

## Application of Renewable Energy and Internet of Things on Retort Machine to Improve Sterilization Process Efficiency of Cakalang Fufu Fish

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### ABSTRACT

The conventional preservation process of fufu skipjack fish still relies on traditional smoking methods that depend on heat directly from combustion. These methods are less energy efficient, difficult to control in terms of temperature and time, and produce products with inconsistent quality and shelf life. This research was conducted to develop a fufu skipjack sterilization system based on an integrated retort machine with boilers and ovens supported by renewable energy and the Internet of Things (IoT). The system is designed to improve energy efficiency, process stability, and extend product life. Renewable energy is obtained from solar cells used to drive the blower in the oven, activate the solenoid valve between the boiler and the retort, and support a microcontroller-based control system. IoT technology is integrated to monitor temperature and pressure in real time, control the oven blower, and automatically set the solenoid over the internet network. The test results show that this retort system can maintain a sterilization temperature of up to 121°C stably, reduce energy consumption by up to 25% compared to conventional methods, and extend the shelf life of fufu skipjack fish by more than two times without degrading organoleptic quality. The application of renewable energy and IoT in this integrated retort machine proves its effectiveness in improving process efficiency, production reliability, and the sustainable export potential of local processed fish products.

### KEYWORDS

energy efficiency, Internet of Things, renewable energy, retort machines, skipjack fufu.



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### INTRODUCTION

The fish processing industry is one of the important sectors in supporting Indonesia's coastal economy, especially in the North Sulawesi region, which is known as the center of skipjack fish production (Hutajulu, Imran, Budiharsono, & Kusumastanto, 2019). One of its distinctive processed products is *fufu skipjack fish*, a traditional smoking product that uses a method of processing or preservation by utilizing a combination of drying treatment and the application of natural chemical compounds from the combustion of natural fuels such as liquid smoke (Zulviki Alinti, 2018). This product is popular among local people and tourists (Gonda, Angler, & Csóka, 2021). It has a distinctive taste and high cultural value but faces fundamental

problems in limited shelf life and inconsistency in product quality (Perrea, Grunert, & Krystallis, 2015).

Skipjack fish is classified as a product that is very susceptible to deterioration or damage (highly perishable food) (Lekahena & Jamin, 2018). According to (Erkmen & Bozoglu, 2016), the deterioration in quality is caused by the high water content, which is around 70–80%, as well as its nutritional content that can serve as an ideal medium for the growth of microorganisms (Erkmen & Bozoglu, 2016). The conventional fumigation process, which is still carried out manually, produces fluctuating and uncontrolled temperatures, so it is not able to achieve microbiologically sterile conditions (Bukłaha et al., 2022). As a result, *fufu skipjack fish* is prone to fat oxidation, discoloration, and degradation of texture and flavor (Chan et al., 2023). This condition directly impacts a short shelf life and inhibits export potential to national and international markets (Kusumaningrum, Lee, Lee, Mo, & Cho, 2015).

In the Industry 4.0 era, demands for energy efficiency, sustainability of production processes, and food safety guarantees are higher than ever (Hassoun et al., 2023). To address these challenges, innovative solutions based on integrated technology that combine renewable energy and automation through the Internet of Things (IoT) are needed (Hosseini Motlagh, Mohammadrezaei, Hunt, & Zakeri, 2020). One promising approach is the application of retort machines, which are high-pressure sterilizers operating at temperatures between 115°C and 121°C, allowing the inactivation of pathogenic microorganisms such as *Clostridium botulinum* (Jimenez, Bangar, Suffern, & Whiteside, 2024). With this working principle, retort machines have been proven to extend the shelf life of food products without the use of chemical preservatives, while maintaining the nutritional and sensory quality of the product (Amit, Uddin, Rahman, Islam, & Khan, 2017).

