

Hybrid Solar Heat Concentrator Salted Egg Cooker

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Abstract- In order to produce salted eggs sustainably, this study designed, built, and assessed a hybrid solar heat concentrator salted egg cooker that uses a Fresnel lens and an additional electric heating element. The suggested device was created to use less conventional fuel while producing steam effectively and cooking food of a satisfactory caliber. The device focused solar energy onto a cylindrical stainless-steel receiver that measured 24 cm in diameter and 29 cm in height using a 500 mm × 500 mm Fresnel lens with a 4–5 cm focal point. To increase heat absorption and lower thermal losses, the receiver was insulated with rockwool and painted matte black to withstand high temperatures. A 1500 W, 230 V a.c. auxiliary electric heating element was placed underneath the receiver to support continuous heating. In addition, the device had gate valves, a cooking chamber for steam circulation, a pressure header, and a steam piping system. Using the combined effects of sun concentration and electric heating, experimental testing revealed that four liters of water inside the receiver achieved boiling condition in about thirty minutes. Before being discharged into the cooking chamber, the steam was stabilized in the pressure header for ten minutes. To adequately cook the salted eggs, the steaming procedure took about 45 minutes, thus the total operating time was around 1 hour and 25 minutes. The input of raw salted eggs were 60 pieces resulting with 60 pieces of cooked salted eggs interpreted as 100% efficiency under high setting of auxiliary electric heating element and proper position of focal spot. A weighted mean of 4.80, which indicates "Strongly Agree" for cooking quality, efficiency, and sustainability, was obtained from a survey of 20 respondents regarding the machine's acceptability. Excellent reliability was demonstrated by the questionnaire's Cronbach's Alpha coefficient of 0.97. The Hybrid Solar Heat Concentrator Salted Egg Cooker is perfect for small-scale production since it efficiently uses a hybrid renewable-electric heating technology to produce well-cooked salted eggs.

Keywords: *Fresnel Lens, Solar Concentrator, Salted Egg Cooker, Steam Generation, Renewable Energy, Hybrid Solar Cooking, Auxiliary Electric Heating Element*

I. INTRODUCTION

The Philippines is now facing a bigger threat of energy crisis since the Malampaya natural gas resources, which currently supply 30% of Luzon's energy consumption, are expected to be depleted by 2024–2025. An expanding population, a new administration, and some of Southeast Asia's highest electricity costs are just a few of the nation's major energy generation issues.

With these issues, renewable energy has the most advantage to be addressed, with the reason of this sector being comprised of hydropower (4.1%/1,161 MW installed capacity), biomass (12.6%) 759 MW, solar/wind energy (1.4%; solar at 1,382 MW; wind at 443 MW), and geothermal resources (14.6%/1,932 MW) as sources of renewable energy [1].

Solar cooking, in particular, has been extensively studied and applied in regions with high solar insolation. However, while many solar cookers use direct or dry heat methods, there is limited literature and application in moist-heat cooking, such as steaming, which is essential for traditional food products like salted eggs.

Salted eggs are a common delicacy in Southeast Asia, particularly in the Philippines, where they are commonly consumed as breakfast items or ingredients in local dishes. Traditionally, cooking salted eggs requires considerable energy—typically through boiling or steaming using liquefied petroleum gas (LPG) or electric cookers. These methods not only contribute to greenhouse gas emissions but also incur recurring operational costs, particularly in rural and off-grid areas [2].

To address this issue, the study introduces a Fresnel lens-based solar steamer designed to cook salted eggs using steam generated from concentrated solar heat

assisted with auxiliary electric heating element. A Fresnel lens—a lightweight optical device capable of concentrating sunlight into a small focal area—has been successfully used in solar thermal applications due to its high concentration ratio and compact form factor [3]. By integrating this lens with a auxiliary electric heating element, steam-generating receiver and a stainless-steel cooking chamber, the system seeks to provide a cost-effective, clean-energy alternative to traditional steaming methods.

Despite ongoing advancements in solar thermal technologies, current solar cooking systems predominantly rely on dry heat mechanisms, such as parabolic reflectors or solar ovens, which are unsuitable for foods requiring moist-heat cooking [4]. Moreover, very few existing solar cooking systems incorporate fresnel lenses for targeted steam generation, especially in a closed, food-safe configuration suitable for traditional food items. This presents a research gap in designing solar-powered steamers tailored for specific culinary processes like salted egg preparation.

