) ② and ③ for the compensation of thermal losses in the incubation chamber, ③ and ⑧ for the heat supply to the hot water reserve and ⑧ and ⑤ for the heat discharge from the solar collector, is due to the thermosiphon phenomenon, which occurs when there is hot water at the bottom and cold water at the top [9]. The study according to Onana *et al*. (2022) has theoretically demonstrated through a simulation model the feasibility of these three interconnected thermosiphon circuits when the operating regime is stationary. A recent study has shown that the mechanical and thermal transients produced in the hatchery give it reactivity compatible with the maintenance of incubation conditions.

Application of the sizing methods presented in Onana *et al*. (2022) to the present hatchery with a capacity of 130 to 231 eggs kept between 36°C and 38.8°C for 100% time and placed in a medium whose temperature ranges from 12°C

Table 1. Length of the ballast side a according to the normalized plate thicknesses e.

e	3 mm	4 mm	5 mm	6 mm	7 mm	8 mm	9 mm	10 mm
a	360 mm	312 mm	279 mm	254 mm	235 mm	220 mm	208 mm	197 mm
δ	58 mm	99 mm	125 mm	143 mm	157 mm	167 mm	176 mm	183 mm

δ: maximum shift of the ballasts.

Table 2. Inventory of supplies for the solar hatchery.

Material	Supply	Feature	Quantity
wood	rafters	40 x 40	7.12 m
		15 x 50	15.78 m
		5 x 70	2.4 m
		15 x 70	0.98 m
		15 x 90	0.95 m
		20 x 100	4.00 m
	rounds	Φ 5	2.60 m
		Φ 20	0.5 m
PVC	components in Φ 16	pipe	3.30 m
		connection 16/32	1
	components in Φ 20	pipe	4.70 m
		bends	2
	components in Φ 25	pipe	0.150 m
	components in Φ 32	pipe	8.25 m
		bends	18
		tees	2
		screw cap	1
	components in Φ 40	pipe	6.60 m
		bends	8
		simple caps	8
		connections 20/40	2
	components in Φ 600	pipe	0.625 m
		simple caps	2
common metallurgy	steel sheet	thickness 0.3 mm	3 feuilles 2.5 x 2.5 m
	aluminium sheet	thickness 0.3 mm	1 feuille 0.7 x 0.7 m
	corrugated sheet	standard 78 mm x 18 mm	
	expanded metal	thickness 2 à 3 mm	2 plaques 470 x 470 mm
	standard profile	in T 20 x 20 mm	1 barre de 2 m
elaborate metallurgy	rivets	Φ 3 to 4 mm	160
	capillary tube	Φint 0.15 mm x Φext indif.	130 mm
	bimetal	type AS preferred than SP or R, in 1.4 mm x 8 mm	13 m
micellaneous	nylon fishing line	Φ 0.1 mm (0.5 kg)	150 mm
	polyurethane foam	density 30 kg.m^{-3}	0.180 m^3
	glass	thickness 4 mm	900 x 900 mm

to 35°C, has resulted in a hot water reserve of 159.9 kg contained in a PVC tube of 600 mm diameter and 625 mm length thermally insulated by 100 mm thick polyurethane foam placed over its entire surface, a 0.780 m^2 surface area solar collector consisting of a 11-channel corrugated plate exchanger, a heat discharge radiator with 4 10-channel corrugated plate exchangers and an incubation chamber with 2 0.208 m^2 surface area incubation radiators (squares of 6 lateral undulations) surrounded by a thermal insulation enclosure 125 mm thick and subjected to maximum thermal losses of 15.74 W.

Table 1 shows the sizes of ballasts to achieve the functional thrust of the shuttle. The values presented correspond to a shuttle of diameter D' =597 mm, thickness E=20 mm and a paint layer of thickness ε=0.5 mm.

Assessment of the economic performance of this hatchery based on inventory in Table 2 and 2022 business data in France according to Onana *et al*. (2022) has resulted in a manufacturing cost of $900 and a return on investment of 2 to 3 months (annual income of $3,000). With a payback period of 5 years, the chicken of the day should cost 4-6 times less than the chicken born with electric power.

CONCLUSION

This technical note presented a low-cost solar hatchery using thermosiphon flows for heat transfer. The system offers a sustainable and cost-effective alternative to conventional incubators, especially for small and medium-sized farmers. Future research should focus on the practical application of the system and the evaluation of its performance under different conditions.

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