However, the use of retort machines in micro, small, and medium enterprises (SMEs) processing fish in coastal areas is still limited due to energy cost constraints and the lack of efficient automation systems (Hassoun et al., 2022). Therefore, the integration of solar energy (solar cells) as a source of renewable energy is an important alternative to support energy efficiency and environmental sustainability. Solar PV makes a positive contribution to preserving the environment and ecosystem (Branker et al., 2011). Photovoltaic (PV) technology can generate electricity from sunlight to operate various components in retort systems such as fans, pumps, solenoid valves, and temperature and pressure control systems (Kalogirou, 2023). CO<sub>2</sub> emissions from electricity usage activities come from power plants supplying the electricity, and the CO<sub>2</sub> value produced is calculated from the amount of daily electricity use (Rahmadania, 2022). Using solar energy significantly reduces conventional energy consumption while contributing to carbon emission reduction (Yu et al., 2022).

In addition, the application of the Internet of Things (IoT) in retort systems provides advantages in remote monitoring and control (Popa et al., 2019). It can increase production efficiency by up to 30%, reduce human error, and optimize energy use (Hadiat Permadi, 2025). Through the integration of temperature, pressure, and humidity sensors connected to microcontrollers and internet networks, the system can automate sterilization processes, perform real-time monitoring, and record data to the cloud for long-term performance analysis. The combination of renewable energy and IoT is a strategic step toward the concept of the Green Smart Food Processing System, an environmentally friendly and energy-efficient smart food processing system.

This research aims to design and implement an integrated retort machine consisting of a retort, boiler, and oven in one system, with solar cells as the main energy source and IoT as the automatic control system. This machine is designed to improve the efficiency of the sterilization process, extend the shelf life of *fufu skipjack fish*, and improve product quality to make it suitable for export without the risk of quality degradation. In addition, this research is expected to make a scientific and practical contribution to developing appropriate technologies based on clean energy and intelligent automation, especially in the fishery product processing sector in Indonesia's coastal areas. The benefits of this research include providing a sustainable and efficient technological solution for SMEs in the fisheries sector, reducing operational costs and carbon footprint, and ultimately increasing the competitiveness of local processed fish products in the global market through improved quality, safety, and sustainability.

## RESEARCH METHOD

This research is an applied research that focuses on the design and testing of food sterilization technology systems based on renewable energy and the Internet of Things (IoT). The approach used is an engineering experimental approach, where a prototype system of a retort machine is designed, built, and tested directly to evaluate its functional performance and energy efficiency. This research aims to produce a prototype of a retort machine that is able to replace the conventional sterilization method of *fufu skipjack fish* with a more hygienic, efficient, and sustainable system.

The research was carried out at the Mechanical Engineering Laboratory of the Manado State Polytechnic, as well as at the production unit of the *fufu skipjack fish* processing unit in Manado, as a field test location. The implementation of the research was carried out for 6 months, starting from the design stage to testing the performance of the system, namely April-October 2025.

The stages of research consist of several systematic phases that are mutually continuous

### 1. Literature Study and Needs Analysis

The initial stage is carried out by reviewing the literature on:

- a) Working principle of retort machine and thermal sterilization system
- b) Solar energy technology and photovoltaic system integration
- c) Concept and application of IoT in food industry systems

Needs analysis is carried out to determine technical specifications, including retort capacity, operating temperature range, pressure, control system, and power needs of the solar PV system.

### 2. Integrated Retort System Design

The design of the system includes the integration of three main components, namely:

- a) Retort Unit: a high-pressure sterilization container made of stainless steel, equipped with temperature, pressure, and humidity sensors.
- b) Boiler and Oven Unit: a steam heating system and auxiliary heating system based on a DC electric heating element supplied by a solar cell.
- c) IoT Control Unit: ESP32 microcontroller-based with Wi-Fi module, DHT22 sensor and digital pressure, and monitoring system based on IoT platform (Blynk or ThingSpeak).

The system design uses CAD software for mechanical simulation and Proteus/Arduino IDE for electronic system simulation and automatic control.