Traditional methods of steaming salted eggs are energy-intensive, environmentally unsustainable, and costly for rural producers. Furthermore, existing solar cookers are not optimized for generating and distributing steam efficiently. This study sought to address this gap by developing a compact, Fresnel-lens-based solar steamer that uses concentrated solar power to generate steam and cook salted eggs in a controlled and sustainable manner assisted with auxiliary electric heating element.

II. LITERATURE REVIEW

Solar Energy and Renewable Energy Applications. Solar energy is one of the most abundant and sustainable renewable energy sources available today. As concerns regarding energy security and environmental sustainability continue to increase, solar technologies have become viable alternatives to conventional fuel-dependent systems. Solar thermal technologies convert solar radiation into useful heat energy for applications such as water heating, drying, cooking, and steam generation. The Philippines, being located near the equator, receives significant solar irradiation throughout the year, making solar-

powered technologies suitable for rural and agricultural applications [18], [22].

Fresnel Lens Technology. A Fresnel lens is a compact optical device composed of concentric grooves designed to concentrate sunlight into a small focal point. Compared with conventional convex lenses, Fresnel lenses are lighter, less expensive, and capable of producing high temperatures suitable for thermal applications. Previous studies reported that Fresnel lens concentrators can achieve temperatures ranging from 125°C to over 300°C depending on lens size, concentration ratio, and environmental conditions [19], [23]. Because of these characteristics, Fresnel lenses have been widely utilized in solar cookers, steam generators, water purification systems, and solar thermal power applications [13].

Solar Steam Generation Systems. Steam generation through concentrated solar energy has gained considerable attention due to its potential to reduce dependence on fossil fuels. Studies demonstrated that Fresnel lens concentrators can effectively generate steam by focusing solar radiation onto a receiver containing water. Research conducted in Iraq showed that a Fresnel-lens-based steam generator was capable of producing temperatures exceeding 100°C and achieving efficient steam production when combined with appropriate thermal insulation and receiver design [12], [48]. These findings indicate the potential of solar steam generation systems for food processing applications that require moist heat.

Salted Egg Processing and Steaming Technology. Salted eggs are widely consumed in the Philippines and other Southeast Asian countries. Traditional processing methods typically involve curing followed by boiling or steaming. Steaming is generally preferred because it preserves egg texture, minimizes shell cracking, and promotes uniform heat distribution. However, conventional steaming systems rely on LPG or electricity as primary energy sources, resulting in recurring operational expenses and environmental impacts [7]. Previous studies emphasized that controlled steaming conditions are essential for maintaining desirable yolk texture, flavor, and overall product quality [31], [49].

Hybrid Solar Thermal Systems. Hybrid solar thermal systems combine solar energy with auxiliary heating sources to ensure continuous operation during periods of reduced solar intensity. This approach improves system reliability while maintaining the environmental benefits associated with renewable energy utilization. Researchers have demonstrated that hybrid systems can provide stable operating temperatures and reduce overall energy consumption compared to conventional fuel-based technologies. The incorporation of auxiliary electric heating elements allows uninterrupted steam generation during cloudy weather conditions and periods of fluctuating solar radiation [11].

Energy Efficiency and Sustainable Food Processing. Food-processing operations require substantial amounts of thermal energy, making energy efficiency an important consideration in equipment design. Solar-powered food-processing systems provide opportunities to reduce operating costs and greenhouse gas emissions. Studies have shown that concentrated solar cooking systems can improve thermal efficiency and decrease dependence on conventional energy sources while maintaining acceptable cooking performance [35], [38]. Such technologies are particularly beneficial for small-scale producers and rural communities where access to affordable energy may be limited.

Research Gap. Existing studies have demonstrated the effectiveness of Fresnel lenses for solar concentration and steam generation. Likewise, previous research has confirmed the advantages of steam cooking for salted egg processing. However, limited studies have focused on the development of a hybrid solar-powered salted egg steamer utilizing a Fresnel lens and an auxiliary electric heating element. Most available solar cooking systems concentrate on dry-heat cooking methods and do not specifically address the requirements of steam-based salted egg production. Therefore, this study was conducted to design, fabricate, and evaluate a Hybrid Solar Heat Concentrator Salted Egg Cooker capable of providing efficient and sustainable steam generation for salted egg processing.