3. System Implementation and Integration This stage includes:
  - a) Assembly of mechanical and electronic components;
  - b) Integration of electrical systems between solar PV modules, batteries, and loads;
  - c) Microcontroller programming for automatic setting of temperature and pressure according to the sterilization curve.

The automation function is tested to ensure the system is able to maintain a stable temperature of 115–121°C and a pressure of 1–2 atm continuously.

4. Testing and Calibration. Testing is done through two approaches:
  - a) Technical Test of the Retort System:

The parameters are tested: heating time, temperature stability, pressure, energy consumption, and efficiency of the PV system.  
Measuring instruments: digital thermocouple, pressure gauge, watt meter, and data logger.
  - b) Skipjack Fufu Product Quality Test:

Quality parameters: moisture content, total plate count (TPC), color, aroma, and texture.  
Testing was carried out before and after the sterilization process using the SNI 2725:2016 standard on smoked fish.

The test results data are compared with conventional methods to assess the improvement in product efficiency and shelf life.

5. Data Analysis

Data analysis was carried out quantitatively and descriptively.

  - a) The energy efficiency analysis is carried out by calculating the ratio between the effective output power to the total power absorbed from the solar PV system.
  - b) Thermodynamic analysis includes the calculation of heat transfer rate and sterilization value ( $F_0$ ).
  - c) Product quality analysis is carried out by comparing the physical and microbiological results of fish before and after the sterilization process.

The results of the analysis are displayed in the form of tables, system performance graphs, and visual and numerical product quality evaluations.

6. Evaluation and Preparation of System Models

Based on the test results, a performance evaluation was carried out to produce a model of an intelligent sterilization system based on renewable energy. This model can be used as a reference for the development of appropriate technology for the small and medium-scale fish processing industry.

## **RESULT AND DISCUSSION**

### **Design and Implementation of Retort Machine Systems**

The design results resulted in an integrated retort machine system consisting of three main components, namely a retort unit, boiler, and oven that are integrated in one control system based on the Internet of Things (IoT) and solar energy (solar cell).

This retort system is designed using a stainless steel tank with a capacity of 15 kg of fish per cycle, with an electric heating element supplied from a photovoltaic (PV) system with a

capacity of 400 Wp. Energy from the solar cell is stored in a 12V 100Ah battery and is fed to the heating system through a DC–AC inverter.

The boiler unit functions to produce hot steam that is channeled to the retort chamber through a solenoid valve pipe, while the oven is used for the post-sterilization drying process so that the moisture content of the product is in accordance with quality standards.

All devices are automatically controlled using the ESP32 microcontroller, which connects to Blynk Cloud-based IoT dashboards for remote monitoring and control.

#### **The sensors used include:**

1. DS18B20 temperature sensor for temperature monitoring of retort and oven chambers;
2. MPX5700AP pressure sensor to measure internal pressure;
3. ACS712 current sensor to monitor system power consumption.

The results of the system design are shown in Figure 2, which depicts an integration diagram between the solar PV module, the IoT control unit, and the retort-boiler-oven system.

### **Performance Testing of Retort Systems**

#### **Temperature and Pressure Stability**

The test results showed that the system was able to reach a sterilization temperature of 121°C within 18 minutes, and maintained a stable temperature for 30 minutes with fluctuations of only  $\pm 1.5^\circ\text{C}$ .

The internal pressure ranges from 1.7–2.0 atm, according to the standard of thermal sterilization operation for fish products.

Real-time IoT-based automatic control maintains temperature stability with a feedback loop system, where the temperature sensor sends data every 5 seconds to the microcontroller to regulate heating and solenoid power. Process data is also stored to the cloud, so temperature and pressure history can be analyzed for performance evaluation.

#### **Energy Efficiency**

From the measurement results, the total energy consumption in one sterilization cycle is 0.95 kWh, while the electrical energy supplied from solar PV reaches an average of 0.42 kWh per cycle. Thus, the use of renewable energy contributes to a 31% reduction in conventional energy consumption compared to retort systems without PV integration.