III. METHODOLOGY

This study focused on the design, fabrication, and evaluation of a Hybrid Solar Heat Concentrator Salted Egg Cooker utilizing a Fresnel lens as a solar concentrator assisted by an auxiliary electric heating element. The primary objective was to develop a sustainable and energy-efficient steaming system capable of cooking salted eggs through steam generated from concentrated solar energy while minimizing dependence on conventional fuel sources.

The design of the system was developed using computer-aided design software to ensure proper component arrangement, structural stability, and efficient heat transfer. Following the design phase, materials were prepared and assembled according to the developed engineering drawings. The fabricated prototype underwent preliminary testing and adjustments to ensure proper steam generation, temperature regulation, and operational safety before conducting performance evaluation.

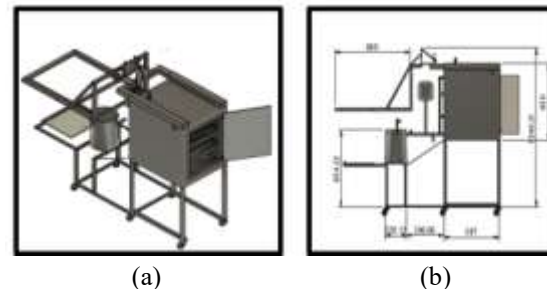


Fig. 1: Hybrid solar heat concentrator salted egg cooker: (a) isometric view, (b) side view.

The prototype was fabricated using locally available materials and engineering components. The major parts of the machine consisted of a stainless-steel cooking chamber, a solar receiver tank, a Fresnel lens concentrator, an auxiliary electric heating element, thermal insulation, stainless-steel piping, ball valves, a pressure release valve, temperature sensors, and a supporting structural frame. The Fresnel lens was positioned to focus solar radiation onto the receiver tank, where water was heated and converted into steam. The generated steam was then directed into the cooking chamber through a steam distribution system designed to provide uniform heat transfer during the steaming process.



Figure 2. Actual prototype of the hybrid solar heat concentrator salted egg cooker

Prior to the performance evaluation of the Hybrid Solar Heat Concentrator Salted Egg Cooker, the salted eggs were prepared and arranged systematically to ensure proper sampling and accurate assessment of cooking quality. A total of sixty salted eggs were utilized during the testing procedure. Each egg was assigned a unique identification number from 1 to 60 and placed on two steaming trays arranged in a 6×5 configuration per tray. The numbering system enabled the researchers to monitor the location of each egg throughout the steaming process and facilitated the selection of representative samples after cooking.

Following the steaming operation, a stratified sampling method was employed to evaluate the cooking performance of the machine. The steaming trays were divided into strata according to egg location, representing the front, middle, rear, left, right, upper, and lower portions of the cooking chamber. Sample eggs were then selected proportionally from each stratum to ensure that all sections of the steamer were represented during quality assessment. This method allowed the researchers to determine whether steam distribution and heat transfer were uniform throughout the cooking chamber.



Fig. 3 Manual placement of salted eggs

The selected eggs were opened and evaluated for cooking quality, yolk texture, albumen firmness, and overall doneness. The use of stratified sampling minimized sampling bias and provided a more reliable representation of the machine's performance across different tray locations. This procedure ensured that the evaluation accurately reflected the effectiveness of the Hybrid Solar Heat Concentrator Salted Egg Cooker in producing uniformly cooked salted eggs.

Performance testing was carried out using actual salted eggs under controlled operating conditions. The evaluation focused on determining the cooking time, steam production capability, energy consumption, and overall output efficiency of the developed machine. Comparative analysis was also conducted against conventional LPG-based and electric steaming methods to determine the economic and operational advantages of the proposed system. Data gathered from the testing procedures were analyzed and interpreted to assess the effectiveness and feasibility of the developed Hybrid Solar Heat Concentrator Salted Egg Cooker.

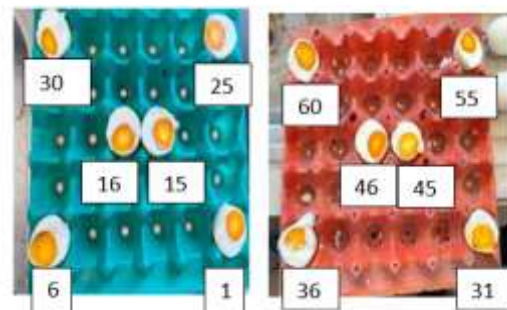


Fig. 4. Salted egg selection using stratified sampling method

IV. RESULTS

The Hybrid Solar Heat Concentrator Salted Egg Cooker was evaluated to determine its operational performance in terms of steam generation, cooking time, energy consumption, product output, and overall efficiency. The testing procedure involved steaming sixty salted eggs using concentrated solar energy supplemented by an auxiliary electric heating element. Performance measurements were conducted under actual operating conditions to assess the capability of the developed machine to provide uniform heat distribution and consistent cooking quality. The results obtained from the evaluation were analyzed and compared with conventional steaming methods to determine the effectiveness, efficiency, and practicality of the developed system.

Steam Generation Performance. The steam generation performance of the developed machine was evaluated by measuring the time required to heat water to its boiling point and produce sufficient steam for cooking. Results showed that the combined action of Fresnel lens solar concentrator and auxiliary electric heating element successfully generated steam was distributed uniformly throughout the cooking chamber, allowing all salted eggs to be exposed to adequate cooking temperatures.

Table I. Performance Output Efficiency

LP G Size	LPG Price	Time Consumption for Boiling Salted Eggs	Average Gas Loss in 3 Hours	Operational Cost
50 kg	PHP 4,386.00	3 hours	0.90 kg	PHP 78.95

These result shows that performance of machine is 100% efficient with 60 Pcs cooked salted eggs output over 60 Pcs input of raw salted eggs under high setting lasted with 1 hr and 25 minutes operational time.

Table II. Steam Required to Cook 60 Salted Eggs

Input Liters of Water	Excess Liters of Water After 1.25 Operational Hours	Required Liters of Water for Adequate Steam Production
4.0 L	2.4 L	1.6 L (0.0016 m ³)

This table shows the required liters of water required to steam and cook 60 salted eggs. This indicates that the input of 4 L of water is more than enough to steam and cook 60 salted eggs with the excess of 2.4 L which clearly identifies that 1.6 L or 0.0016m³ of steam is required to cook 60 salted eggs.

Table III. Energy Consumption of Hybrid

Auxiliary Electric Heating Element	Time Consumption	Operational Consumption (kWh)	kWh Price (May 2026)	Operational Electricity Cost
1500 W (1.5 kW)	1.25 hours	1.875 kWh	PHP 14.3325/kWh	PHP 26.87

Solar Heat Concentrated Salted Egg Cooker

Table III indicates that the auxiliary electric heating element containing 1.5 kW to be functional, consumed 1.875 kWh. As of May 2026, the kWh price is PHP 14.3325 which clearly shows that the operational kWh Price was PHP 26.87.

Table IV. LPG Energy Consumption Based on Interview and RRL

Input	Setting	Operational Time	Output	Output Efficiency
60 pcs	High	1 hour 25 minutes	60 pcs	100%

Table IV reveals that LPG energy consumption that contains 50 kg with PHP 4, 386.00 price for 3 hours operational cooking time based on the interview can lost 0.90kg of used Gas and clearly indicates that the result of operational price of PHP 78.95 is higher than energy consumption of Hybrid Solar Heat Concentrated Salted Egg Cooker. This basically

conclude that the said proposed machine saves more energy price of PHP 52.08.

(1.5 kW)			kWh	
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Table V. Pure Electric Consumption

Pure Electric Heating Element	Time Consumption	Operational Consumption (kWh)	kWh Price (May 2026)	Operational Electricity Cost
1500 W	1.28 hours	1.92 kWh	PHP 14.3325/	PHP 27.5184

Table V shows that pure electric usage for steaming that similarly contains 1.5kW can consume 1.28 hours of overall cooking consuming 1.92kWh. This indicates that pure electric steaming concludes operational price of PHP 27.5184. It clearly reveals that the said proposed machine is more energy price saver than pure electric steamer saving PHP 0.6484 per operation.