In addition, the automatic setting of oven and solenoid fans using IoT is able to reduce idle time and prevent overheating, which has an impact on increasing thermal efficiency by  $\pm 27\%$  compared to manual systems.

### **Sterilization Results on the Quality of Skipjack Fufu Fish**

#### **Physical and Microbiological Parameters**

Product quality analysis was carried out by comparing the results of sterilization using a retort machine with traditional (conventional) fumigation methods.

The test results are presented in Table 1 below.

**Table 1. Comparison of Product Quality Parameters between Conventional and Retort Methods**

<b>Parameter</b>	<b>Conventional</b>	<b>Retort Machine</b>	<b>Increased</b>
Maximum process temperature	90–100°C	121°C	+21%

Parameter	Conventional	Retort Machine	Increased
Process pressure	Immeasurable	1.8 atm	-
Final moisture content	15,2%	12,1%	Drier
Total Plate Count (TPC)	$4.1 \times 10^5$ cfu/g	$2.8 \times 10^2$ cfu/g	99.9% drop
Shelf life (room temperature)	7 days	30 days	+328%

Source: Data processed from test results, 2025

The results show that the retort machine significantly improves microbiological safety and extends the shelf life of fufu skipjack fish by more than four times compared to traditional methods.

Sensory qualities (color, aroma, and texture) are also more uniform due to even heat distribution and auto-controlled process times.

### IoT and Renewable Energy Integration Analysis

The application of IoT has been proven to improve the accuracy of temperature and pressure control, while also enabling remote monitoring over the internet network. This is particularly relevant for small and medium industries (SMEs) in coastal areas that have limited technical human resources.

Meanwhile, the use of solar energy makes a direct contribution to reducing operational costs and carbon emissions. In the daily load simulation, the 400 Wp PV system is able to reduce PLN's electrical energy consumption by up to 0.6 kWh per day, which is equivalent to savings of 45 kWh per month.

Thus, this retort system supports the Green Smart Processing paradigm, which is a combination of energy efficiency, environmental sustainability, and digitalization of the production process.

### General Discussion

The results of this study prove that the integration of renewable energy and IoT in retort systems not only improves energy efficiency and process stability, but also provides significant economic and environmental impacts.

From a technological perspective, this system demonstrates that data-driven automation and monitoring can be implemented at scale in local fish production without the need for large industrial infrastructure. Scientifically, the application of sterile temperature and pressure to the retort machine contributes to the more effective inactivation of pathogenic microorganisms, while digital control ensures quality consistency between production cycles. In addition, the integration of solar cells makes this system energy independent and has the potential to be applied to coastal areas that have not been reached by a stable electricity supply. With these results, the retort machine developed can be a suitable technological solution to support the export of hygienic, durable, and highly competitive fufu skipjack fish in the global market.

## CONCLUSION

This research successfully designed and implemented a retort machine integrating renewable energy from solar cells and Internet of Things (IoT) technology to enhance the sterilization process efficiency and quality of skipjack fufu fish. The integrated system—comprising a retort, boiler, and oven controlled via IoT—maintained stable temperature

( $\pm 1.5^{\circ}\text{C}$ ) and pressure (1.7–2.0 atm), delivering consistent sterilization compared to traditional fumigation. Solar energy contributed up to 31% of the machine's power, reducing reliance on conventional electricity and supporting green energy principles. Quality tests revealed a 99.9% reduction in microbial counts, lower moisture content (12.1%), and an extended shelf life of 30 days versus 7 days with conventional methods. IoT-enabled real-time monitoring and control further optimized production efficiency and safety, positioning this innovation as a strategic step for small- and medium-scale coastal fish processors to improve competitiveness in export markets. The study advances the Smart Renewable Food Processing concept, uniting energy efficiency, automation, and sustainability in Indonesia's fisheries sector. Future research should explore the application of this technology in other food sectors and assess additional factors influencing firm value and operational performance to broaden understanding and enhance outcomes across industries. This will support firms and investors in strategic decision-making to sustain and increase company value in dynamic markets.

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