Table VI. Energy Consumption Cost Difference

Existing Steamer	Consumption Cost per Batch (PHP)	Proposed Machine Operational Energy Cost (PHP)	Difference (PHP)	Remarks
LPG	78.9480	26.8700	52.0780	LPG consumed higher energy cost.
Pure Electric	27.5184	26.8700	0.6484	Pure electric consumed slightly higher energy cost.

Table VI shows the difference of energy consumption cost during operational hours of LPG and pure electric-based steamer against the proposed Hybrid Solar Heat Concentrator Salted Egg Cooker. The difference clearly shows that the proposed machine saves more energy among the existing steamer machines.

V. CONCLUSION

The study successfully designed, fabricated, and evaluated a Hybrid Solar Heat Concentrator Salted Egg Cooker utilizing a Fresnel lens as a solar concentrator assisted by an auxiliary electric heating element. Based on the findings of the study, the developed machine was capable of producing cooked salted eggs efficiently through steam generated from concentrated solar energy and supplemental electric heating.

The machine successfully achieved the intended product output by cooking sixty salted eggs per batch while maintaining acceptable cooking quality and uniformity. In terms of operational performance, the developed system effectively generated the steam

required for cooking and maintained the necessary temperature conditions throughout the steaming process. The results further demonstrated that the machine can operate with reduced dependence on conventional energy sources through the utilization of solar thermal energy.

The economic evaluation revealed that the developed Hybrid Solar Heat Concentrator Salted Egg Cooker has the potential to reduce operating costs compared with conventional steaming methods that rely solely on LPG or electricity. The integration of solar energy contributed to lower overall energy consumption while maintaining satisfactory cooking performance.

Therefore, the Hybrid Solar Heat Concentrator Salted Egg Cooker was found to be a practical, sustainable, and environmentally friendly alternative for small-scale salted egg processing. The developed technology demonstrates the potential application of renewable energy in food processing operations and may contribute to reducing energy costs while promoting sustainable production practices.

Key outcomes of the study include:

Successful Development of the Hybrid Solar Heat Concentrator Salted Egg Cooker. The study successfully designed, fabricated, and evaluated a hybrid steaming system utilizing a Fresnel lens solar concentrator assisted by an auxiliary electric heating element for steam generation. The developed machine demonstrated the feasibility of integrating solar thermal technology into salted egg processing.

Efficient Salted Egg Production. The developed machine successfully processed up to sixty salted eggs per batch. During the final testing trials, all sixty eggs were properly cooked and found acceptable, demonstrating the machine's capability to produce consistent and satisfactory output.

Improved Steam Distribution and Cooking Performance. Prototype testing showed that proper tray positioning and egg arrangement significantly improved steam circulation and heat distribution inside the cooking chamber. Design modifications made during testing resulted in more uniform cooking performance and reduced the occurrence of undercooked eggs.

Reduced Dependence on Conventional Energy Sources. The integration of concentrated solar energy and auxiliary electric heating reduced reliance on conventional LPG-based steaming methods. The system demonstrated the potential of renewable energy utilization in small-scale food processing applications.

Operational Effectiveness in Terms of Cooking Time and Steam Generation. The developed machine was capable of generating sufficient steam to cook salted eggs under both medium and high operating settings. Results showed that complete cooking could be achieved within forty-five minutes under high settings and within two hours and thirty minutes under medium settings.

Sustainable and Environmentally Friendly Food Processing Technology. The developed system promotes the use of solar thermal energy as an alternative heat source for food processing. Its application contributes to the reduction of greenhouse

gas emissions associated with traditional cooking methods while supporting sustainable agricultural and food production practices.

Potential for Rural and Small-Scale Enterprise Applications. The machine provides a practical and cost-effective solution for small-scale salted egg producers, particularly in rural and off-grid communities where access to affordable energy resources may be limited. The technology supports local food production while reducing operational costs associated with conventional steaming methods.

Foundation for Future Solar Food Processing Innovations. The study establishes a basis for future improvements involving automated solar tracking systems, thermal energy storage, and enhanced steam generation technologies. These developments may further improve the efficiency, reliability, and commercial viability of solar-powered food processing equipment.

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